Dissecting Earliness *per se* and Photoperiod heading date effects in bread wheat (*Triticum aestivum*)

Meluleki Zikhali

A thesis submitted to the University of East Anglia for the degree of Doctor of Philosophy

John Innes Centre
Norwich
September 2013

Abstract

Vernalization, photoperiod and the poorly defined earliness *per se* (*Eps*) genes regulate flowering in plants. This thesis used elite hexaploid wheat varieties and focused on an *Eps* QTL on 1DL, and photoperiod QTLs on 1BL and 5AL short day QTL using doubled haploid (DH) populations. Four independent backcross two F_5 (BC_2F_5) populations with 70 lines each of a cross between Spark and Rialto derived from BC_2F_2 by single seed decent (SSD), and four independent pairs of near isogenic lines (NILs) in the background Rialto were used for 1DL. Genomics and bioinformatics approach was used to design genome specific primers for genes on 1DL, 1BL and 5AL QTL regions using the *Brachypodium distachyon* syntenic genes. Resequencing genes on 1DL revealed that Spark and Cadenza have a chromosomal deletion including several genes. The equivalent region in Rialto and Avalon is intact. The DH, SSD and NILs all showed that the 1DL deletion was associated with early flowering. Recombinants from the BC_2F_5 populations indicate that the 1DL deletion likely contains the candidate gene(s). The 1DL QTL was defined as a discrete Mendelian factor. The 1BL QTL was short day specific for Spark X Rialto and Avalon X Cadenza but the QTL was observed under both short and long day conditions for Charger X Badger. The gene *TaFT3* a homologue of the *HvFT3/Ppd-H2* is suggested as the candidate for the 1BL QTL because two mutant alleles, a deletion and a conserved amino acid change seem to account for most of the variation under short days. Twenty-five varieties from Sweden segregate for the *FT3-1B* and loss of function mutation results in delayed flowering under short days. This thesis describes evidence that has allowed prioritization of candidate genes for the QTLs. The data from this thesis is useful for understanding wheat adaptation and marker assisted selection.

Acknowledgements

I would like to thank my supervisor, Dr Simon Griffiths, for his guidance and sustained effort that helped me to complete this thesis. I would like to recognise his advice and the memorable times we had discussing ways to solve problems related to the thesis. I am particularly grateful that Simon always had time to discuss any matter related to the thesis despite his very busy schedule. Thank you for being a good supervisor.

I would also like to thank Professor Caroline Dean who was my secondary supervisor. It was a great privilege to discuss with Caroline during and outside the supervisory meetings. I am grateful that she never turned me away despite her busy schedule. I would also like to thank Dr. David A. Laurie who was in my supervisory team and continued assisting me even when he eventually retired. I am particularly grateful that Dave trained me during my MSc, my third PhD rotation and even during my PhD and he read through my thesis and his comments made a great difference. I am also grateful to Dr. Adrian Turner and Michel Leverington –Waite who were also members of my supervisory committee, for their guidance throughout. Adrian also helped me during my MSc and my third rotation as well as my PhD and I view him as my academic big brother.

I would also like to thank all the members in Dr. Simon Griffith's group and in particular Dr. Luzie U. Wingen who assisted me with QTL analysis and Simon Orford for maintaining the crops when I was away. I also thank Oscar Gonzalez and Ania Kowalski my fellow PhD students in the Griffiths lab. I particularly enjoyed working with Ania during her rotation and with Oscar I enjoyed and appreciate most the time we spent together in Mexico where he gave me exceptional hospitality and help with physiology work. A thank you also goes to Lesley Fish who cared for the plant material that I inherited for this work particularly the Near Isogenic Lines.

I also thank Dr. Peter Isaac and Dr Gelli Christodoulou from iDNA Genetics Ltd for running some of my KASPar makers. It was a pleasure to work with both of them.

I thank the Horticulture and Field Service staff at the John Innes Centre for taking care of the plants. Particularly Barry Robertson, Lionel Perkins, Peter Sawdon and Damian Alger who I interacted with regularly. I also want to thank Caroline Munnings the Crop Genetics Department administrator who was very helpful throughout my study period particularly in organising all my flights to China, France, USA, Mexico, Hungary, Japan and German as well as organising the train tickets for travel within UK as well as helping me with the paperwork for all my VISA applications. I believe no one could have done it better than Caroline.

I would also like to thank Professor Phillip Poole and Professor James Brown for hosting me during the rotation year of my PhD. Both rotations were very fruitful and enlightening. I thank Dr Elizabeth Orton, Margaret Corbitt and Dr Karunakaran Ramakrishnan for helping me during my rotation year. I would also like to thank Professor Nick Brewin, for the wonderful rotation year and particularly for teaching me how to analyse scientific papers during the journal club meetings. I am also grateful to my colleagues in the 2009 class of rotation students Athena Chu, Pauline Haleux, Nikolai Adamski and Yang Zhang for the wonderful time we shared. Thank you also goes to Professor Mike Merrick and the graduate studies team for keeping track of my progress and especially the valuable comments during the rotation year and throughout the PhD course from Professor Mike Merrick. I would also like to thank Professor Jonathan Jones who was my mentor throughout my rotation year. I appreciate the advice and words of wisdom I got from him.

I would also like to thank Professor Chun-Ming Liu for hosting me for two weeks in his lab at the Chinese Academy of Sciences, Institute of Botany in Beijing. I am grateful to Dr. Guo-Qiang Jiang for the training I got on **T**argeting **I**nduced **L**ocal **L**esions **i**n **G**enomes (TILLING) in Professor Chun-Ming Liu's lab. I would also like to thank Dr Matthew Reynolds for hosting me for five weeks in his physiology group at CIMMYT, Ciudad Obregon, Sonora, Mexico. The training I got in these two groups was valuable.

I am also grateful to the UEA accommodation office for making my stay comfortable during the four years of my study. I am also thankful to the UK Biotechnology and Biological Sciences Research Council (BBSRC), John Innes Foundation, John Innes Centre and the Sainsbury Laboratory for generously funding my studies.

I would also like to give a special thank you to my wife Nomagugu and my lovely daughter Melokuhle and wonderful son Melubuhle for making me happy throughout the PhD. Each time I went home I was greeted by the wonderful words "daddy is here!" which reminded me that I was living in the real world rather than the very small molecular world I worked on daily at the John Innes Centre. I would like to thank my wife for understanding and taking care of the children on the various occasions I had to leave the UK for training and attending conferences. It could have been harder without the support I got from my wife. The support I got from my wife was exceptional throughout my study and I would like to say thank you for being a true sweetheart.

I would like to thank my mum (Planty) and dad (Edward) Zikhali. It was the wisdom, vision and sacrifice of my parents that I am submitting this thesis now and I thank them for that. My brothers and sisters gave me moral support particularly Rachel my eldest sister and her husband Dr. Simon Manyiwa who were also in the UK. I would also like to thank my friend and teacher Washington Mabuto and his wife Alice as well as my friend and teacher Christopher Muchekeza for continuing to give me advice from where they left at high school. I also got a lot of moral support from George & Linah Nyatanga, Terrence Mapiye, Beatrice & Farai Satande and I would like to say thank you. I am also grateful to all the teachers from my parents (my first teachers), siblings, pre-school, primary school, high school and university to Simon Griffiths my PhD supervisor. It is the combined effort and commitment of all the teachers that I cannot all name that I am submitting this thesis and I would like to say thank you to all.

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Abbreviations

1DL	Long arm of wheat group 1 chromosome D
A. tauschii	*Aegilops tauschii*
ADK1	*Adenylate* kinase *1*
Arabidopsis	*Arabidopsis thaliana*
B. disctachyon	*Brachypodium distachyon*
BdELF3	*Brachypodium distachyon Early Flowering 3*
CO1	*CONSTANS 1*
CO_2	carbon dioxide
DH	Doubled Haploid
DNA	Deoxy ribonucleic acid
dNTPs	Deoxy Nucleoside Tri phosphates
ELF3	*Early Flowering 3*
Eps	Earliness *per se*
FT	*Flowering Locus T*
FT3	*Flowering Time 3*
GI	*Gigantean*
H. vulgare	*Hordeum vulgare*
HvVRN3	*Hordeum vulgare Vernalization 3*
META	Multi Environment Trait Analysis
MOT1	*Molybdenum Transporter 1*
mvp1 and mvp2	*Maintained Vegetative Phase 1 and 2*
Ndk3	Nucleoside diphosphate kinase 3
NIL(s)	Near Isogenic line(s)
OsELF3	*Oryza sativa Early Flowering 3*
PCR	Polymerase Chain Reaction
PHYC	*PHYTOCHROME C*
Ppd-1a/b	*Photoperiod-1a/b*
PRR	*Pseudo Response Regulator*
QTL	Quantitative Trait Locus
RNA	Ribonucleic acid
RuBisCO	Ribulose-1,5-bisphosphate carboxylase oxygenase
SSD	Single seed descent
SSR	Simple sequence repeat
T. aestivum	*Triticum aestivum*
T. monococcum	*Triticum monoccccum*
T. urartu	*Triticum urartu*
TaELF3	*Triticum aestivum Early Flowering 3*
TaFT	*Triticum aestivum Flowering Time*
TaFT3	*Triticum aestivum Flowering Time 3*
TaHd1	*TRITICUM AESTIVUM HEADING DATE 1*
TaMOT1	*Triticum aestivum Molybdenum Transporter 1*
TaVRN3	*Triticum aestivum Vernalization 3*
TmPHYC	*Triticum monoccccum PHYTOCHROME C*
UTR	Untranslated region
vatpC	vacuolar ATP synthetase subunit C
VRN1	*Vernalization 1*
VRN2	*Vernalization 2*
VRN3	*Vernalization 3*
WAP1	Wheat *APETALA 1*
WCO1	*WHEAT CONSTANS 1*
WFT	*Wheat Flowering Time*
ZmELF3	*Zea mays Early Flowering 3*

1 Chapter 1

1.1 General Introduction

1.1.1 Importance of wheat as a Global cereal

Humans obtain about one fifth of their calories from wheat and 20% of the diet protein for poor countries is obtained from wheat (Reynolds *et al*., 2012). A recent report argues that wheat could be the world's most important plant (Langridge, 2012). Two hundred million hectares of land are used to cultivate bread wheat and in 2011 more than half a billion tonnes of wheat were produced (FAOSTAT 2012). In terms of global grain production, maize and rice yield are higher than wheat but humans still consume most of their calories from wheat hence it is projected that wheat will have more influence on global food security (Reynolds *et al*., 2012). What makes wheat more useful and important is its ability to be grown on a wide range of environments across the globe. There are numerous uses of wheat, both food and non-food, ranging from food for humans including bread, pasta, cereals, noodles, feed and fodder for animals to cosmetics, detergents, biofuels and medical swabs, only to mention a few (Nass *et al*., 2008; Steer *et al*., 2008; Cauvain and Cauvain 2003; Singh and Smith, 1997).

1.1.2 Challenges to meet food security in the coming decades

The world population demands more food, greater diversity of food, a balanced and healthy diet, safer food, produced on no more, and preferably less land, while conserving soil, water, and genetic resources. There are a number of challenges that are faced with wheat breeders and researchers in their quest to achieve global food security particularly in the coming decades. The major problem is that even though wheat yields are increasing (Lopes *et al*., 2012), the percentage increase is below the projected percentage demand with about 0.6% deficit annually until 2050 (Rosegrant & Agcaoli 2010; Dixon *et al*., 2009). The challenge is to bridge the gap between wheat demand and wheat production.

Some of the green revolution gains of the previous century are being eroded now. For example the green revolution enabled the production of semi-dwarf varieties which greatly reduced lodging and greatly increased yield (Hedden, 2003). The green revolution turned some countries like Mexico from being importers of wheat to exporters of wheat. However, with improvements in wheat yield, lodging is increasingly becoming a problem as the stems cannot at times support the heavier wheat ears due to modern yield increases.

Some of the dwarfing genes like ***R**educed **H**eigh**t 1*** (*Rht1*) have a drawback of reducing coleoptile length and seedling vigour which reduces germination and by extension reduces yield particularly where deep sowing is required (Rebetzke *et al*., 2001). Recently, Rebetzke *et al*., (2011) reported of a novel ***R**educed **H**eigh**t 13*** **(***Rht13*) gene that can be used to replace *Rht1*. The *Rht13* was reported to be on the long arm of chromosome 7B and reduces overall plant height without affecting coleoptiles (Rebetzke *et al*., 2011).

The other problem faced with wheat breeders is the trade-off between selecting for increased yield and also maintaining some physiological aspects of the plants. The *Rht1* example given above is one such example. Another example is the wheat mutant with reduced tillering named *tin* (**T**iller **in**hibition) (Richards, 1988). The mutant has fewer tillers, wide dark leaves, thicker stems, more spikes with increased grain number and size relative to the wild type (Richards, 1988). The mutant has not found great commercial use because of stunted growth (Tesfamichael *et al*., 2012) when grown under long days and at low temperature (Atsmon *et al*., 1986; Duggan *et al*., 2002).

1.1.3 The problem of pests and diseases

The outbreak of diseases is one of the major factors that reduce wheat yield across the globe. A recent example is the outbreak of UG99 a lineage of stem rust *(Puccinia graminis f. sp. Tritici)* which was first identified in Uganda and has spread to Kenya, Ethiopia, Eritrea, Sudan, Yemen, Iran, Uganda, Tanzania, Mozambique, Zimbabwe, and South Africa and now threatens global food security because it can cause as much as 100% yield loss (Singh *et al*., 2011). A screen of about 200 000 improved varieties showed that more than 80% of the varieties lacked resistance genes to UG99 although the wild species and landraces had some resistance genes (Singh *et al*., 2011). A new variant of UG99 was identified in Kenya and about 8 races of UG99 are known (Singh *et al*., 2008).

An important objective of wheat breeders is breeding for durable disease resistance (Spielmeyer *et al.,* 2005). An illustration of the delicate balance that breeders have to handle in breeding wheat that is resistant to diseases comes from the leaf rust durable disease resistance genes at loci *Lr34* and *Lr46*. The loci *Lr34* and *Lr46* contain two of the most important genes in world plant breeding because they confer durable resistance to rust diseases of wheat (Spielmeyer *et al.,* 2005). Rust diseases are currently the most serious diseases of the world's largest crop. However, *Lr34* and *Lr46* have a significant drawback because they increase the susceptibility of wheat to another important disease, *Septoria tritici* blotch. It is suggested that these *Lr* genes suppress gene-for-gene resistance to Septoria (Professor James Brown personal communication). This reflects what seems to be a common trade-off in plants between responses to diseases caused by biotrophic parasites, like the rust fungi, and those caused by necrotrophic or hemibiotrophic pathogens like *S. tritici*.

1.1.4 The complexity of the wheat genome

The other problem faced with wheat breeders is the daunting task of sequencing about 17 Gb of the hexaploid genome. Even the diploid species have proven a challenge to sequence and assemble mainly because of the repetitive elements that make up about 80% of the wheat genome. Bread wheat which is the most cultivated is an allohexaploid made up of the A, B and D genomes (Wanjugi *et al*., 2009).

It is suggested that the A genome of bread wheat came from *Triticum urartu* and the D genome is thought to have come from *Aegilops tauschii* (Langridge, 2012). As for the B genome, the donor to the hexaploid wheat remains elusive and is yet to be determined conclusively although *Aegilops speltoides* has been suggested as having the closest similarity to the B genome of hexaploid wheat (Langridge, 2012). Tetraploid wheat *Triticum durum* is made up of the A and B genomes and is used mainly for making pasta. Durum wheat cultivation takes up about 7% of the global wheat cultivated land (Kubaláková, 2005).
The problem that is encountered when assembling the wheat genome is that some genes are duplicated, deleted, some are truncated while some segments are rearranged among the three homologues of bread wheat and hence assembling the whole bread wheat genome remains a challenge. The genes are in the minority and most of the wheat DNA is made up of repetitive sequences. Despite these challenges, a lot of progress had been made in the past ten years to sequence both hexaploid wheat and the diploid species. Both *Triticum urartu* (Ling *et al*.,

2013) and *Aegilops tauschii* (Jizeng *et al*., 2013; You *et al*., 2011) have now been sequenced using the shotgun method and the data is publicly available. The hexaploid genome has been sequenced, using the Shotgun method, by the wheat sequencing consortium (Brenchley *et al*., 2012).

Furthermore, the use of flow sorted chromosome arms has enabled the sequencing of the individual chromosome arms (http://www.wheatgenome.org/). These recent advances in wheat genomics result in greatly increased understanding of the wheat genome and particularly in identifying useful genes that can be manipulated and used in marker assisted selection or even the more accurate gene assisted selection (use of genes as markers). However a lot of work remains to be done to fully annotate the sequenced genomes of wheat.

1.1.5 How wheat improvement can be achieved

Wheat improvement can be achieved either by breeding wheat adapted to given soils and environments or changing the soils to make them suitable for wheat growth (Vose, 1983). Gill *et al*., (2004) indicated that yield increase can be achieved if we have thorough knowledge about plant biology. Two aspects to be considered are; 1) increasing the physiological efficiency of wheat by, for example manipulating photosynthesis. 2) Adjusting the life cycle to extract the most yields from a given environment. For example; there are no crops with carbon 3 to carbon 4 (C3-C4) pathways, which makes desert plants adapted to low moisture content soils and excessive heat. Introducing this pathway in cereals particularly wheat could greatly increase crop production in semi-arid areas given that droughts are now becoming a global phenomenon.

Plants make excessive *Ribulose-1,5-bisphosphate carboxylase oxygenase* (*RuBisCo*) hence use a lot of the carbon that is fixed by photosynthesis such that if rubisco can be engineered to be more specific to carbon dioxide ($CO_{2)}$ uptake, it would mean less RuBisCo would be need to be produced and the fixed carbon would be used for growth and development by the plant. Khan (2007) showed that introducing the glycolate pathway into chloroplasts resulted in increased plant growth. Recent reports suggest targeting *RuBisCo* for crop improvement (Mueller-Cajar *et al*., 2013; Parry *et al*., 2013).

1.1.6 Reclaiming problem soils

Vose (1983) stated that breeding crop varieties that are adapted to problem soils could be the means of increasing production on thousands of hectares of soil (Sharpley *et al.*, 1994). An example is triticale which is more tolerant to saline soils than wheat. Globally there are one billion hectares of land affected by high concentration of salt in the soil known as salinity (Massoud 1974). Choosing crops adapted to widely differing climatic and soil condition has resulted in successful global rice and wheat breeding (Borlaug 1973) and there is potential for reclaiming saline soils (Brinkman 1980).

Most of the wheat used in the baking industry and feed manufacture uses the grain that is produced by the wheat plant. The production of the wheat grain is dependent on flowering. The wheat grains should be of the right quality with a balance of carbohydrate and protein content. The quality of the grain depends on wheat flowering at the right time to make maximum use of the rain season and avoid the stress caused by frost, heat and even pests. The winter wheat varieties avoid flowering during the cold season using a combination of vernalization and photoperiod genes (Distelfeld *et al*., 2009b). The role of different flowering time genes on wheat will now be discussed in detail.

1.1.7 Wheat flowering time

Three major factors are responsible for the variation in flowering time observed in the bread wheat varieties. These factors, which interact with the environment in mediating the transition from vegetative to floral growth, are: vernalization, photoperiod and earliness *per se* (Herndl *et al*., 2008; van Beem *et al*., 2005; Bullrich *et al.*, 2002). The vegetative to reproductive phase conversion is fundamental to plant survival in that it allows plant species to flower at the most suitable period which will allow pollination, seed set as well as dispersal (Cockram *et al*., 2007). While vernalization and photoperiod response of wheat is relatively well understood and documented, our current knowledge of *Eps* in cereals is minimal and no *Eps* gene has been cloned in wheat. Flowering time is an important adaptive trait and its manipulation may be one avenue to increase grain yield. Vernalization, photoperiod response and earliness *per se* are described here.

1.1.8 Vernalization requirement in wheat

Vernalization is a response to extended exposure to cold temperature before plants can then respond to the long day environmental cue to flower (Distelfeld and Dubcovsky 2010; Diaz *et al*., 2012). Winter wheat varieties require vernalization (4-8 weeks of cold treatment) before flowering while spring wheat varieties do not (Herndl *et al*., 2008). Three main genes *VRN1*, *VRN2* and *VRN3* are responsible for the vernalization response in wheat (Yan *et al*., 2003, Trevaskis *et al*., 2007, Distelfeld *et al*., 2009a; Distelfeld *et al*., 2009b). The *VRN1* gene was positionally cloned to chromosome 5A in *Triticum monococcum* (*T. monococcum*) and found to be a homologue of the *Arabidopsis thaliana APETALA1* (Yan *et al*., 2003) and is also known as wheat *APETALA 1* (*WAP1*) (Shitsukawa *et al*., 2007). Allelic variation of the vernalization gene (*VRN1*) locus divides wheat into spring types which do not require vernalization and winter types which require an extended exposure to cold before flowering (Fu *et al*., 2005). The spring (vernalization insensitive) cultivars have mutations in the promoter or deletion within the first intron of the *VRN1* gene (Fu *et al*., 2005; Yan *et al*., 2004b; Yan *et al*. 2003). The *VRN1* gene accounts for most of the vernalization response in wheat (Distelfeld and Dubcovsky 2010).

Spring growth habit is also conferred by loss of function mutations at the flowering repressor *VRN2* locus which is made up of two genes which share the common feature of having the zinc finger and CCT domain and are designated *TmZCCT1* and *TmZCCT2* (Yan *et al*., 2004a). Loss of function mutations at the *VRN2* locus have been shown to eliminate the vernalization requirement and confer spring growth habit in diploid wheat (Yan *et al*., 2004b; Distelfeld *et al*., 2009a). A single functional copy of the two *ZCCT* genes represses flowering and leads to a winter growth in *T monococcum* (Distelfeld and Dubcovsky 2010). However, there is no report of how *Vrn2* mutants affect hexaploid wheat growth and this is worth investigating.

Recently, copy number variation (CNV) at the barley gene *FT1* (*HvFT1*) a homologue of the wheat gene *VRN3* has been shown to be associated with accelerated flowering time (Nitcher *et al*., 2013). An earlier report in studies done using hexaploid wheat, copy number variation at the *Vrn-A1* gene was shown to be associated with altered flowering where an increase in copy number resulted in increased vernalization requirement (Diaz *et al*., 2012). The study showed using three varieties of wheat Claire, Malacca and Hereward which have 1, 2 and 3 copies of the *Vrn-A1* gene and require short, medium and long exposure to vernalization respectively before flowering (Diaz *et al*., 2012). This copy number variation accounts for most of the variation observed in vernalization requirement among these winter wheat varieties.

However, Li *et al*., (2013) recently suggested that vernzalization requirement duration was controlled at the protein level and hence was not due to copy number variation as suggested by Diaz *et al*., (2012). Li *et al*., (2013) used the variety Jagger which has 1 copy of *Vrn-A1* just like Claire which also has one copy of *Vrn-A1* (Diaz *et al*., 2012) and the protein sequences are identical for both varieties. The study by Li *et al*., (2013) also used a line only identified as 2174 which was claimed to have a duplication of *Vrn-A1* and an allele similar to Hereward although no taqman copy number assays or sequences for 2174 were provided. Li *et al*., 2013 go on to conclude that the wild type *Vrn-A1* protein produced by Jagger was dominant over the protein produced by 2174 regardless of the extra copy in 2174 because of an amino acid change at position 180.

There are a few shortcomings with the way Li *et al*., (2013) reach their conclusion. Firstly, Jagger and 2174 segregate for both copy number variation and sequence polymorphism which make these two lines inadequate to reach the conclusion whether copy number or sequence polymorphism is the cause of the variation. It is not clear if the copy number or sequence polymorphism causes Jagger to be more dominant than 2174. Furthermore, the study by Diaz *et al*., (2012) used three varieties Claire, Malacca and Hereward which had 1, 2 and 3 copies respectively of *Vrn-A1* and show using gene expression data that there is a dose dependent induction of *Vrn-A1* leading to earlier flowering for Claire with one copy and late flowering for Hereward with 3 copies while Malacca is intermediate. More interestingly, Diaz *et al*., (2012) show that Malacca and Hereward both have the same amino acid at position 180 which was suggested by Li *et al*., (2013) to be responsible for the Jagger protein being more dominant than that of line 2174. The genomic DNA sequences for the Malacca and Hereward *Vrn-A1* genes are two identical copies for each variety except that Hereward has an extra copy of one of the two sequences (Diaz *et al*., 2012). Malacca and Hereward produce two identical *Vrn-A1* protein copies each except that Hereward has an extra copy of one of the proteins leading to the conclusion that copy number variation was associated with altered flowering time (Diaz *et al*., 2012).

The wheat and barley genes Ta*VRN3* and *HvVRN3* respectively are homologues of the *Arabidopsis thaliana* gene *Flowering Locus T* (*FT*) (Yan *et al*., 2006). There are currently two main schools of thought about how *TaVRN3* regulates flowering (Fig. 1.1). The long standing view is that *VRN3* is a promoter of flowering via the upregulation of *VRN1* in long days (Distelfeld *et al*., 2009b; Trevaskis *et al*., 2007). In this model known as the *VRN2*-to-*FT* (*VRN2* acts as a repressor of *FT*), *VRN1* is a repressor of *VRN2* while *VRN2* is a repressor of *VRN3/TaFT1* (Distelfeld and Dubcovsky 2010). On the other hand, another school of thought suggests that *FT* is a repressor of *VRN2* (Shimada *et al*., 2009) and has been designated *FT*-to-*VRN2* (Distelfeld and Dubcovsky 2010).

The *FT*-to-*VRN2* model was proposed because of the studies done on two *Triticum monococcum* (*T. monococcum*) mutants that were designated *Maintained Vegetative Phase 1 and 2* (*mvp1 and mvp2*) due to a deletion which at that time was reported to include only the *VRN1* gene (Shitsukawa *et al*., 2007). The mutant remained in the vegetative phase without the floral transition even after four years of growing (Shitsukawa *et al*., 2007). Shimada *et al*., (2009) then showed that the *mvp* mutants had low *TaFT* transcripts despite lacking the *VRN2* suppressor and this could not be explained by the *VRN2*-to- *FT* model. Shimada *et al*., (2009) then proposed that *VRN1* was a promoter of *FT* and *FT* was a repressor of *VRN2* and that *VRN2* was a repressor of *VRN1* a reversal of the roles of the genes in the *VRN2*-to- *FT* model (Shimada *et al*., 2009; Distelfeld and Dubcovsky 2010).

However, recent work done by Dubcovsky's group showed that the *mvp* mutants were due to a deletion that included several genes including *TmAGLG1*, *TmCYS and TmPHYC* in addition to *TmVRN1* (Distelfeld and Dubcovsky 2010). The current hypothesis is that the *VRN1* deletion in the *mvp* mutants causes the non-flowering phenotype while the deletion of *PHYTOCHROME C* (*PHYC*) is responsible for the down regulation of *VRN2* and *FT* in unvernalized long day grown plants (Distelfeld and Dubcovsky 2010).

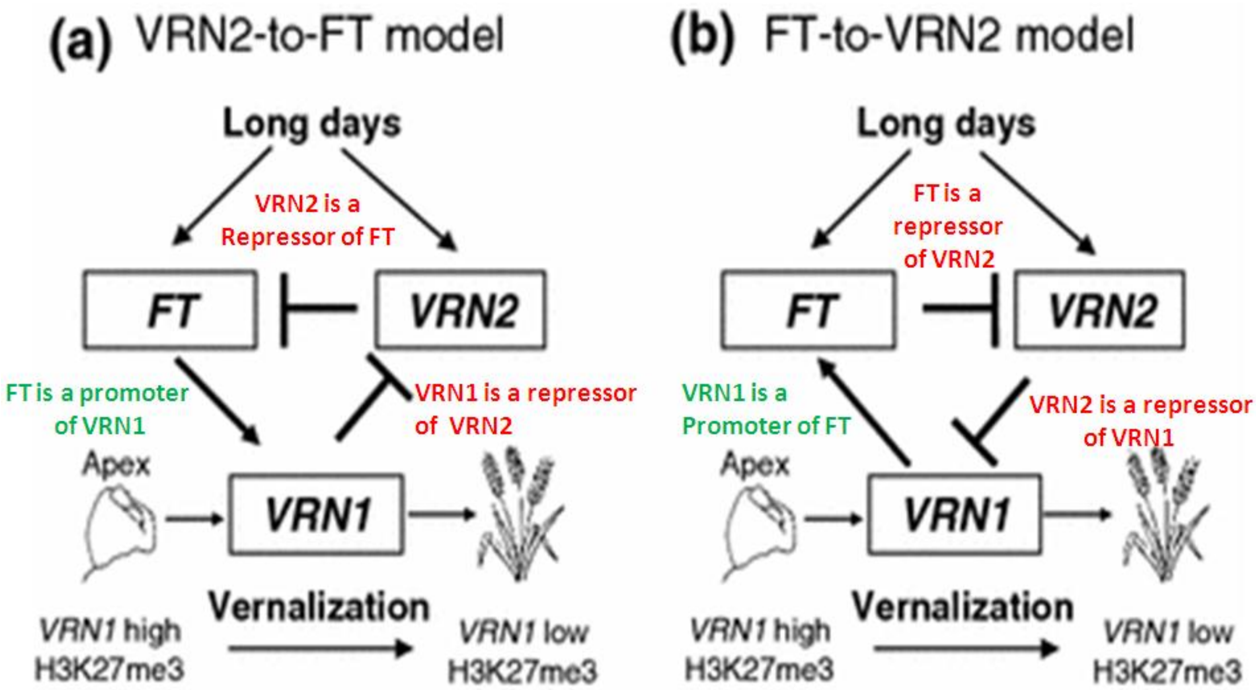


Fig. 1.1 The conflicting models of how *VRN* genes regulate flowering in wheat. The figure is adapted and annotated from Distelfeld and Dubcovsky (2010). Model (a) was proposed by Distelfeld *et al*., (2009a, b) and Trevaskis *et al*., 2007 while model (b) was proposed by Shimada *et al*., (2009). The two models agree that long days promote both *FT* and *VRN2* and also agree that *VRN1* is a promoter of flowering but differ in how the three genes *FT*, *VRN1* and *VRN2* regulate each other

1.1.9 Photoperiod response in wheat

Photoperiod response in bread wheat is mainly affected by mutations of the photoperiod genes *PHOTOPERIOD-D1* (*Ppd-D1*) and *PHOTOPERIOD-B1* (*Ppd-B1*), *PHOTOPERIOD-A1* (Beales *et al*., 2007; Wilhelm *et al*., 2009; Herndl *et al*. 2008). Dominant mutant alleles make wheat plants photoperiod insensitive (day neutral) and are given a suffix *a* (*Ppd-A1a*, *Ppd-B1a* and *Ppd_D1a*) and cause early ear emergence under short days, while those carrying the recessive wild-type alleles are given a suffix *b* and are very late flowering unless exposed to long days (Diaz *et al*., 2012; Beales *et al*., 2007; Wilhelm *et al*., 2009; McIntosh *et al*., 2003). Photoperiod and vernalization genes contribute most to mega-environment adaptation (Griffiths *et al.,* 2009). UK wheat varieties are mostly photoperiod sensitive, with winter growth habit (vernalization requiring types). David Laurie's group succeeded in positional cloning of the barley *Ppd-H1* gene, identifying it as a pseudo response regulator (*PRR*) related to genes in the *Arabidopsis thaliana* circadian clock genes (Turner *et al*., 2005). The wheat genes *Ppd-A1*, *Ppd-B1 and Ppd-D1* were then identified by homology (Beales *et al*., 2007; Wilhelm *et al*., 2009).

1.1.10 Interaction between vernalization and photoperiod pathways

VRN2 is dowregulated by short days and *VRN1* is upregulated by vernalization during short days (Dubcovsky *et al*., 2006; Trevaskis *et al*., 2006). *VRN1* accumulates under long days following vernalization. Transcript levels of *FT1* have also been shown to be low in both wheat and barley when plants are grown under short day conditions (Dubcovsky *et al*., 2006), or during the dark phase of plants grown in long days (Shimada *et al*., 2009). In barley, it has also been reported that *FT1* does not accumulate when plants are grown under short days (Casao *et al*., 2011a).

It has been reported that the allele *Ppd-1b* of the photoperiod gene down-regulates *VRN3/WFT* under short photoperiod conditions but *Ppd-1b* does not regulate *VRN1* (Kitagawa *et al*., 2012). The *VRN3* (wheat *FT1*) is reported to be the integrator of the vernalization and photoperiod pathways via the circadian clock gene CONSTANS 1 (*CO1*) shown on fig.1.2 and Fig.1.3 (Chen and Dubcovky 2012; Distelfeld *et al*., 2009; Kitagawa *et al*., 2012).

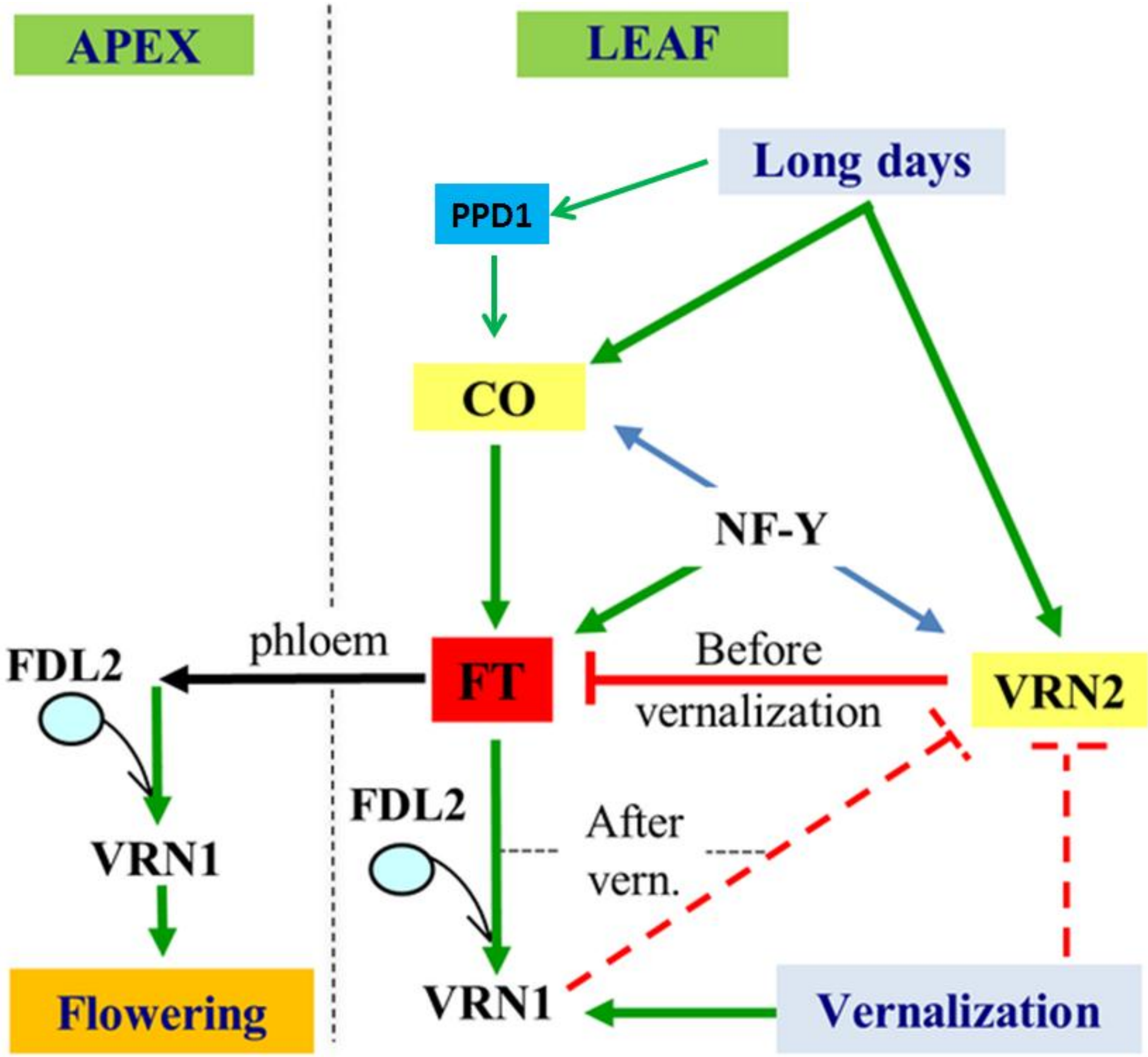


Fig. 1.2 The interaction between *PPD-1* and *VRN* genes in regulating flowering time in wheat (adapted from Chen and Dubcovky 2012; Distelfeld *et al*., 2009b). Key: *PHOTOPERIOD 1* (*Ppd-1*), *CONSTANS* (*CO*), *VERNALIZATION 1*and *2* (*VRN1*, *VRN2* respectively), *FLOWERING TIME* (*FT*), *FD-LIKE* protein *2* (*FDL2*), *NUCLEAR TRANSCRIPTION FACTOR Y* (*NF-Y*).

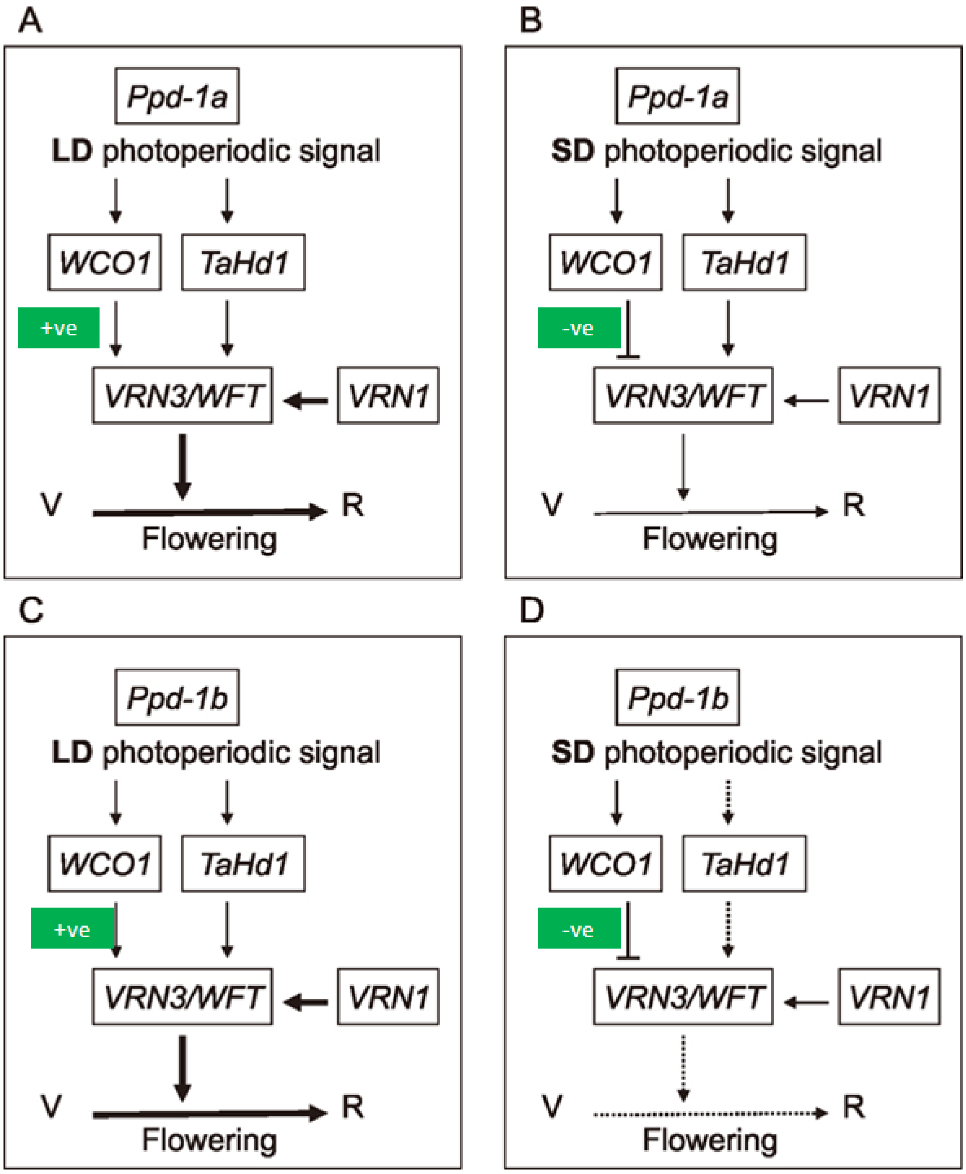


Fig.1.3 The proposed flowering time models in wheat showing the role of *Ppd-1* in regulating flowering in both long (LD) and short days (SD) (Kitagawa *et al*., 2012). The gene *WCO1* is a promoter of *VRN3* under long days but has an opposite effect under short days. Key: *PHOTOPERIOD 1a/b* (*Ppd-1a/b*), *WHEAT CONSTANS 1* (*WCO1*), *TRITICUM AESTIVUM HEADING DATE 1* (*TaHd1*), *VERNALIZATION 1* and *3* (*VRN1*, *VRN3* respectively), *WHEAT FLOWERING TIME 3* (*WFT*), V = vegetative state, R = reproductive state. The bold and dotted arrows indicate strong and weak effects respectively (Kitagawa *et al*., 2012).

1.1.11 **Earliness *per se***

Earliness *per se* (*Eps*) can be defined as the minimum number of days to reproductive growth, after vernalization and photoperiod requirements are satisfied (van Beem *et al*., 2005). Earliness *per se* (*Eps*) is the time to heading after both vernalization and photoperiod requirements are satisfied (Appendino *et al.,* 2003). Shitsukawa *et al*., 2007 defined narrow sense earliness or ealiness *per se* as the earliness of fully vernalized plants grown under long days. Lewis *et al.* (2008) described *Eps* as all other genes controlling flowering time but not involved in either vernalization or photoperiod requirements. Earliness *per se* is also referred to as ear emergence *per se*, earliness in narrow sense, intrinsic earliness, and at times is called basic development rate (Lewis *et al.,* 2008; Shitsukawa *et al*., 2007; Cockram *et al.,* 2007; Laurie *et al*., 2004).

It is suggested that *Eps* genes regulate flowering independent of both vernalization or photoperiod environmental cues (Bullrich *et al.,* 2002). The *Eps* genes are thought to be involved in the fine tuning of wheat flowering time (Valarik *et al.,* 2006) within mega-environments (Griffiths *et al.,* 2009) and are responsible for wide adaptation of wheat to different environments (Lewis *et al*., 2008). Earliness *per se* causes differences of a few days in flowering time under field conditions (Valarik *et al.,* 2006). In *Triticcum monococcum*, it has been shown that while the *Eps* effect on chromosome 1A designated *Eps-*A^m*1* causes flowering differences of only a few days, this difference increased to several weeks when the plants were fully vernalized and grown under long days at 16^{o}C (Appendino and Slafer 2003).

Earliness *per se* is often considered polygenic (Rousset *et al*., 2011) and to involve different developmental phases like transition from vegetative to reproductive growth, early and late spike development, stem elongation, heading (Griffiths *et al.,* 2009; Lewis *et al*., 2008). However, the genetic and physiological basis of the *Eps* genes control of these vital developmental phases, which determine grain yield components (Lewis *et al*., 2008) remains largely a matter of conjecture. Elucidating the role played by the individual *Eps* genes in each developmental phase will enable breeders to fine tune ear emergence in predictive wheat breeding (Griffiths *et al.,* 2009) and increase wheat yield in different environments (Lewis *et al*., 2008). To determine the role of an individual *Eps* gene, on different wheat developmental phases requires knowing what the gene is and hence the need for accurate mapping of the gene responsible (Lewis *et al*., 2008). Relative to vernalization (*Vrn*) and photoperiod (*Ppd*) genes, the genetic map positions and physiological effects of *Eps* genes are not well defined (Miura *et al*., 1999). Because of their relatively small effect, *Eps* genes have been mapped only as QTL (Miura *et al*., 1999).

Laurie *et al*. (2004) suggested that *Eps* factors may be largely responsible for the variation in flowering time in crosses within winter or spring types "that have the same alleles at the major photoperiod and vernalization response loci and therefore have considerable potential for tuning plant development." However, presently there is scant information on the identity of *Eps* genes, and the mechanism of control that these *Eps* genes employ in hexaploid wheat. For instance, it is not certain whether *Eps* genes act independently of environmental cues (Cockram *et al.,* 2007; Laurie *et al.,* 2004; Bullrich *et al.,* 2002), although many reports seems to suggest that this is the case (Lewis *et al.*, 2008; Cockram *et al.,* 2007; Appendino *et al.,* 2003; Bullrich *et al.,* 2002).

Laurie *et al.* (2004) underscored the need to study more about *Eps* genes given that little was known about them despite their immense potential in improving plant breeding. This was alluded to by Cockram *et al*., (2007) who suggested that *Eps* genes were a potential source of variation in targeted breeding given that they were present in both winter and spring crops. Earliness *per se* genes are found on most wheat chromosomes (Bullrich *et al.*, 2002; Griffiths *et al.,* 2009) and cause differences of a few days in flowering time (Valarik *et al.,* 2006).

One *Eps* gene that has been studied for about a decade now is the $Eps\text{-}A^{m}1$ reported to be on the distal region of *T. monococcum* chromosome $1A^{m}L$ (Faricelli *et al*., 2010; Valarik *et al.,* 2006; Bullrich *et al.,* 2002). The gene has been recently reported to be involved in determining the number of spikelets as well as the number of grains per spike in diploid wheat in addition to affecting heading time (Lewis *et al*., 2008). However the gene is yet to be cloned because it has not yet been fine mapped (Faricelli *et al*., 2010).

The *Eps-3Am* QTL interval in *T. monococcum* was fine mapped using high density mapping (Gawrosnski and Schnurbusch 2012). A recent report suggested a *T. monococcum ortholog* of the *Arabidopsis thaliana LUX ARRHYTHMO/ PHYTOCLOCK* 1 (*LUX/ PCL1*) as a potential candidate of the *Eps-3Am* which was suggested to act by distorting the circadian clock (Gawrosnski *et al*., 2014).

Another *Eps* locus identified in *Hordeum vulgare* and designated *EPS2* was mapped onto chromosome 2H more than one and half decades ago (Laurie *et al*., 1995). The *EPS2* was also reported to be orthologous with the wheat group 2 locus (Laurie 1997). The candidate gene for this locus has only been recently shown in barley to be a homolog of the Antirrrhunum gene *CENRORADIALIS* (*CEN*) designated *HvCEN* (Comradan *et al*., 2012). The gene *CEN* was shown to belong to the Phosphatidylethanolamine binding protein (PEBP) gene family and mutations at this gene were shown to cause the wild type indeterminate inflorescence of Antirrhunum to terminate into a flower (Bradely *et al*., 1996). Analysis of the *HvCEN* alleles led to the conclusion that *HvCEN* was important for geographic range extension as well as influencing the gradual separation between spring and winter barley (Comadran *et al*., 2012).

The *Eps-Am1* locus was reported to determine the number of spikelets as well as the number of grains per spike in addition to affecting heading time (Lewis *et al*., 2008). Similarly, the *Eps-3Am* locus was reported to affect spike size and spikelet number (Gawrosnski *et al*., 2014). Again both *Eps-Am1* and *Eps-3Am* have been reported to be thermosensitive (Bullrich *et al*., 2002; Gawrosnski *et al*., 2014). This means there is a possibility of manipulating *Eps* genes to increase yield and optimise adaptation. Grain quality can also be improved by manipulating *Eps* loci given that Herndl *et al*., (2008) showed that *Eps* together with the major genes that control vernalization and photoperiod flowering influence grain protein content.

Griffiths *et al.,* (2009) reported significant QTLs for heading time in hexaploid wheat on all the seven groups of chromosomes. It was suggested that the distal 1BL and 1DL ear emergence genes could be orthologous to the barley early maturity 8 (*eam 8*) mutation (Faure *et al*., 2012) or the $1A^{m}L$ *Eps* reported in *Triticum monococcum* (Griffiths *et al.,* 2009; Valarik *et al.,* 2006). The distal region of chromosome 1DL however had the strongest QTL effect in terms of LOD score, additive effect and stability in the different environments tested (Griffiths *et al.,* (2009) and hence was a good target for further work. A recent association mapping study using 235 wheat lines from diverse geographical locations reported that *Eps* was mainly explained by polymorphisms at *Vrn-3*, *Vrn-1* and *Gigantea* (*GI*) (Rousset *et al*., 2011). The study also revealed that *Eps* had greater effect when the lines were sown in autumn (Rousset *et al*., 2011). However, it is important to point out here that copy number variation at *Vrn-A1* has been shown to cause variation in flowering time (Diaz *et al*., 2012) and a report in barley showed that *HvFT1* the homolog of wheat *VRN3* also had copy number variation which also affected flowering such that what may have been reported as *Eps* by Rousset *et al*., (2011) might be due to copy number variation particularly for *Vrn-A1*.

1.2 **Background to the current study**

Variation in emergence and maturation of wheat ears is the consequence of allelic variation in genes controlling the vegetative to floral transition, inflorescence development, and stem extension. This variation has major implications for yield potential, abiotic and biotic stress tolerance/avoidance, interactions with agronomic interventions, and our ability for predictive breeding of germplasm adapted to specific environments. In UK varieties, the major genes controlling response to vernalisation (*Vrn1*) and photoperiod (*Ppd1*) are largely fixed, but breeding populations still segregate widely for ear emergence. The genes responsible for this variation have been categorized as *earliness per se* (*Eps*) but knowledge of their identities, mechanism and the physiological and agronomic implications of different alleles/allelic combinations are poorly understood.

The objectives of the work in this thesis are to verify and map a large effect *Eps* QTL segregating in UK germplasm (Griffiths *et al*., 2009). This QTL is located on chromosome 1DL. In this project the aim is to define it as a discrete Mendelian factor, using near isogenic lines (NILs) which have been developed in two ongoing projects in the Simon Griffiths group at the John Innes Centre. The NILs will be used as the parents for fine mapping with the ultimate aim of cloning the gene. Description of the gene content of the locus will draw on collinear grass models- *Brachypodium distachyon*, rice, and barley and the emerging genome sequence of hexaploid wheat (Brenchley *et al*., 2012). Single nucleotide polymorphisms (SNPs) will be mapped using KASPar technology established within Crop Genetics and iDNA Genetics Ltd, a private company situated at the Norwich Research Park.

In addition to their use as purely genetic resources the NILs will also be exploited as a unique resource to understand how changes at a single locus can influence agronomic performance between environments and what the specific developmental effects of this gene are. This will be achieved by growing NILs in controlled environments and field conditions.

Given the aforementioned importance of wheat and the challenges at hand of improving this important global crop, the current study seeks to understand the genetic and physiologic basis of *earliness per se* in bread wheat. The aim is to unravel the mechanism of a large effect *Eps* gene on chromosome 1DL (Griffiths *et al.*, 2009) and the possibility that *Early flowering 3* (*ELF3*) is a candidate for this QTL. New candidates may emerge as the fine mapping element of the work proceeds. Each candidate will be mapped in the high resolution population and alleles sequenced if they co-segregate with the flowering time phenotype at this mapping resolution. The knowledge generated from this study will add onto our knowledge of the genetics of this most important cereal and possibly contribute to yield increase to fill the so called yield gap.

1.3 **Rationale of the study**

The *Eps* genes are important but not much is known about them. Presently no *Eps* gene has been cloned in wheat despite the importance of such genes in fine tuning flowering time to adapt wheat for various environments. In *T. monococcum*, the *Eps-*A^m*1* locus has been reported to be thermo sensitive and also to affect the number of spikelets as well as the number of grains per spike (Lewis *et al*., 2008). Cloning such a gene may lead to increasing grain yield as well as improving our understanding of how temperature interacts with other environmental cues in controlling plant growth and development. Again not many genes are known to affect flowering time under short days in wheat. Identifying novel short day flowering time genes will give breeders more control when manipulating flowering time.

It is projected that a 1^{o}C increase in temperature will result in 6-20% yield loss in wheat. When this is taken in light of the deficit that is also projected between yield and demand, it is apparent that something has to be done so as to guarantee food security. Productive land is also being diminished by population increase and urban expansion hence the land being used should be made more productive by breeding higher yielding varieties as well as reducing yield losses in the field and along the supply chain to the consumer.

Increasing yield is one of the major targets for plant breeders especially for wheat which plays a significant role in global food security. Wheat is a staple food in more than 40 countries and has the greatest trade value relative to other cereals (Peng *et al.,* 2004; Gill *et al.,* 2004). The problems associated with climate change and global warming are real and no longer a distant future problem as some of the problems have already manifested themselves in unpredictable rainfall patterns across major crop producing areas.

The novel information generated from this study will help breeders and farmers to make informed decisions, on the best crops to grow in a very dynamic future environment. In the UK, it is estimated that wheat contributes about 3% to gross domestic product. Improving wheat production will therefore contribute to the UK economy. Wheat is a global crop and novel information from this study will have local and global benefits as well. Increasing yield also requires crossing the best varieties and maximising on desirable effects. This study seeks to increase our understanding of *Eps* genes as well as finding novel flowering time genes which can be used by breeders in selecting the best material.

1.4 **Objectives of the current study**

In this thesis, selected *Eps* effects will be studied. The *Eps* QTL on 1DL will be verified and mapped. The aim is to validate the 1DL QTL using NILs, verification of the 1DL QTL in controlled environments, develop new molecular markers for 1DL locus, studying the response to photoperiod of selected fully vernalized European wheat germplasm, and identifying novel photoperiod genes in wheat. These objectively are described here.

1.4.1 Objective 1. Validation of a 1DL *Eps* QTL using Near Isogenic Lines (NILs)

Work within the Griffiths group has produced NILs for the 1DL QTL using the parents Spark, Rialto, Avalon and Cadenza. They were developed by a process of two backcrosses and recovery of homozygous individuals from the BC_2F_2. Genetic background effects are accounted for by the production of NILs from two doubled haploid donors and the selection of two BC1 heterozygotes. In this thesis, the NIL families were grown under long and short day treatments using the JIC photoperiod benches. Ear emergence was measured and statistical significance of ear emergence differences assessed using the Students T-test.

1.4.2 Objective 2. Development of new molecular markers for 1DL locus

The NILs have been prepared by marker assisted selection (MAS) using flanking simple sequence repeat (SSR) markers. It is important to thoroughly describe the genotype of these new lines, particularly in and around the introgressed segment. The collinear regions of rice and Brachypodium will be used to design gene based markers on 1DL.

1.4.3 Objective 3. Verification of the 1DL QTL in controlled environments

The doubled haploid populations that were used in the META study (Griffiths *et al*., 2009) will be grown in controlled environments to determine the effect of vernalization and photoperiod on the 1DL QTL. The plants will be inadequately and fully vernalized to determine the effect of vernalization on the QTL. The plants will also be grown under three photoperiod regimes, short days (10 hrs light), long days (16 hrs light) and very long days (20 hours light) to determine the effect of photoperiod on the 1DL QTL.

1.4.4 Objective 4 studying the response to photoperiod of selected fully vernalized European wheat germplasm.

Wheat varieties from UK, Sweden and Kazakhstan will be fully vernalized and will be grown under three photoperiod regimes, short days (10 hrs light), long days (16 hrs light) and very long days (20 hours light) to determine novel photoperiod genes.

1.4.5 Objective 5. Identifying new photoperiod genes in wheat

The current study also seeks to identify new photoperiod genes using five doubled haploid (DH) populations to map and possibly identify novel photoperiod genes. This thesis will try to identify the wheat homologue of the barley gene *HvFT3* which has been shown to have a larger effect under short days (Faure *et al*., 2007). The current study will grow the DH populations under both short and long day conditions to identify novel photoperiod genes.

2 **Chapter 2**

2.1 **Validation of a 1DL *earliness per se (Eps)* QTL in bread wheat (*Triticum aestivum*)**

2.1.1 Introduction

Wheat yields are not keeping up with demand as the world population is increasing, and this has led to the lowest global wheat stocks ever since the green revolution (Coff *et al*., 2008; Gupta *et al*., 2008). It is therefore vital to breed crops, particularly wheat, with even higher yields in order to ensure current and future food security as well as improving quality. Almost four decades ago, Evans (1975) predicted that the future food security of humanity would depend to a large extent on our knowledge of the environmental adaptability of the crops of the future.

Herndl *et al*., (2008) reported that grain yield and quality were dependent on the time of flowering. A year later, Greenup *et al*., (2009) underscored the need for further studies to reveal the molecular basis of seasonal flowering differences in cereals. Gill *et al*., (2004) had earlier suggested that absolute yield increases can be achieved if we have thorough knowledge of the wheat plant and grain biology.

Genetic variation in emergence and maturation of wheat ears is the consequence of allelic variation at loci controlling the vegetative to floral transition, inflorescence development, and stem extension. This variation has major implications for yield potential, abiotic and biotic stress tolerance/avoidance, interactions with agronomic interventions, and our ability for predictive breeding of germplasm adapted to specific environments. The timing of ear emergence is fundamental to plant survival in that it allows plant species to flower at the most suitable period which will allow pollination, seed set as well as dispersal (Cockram *et al*., 2007). Three major sets of loci are responsible for the variation in flowering time observed in bread wheat varieties. These loci, which interact with the environment in mediating the transition from vegetative to floral growth in wheat are: vernalization, photoperiod and the poorly understood earliness *per se* (Herndl *et al*. 2008; van Beem *et al*. 2005; Bullrich *et al.,* 2002).

Winter wheat varieties require vernalization (4-8 weeks of cold treatment) before flowering while spring wheat varieties do not. The genetic differences between winter wheat and spring wheat are to a great extent due to allelic variation at the vernalization gene (*VRN-1*) locus (Cockram *et al.,* 2007; Yan *et al*., 2003). The spring (vernalization insensitive) cultivars have mutations in the promoter or deletion within the first intron of the *VRN-1* genes (Yan *et al*., 2003).

Photoperiod response in bread wheat is mainly controlled by a **P**seudo **R**esponse **R**egulator (*PRR*) gene whose homoeologues have been identified as *Ppd-A1*, *Ppd-B1* and *Ppd-D1* (Beales *et al*., 2007; Wilhelm *et al*., 2009; Diaz *et al.,* 2012). Dominant alleles of these genes make wheat plants photoperiod insensitive thereby leading to early ear emergence under short days, while those carrying the recessive alleles are very late flowering unless exposed to long days (Worland *et al.,* 1998). Photoperiod and vernalization genes contribute most to mega-environment adaptation (Griffiths *et al.,* 2009). UK wheat varieties are mainly photoperiod sensitive, winter, vernalization requiring types (Griffiths *et al.,* 2009).

In many UK varieties, the major genes controlling response to vernalization (*VRN-1*) and photoperiod (*Ppd-1*) are fixed, but breeding populations still segregate widely for flowering time. The genes responsible for this variation have been categorized as earliness per se (*Eps*) (Worland *et al*., 1998) but knowledge of their identities, mechanism and the physiological and agronomic implications of different alleles/allelic combinations are poorly understood.

Earliness *per se* (*Eps*) is variation in flowering time revealed when plants have been exposed to adequate vernalization and photoperiod requirements (Appendino *et al.,* 2003). *Eps* loci are defined as the genes that regulate flowering independent of both vernalization or photoperiod environmental cues (Bullrich *et al.,* 2002). Lewis *et al.,* (2008) described *Eps* genes as the other genes controlling flowering time but not involved in either vernalization or photoperiod requirements. The *Eps* genes are thought to be involved in the fine tuning of wheat flowering time within mega-environments (Griffiths *et al.,* 2009; Valarik *et al.,* 2006) and are responsible for wide adaptation of wheat to different environments (Lewis *et al.,* 2008; Worland *et al*., 1994).

Eps genes are found on all the wheat chromosomes (Bullrich *et al.,* 2002; Griffiths *et al.,* 2009) and each generally causes differences of a few days (1-5) in flowering time (Valarik *et* *al.,* 2006). *Eps* genes are thought to be involved in different developmental phases like the transition from vegetative to reproductive growth, early and late spike development, stem elongation and heading, which determine grain yield components (Griffiths *et al.*, 2009; Lewis *et al*., 2008). Despite its significance, the genetic and physiological basis of *Eps* gene function remains largely unknown. Elucidating the role played by the individual *Eps* genes in each developmental phase will enable breeders to fine tune ear emergence in predictive wheat breeding (Griffiths *et al.,* 2009), and increase wheat yields in different environments (Lewis *et al*., 2008).

One *Eps* gene that has been studied for about a decade now is the *Eps-*A^m*1* reported to be on the distal region of *Triticum monococcum* chromosome $1A^mL$ (Faricelli *et al*., 2010; Valarik *et al.,* 2006; Bullrich *et al.,* 2002). *Molybdenum Transporter 1* (*MOT1)* and *FILAMENTATION TEMPERATURE SENSITIVE H4* (*FtsH4*) have been suggested as candidates for the *T. monococcum Eps* and work on **T**argeting **I**nduced **L**ocal **L**esions **i**n **G**enomes (TILLING) for the two genes is being done to ascertain if one or both, or another different gene is a likely candidate (Faricelli *et al*., 2010).

The *Triticum monococcum* chromosome $1A^mL$ locus has been reported recently to be involved in determining the number of spikelets as well as the number of grains per spike in diploid wheat in addition to affecting heading time (Lewis *et al*., 2008). Hence, understanding the genetics of *Eps* is one avenue that could lead to optimised adaptation and increased wheat yields. Determining the role of an individual *Eps* gene on different wheat developmental phases requires accurate mapping of the gene responsible (Lewis *et al*., 2008). It is only after cloning the gene that it can be studied further particularly its mechanism of action and how this can be manipulated in wheat breeding. The use of near isogenic lines (NILs) is a step towards fine mapping and eventual cloning of such gene.

The work described here follows a study done by Griffiths *et al*., (2009), who detected significant heading time QTLs on the long arm of chromosome 1DL in four doubled haploid (DH) populations (Spark X Rialto, Charger X Badger, Avalon X Cadenza and Rialto X Savannah) using META QTL analysis. The distal region of chromosome 1DL, a likely orthologue of the *Eps-*A^m*1*, had the strongest QTL effect in terms of LOD score, additive effect and stability in the different environments tested (Griffiths *et al.,* (2009). This thesis reports in this chapter, the validation of four independent pairs of NILs segregating for the

1DL QTL (Griffiths *et al.,* (2009) of a cross between Spark (early) and Rialto (late) grown in the field and controlled environments.

2.2 Materials and Methods

Development of near isogenic lines

Two doubled haploid lines derived from the F_1 of a cross between Spark and Rialto, lines number 9 and 23 (SR9 and SR23) were used for the development of near isogenic lines. These two lines share a common feature of being homozygous for the Spark allele at markers *Xbarc62* and *Xgdm111* (Fig. 2.1) but SR23 has the Rialto allele at marker *Xcfd63* while SR9 has the Spark allele at marker *Xcfd63* (Fig. 2.1). These markers were reported to be in the QTL interval (Griffiths *et al*., 2009). The background of the NILs and SR9 and SR23 were also screened using 421 KASPar markers covering all the 21 wheat chromosomes (Allen *et al*., 2011) and 173 of these were polymorphic and 248 were monomorphic. The 173 polymorphic markers included 34 markers which scored for the Spark allele for SR9 and SR23 selected on all the chromosomes sections that had the Spark allele. Since both of these lines segregated for the early *eps* phenotype, they were ideal as the donating backcross parent with Rialto as recurrent parent because they also had higher than 50% Rialto background.

Two plants each from SR9 and SR23 (SR9_1, SR9_2, SR23_1, SR23_2) were grown and backcrossed into Rialto to produce backcross 1 (BC_1) plants. The seeds from BC_1 plants were grown and then backcrossed into Rialto to produce backcross 2 (BC_2). The BC_2 plants were grown and bagged to enable self-pollination. The BC_2F_2 plants were screened using markers *Xcfd63*, *Xgdm111* and *XBarc62*. For SR23, all the nine plants were fixed for the Rialto allele at marker cfd63. Five plants derived from backcrossing SR23_1 consisted of two homozygous for the Spark allele at markers *Xgdm111* and *Xbarc62* and were designated A1 and A2 and three that were homozygous for the Rialto allele designated B3, B4, B5 and these five plants formed the first NIL validation pair. Four plants derived from SR23_2 formed the second NIL validation pair and were designated A6, A7, B8 and B9 to indicate the NILs homozygous for the Spark allele at markers *Xgdm111* and *Xbarc62.* Five plants screened from the BC_2 derived from SR9_1 formed the third NIL validation pair, A10, A11 B12, B13 and B14 and these were homozygous for the Spark and Rialto alleles, respectively, at markers cfd63, gdm111 and barc62. The fourth NIL validation pair was screened from BC_2

plants derived from SR9_2 and this comprised of A15, A16, B17 and B18, and these were all fixed for the Rialto allele at *Xcfd63* but homozygous for the Spark and the Rialto alleles respectively at markers *Xbarc62* and *Xgdm111*.

2.2.1 Validation of Eps in one pair of the near isogenic lines Summer 2010

A statistical student t-test validation of the 1DL *Eps* heading QTL was carried out using GenStat. This was done using one set of the four near isogenic line pairs in a controlled environment room at the John Innes Centre. The seeds were sown in December 2009. A significant difference (p=0.048) in the mean heading time of the near isogenic lines (NILs) segregating for the Spark and Rialto 1DL QTL regions was obtained (data not shown). A significant difference in the mean of NILs BC_2F_2 measured in the glasshouse was the reason the QTL was pursued further and to validate the rest of the NILs as this result was consistent with the results from the META QTL (Griffiths *et al.*, 2009) work which identified the QTL on 1DL. The experiment was repeated in the field and glasshouse in the summer of 2012.

2.2.2 Validation of *Eps* using four Spark X Rialto near isogenic lines summer 2012

The experiment was divided into two parts with one having the NIL plants grown in the field and the other in controlled environments. For the controlled environment, the plants were sown in December 2010, fully vernalized under short days (10hrs light) for eight weeks at 6-10 ^{o}C using natural vernalization in an unheated glasshouse. The plants were then grown at 13-18 ^{o}C under short days (SD, 10hrs light), long days (LD, 16hrs light) and very long days (VLD, 20hrs light) using movable benches set to give the SD, LD and VLD photoperiods. Additional lighting was provided using 4 hours and 8 hours artificial white light (tungsten bulbs) to aid the LD and VLD respectively. The lights used were eight 60W tungsten lamps in each of LD and VLD treatments spaced 90cm apart and 2.1 m above the bench on which the plants were growing. This delivers 1 micromole s^{-1} m^{-2}.

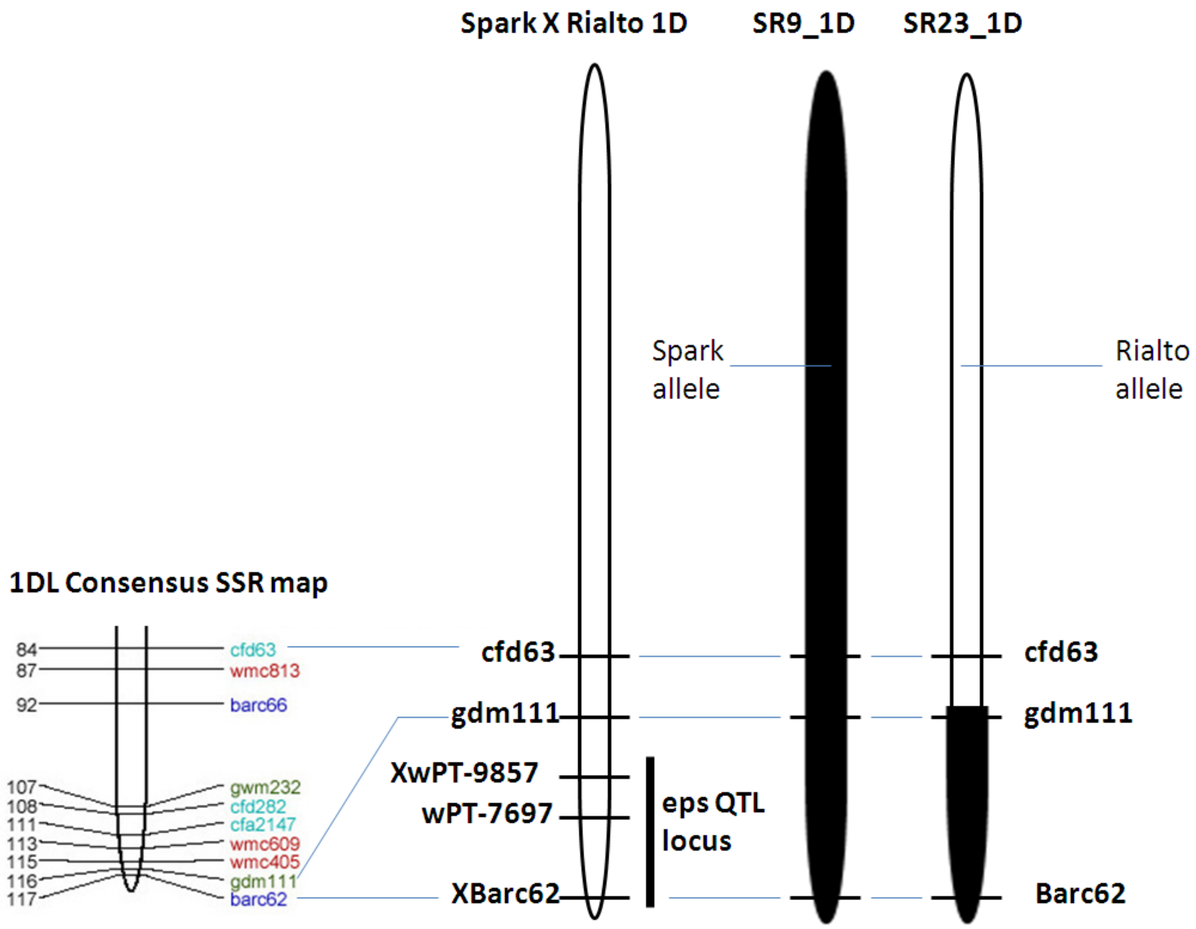


Fig. 2.1 Chromosomal location of the markers (X*cfd63*, *Xgdm111* and *XBarc62*) flanking the ear emergence QTL used for the development of Spark X Rialto near isogenic lines derived from SR9 and SR23. The consensus SSR map was adapted from the GrainGenes 2.0 database (wheat.pw.usda.gov/). The *Eps* QTL locus is adapted from Griffiths *et al*., (2009).

For the controlled environment treatment, five plants were grown in 1 litre pots for each NIL in each photoperiod treatment. The randomized complete block design from EDGAR II experimental design generator and randomizer software (http://www.edgarweb.org.uk/) designed by Professor James KM Brown, John Innes Centre was used. Differences in flowering time between the NIL pairs was determined at growth stage 55 (GS55) according to the scale by Zadoks *et al.*, (1974). The Student's t-test was used to test for significance between the heading date means of the NIL pairs. Five plants each of the wheat cultivars Spark, Rialto, Claire, Malacca and Hereward were grown as controls to determine if the plants had been adequately vernalized. Dı´az *et al.*, (2012) reported that Hereward flowered more than 30 days later than Malacca and Claire when inadequately vernalized (4 weeks) and this was associated with copy number variation at *Vrn-A1*. All plants in this study were vernalized for eight weeks at 6-10 ^{o}C and then grown under SD, LD and VLD. Ear emergence for Spark, Rialto, Claire, Malacca and Hereward was scored the same way as for the NILs.

For the field grown plants, drilling was done on September 2010 at Church farm Norwich, Norfolk. The near isogenic line pairs were drilled in 1m^2 plots and three randomized replicates were grown for each NIL. Individual plants were then scored for ear emergence the same way as the controlled environment plants were scored. Plants in the field were fully vernalized given that the growing season included the whole UK winter season, with plants flowering in May 2011. The differences in heading date between the NILs were scored as days to heading after 1 May 2011 for the whole population.

Sequencing *TaFT3-D1* the homologue of the barley gene *HvFT3*

Homology searching the "Chinese Spring" unassembled reads database

The barley gene *HvFT3* has its homolog on wheat 1DL hereafter designated *TaFT3-D1*. The sequences of *TaFT3-D1* for Spark and Rialto were used to determine if this gene could be the candidate for the wheat 1DL *eps* effect. Since the study was being carried out using hexaploid wheat, it was necessary to assemble the three *TaFT3* gene homoeologues (A, B and D) from the unassembled reads of the Chinese Spring sequence database (Brechley *et al*., 2012) to enable the design of primers which were specific to 1DL. The mRNA sequence of barley gene *HvFT3* accession number DQ411319.1 (Faure *et al*., 2007) was used to homology search the "Chinese Spring" unassembled 454 reads database using the **B**asic **L**ocal **A**llignment **S**earch **T**ool (BLASTn) alogorithym (Altschul *et al*., 1990). The three wheat homoeologues of the gene were then assembled using vector NTI sequence alignment tool. Homoeologous single nucleotide polymorphisms between the putative three homoeologues allowed the identification of the three homoeologues which were designated X, Y and Z at this point.

Identification of the A, B and D homoeologues of *TaFT3* using the *Aegilops tauschii* and *Triticum urartu* unassembled reads database

One of the putative A, B and D genome homoeologues designated X, Y and Z was used to blast search the *A. tauschii* sequence database (You *et al*., 2011) and the *A. tauschii* sequences were assembled and aligned with the three putative wheat homoeologues X, Y and Z. The D genome from the putative wheat homoeologues had the highest sequence identity match with the *A. tauschii* sequence. Furthermore, the SNPs that were specific to the D genome matched the *A. tauchii* sequences and hence enabled accurate assigning of the 1DL sequences. Although it was not essential to this study, the A and the B sequences were distinguished by using the *Triticum urartu* sequence database (Ling *et al*., 2013) to identity the A genome and the remaining sequence was then assigned to the B genome.

Sequencing *TaFT3-D1*

The assembled genes were used to design a series overlapping PCR primers spanning the entire *TaFT3-D1* gene using the method described by Diaz *et al*., (2012). Amplicons were obtained from genomic DNA using the standard PCR protocol and were directly sequenced using ABI Big Dye Mix v3.1 (Applied Biosystems Inc) under the manufacturer's conditions, with products resolved on an ABI 3730 capillary electrophoresis instrument. The primers amplified PCR fragments ranging in size from 400bases to 1500bases from both Spark and Rialto.

Standard PCR protocol

The PCR reactions were done as described by Diaz *et al*., (2012) with a few modifications. 50 ng genomic DNA in 20 µl reactions comprising 1× PCR Buffer and 0.4 units Taq polymerase with 2 mM MgCl2, 250 nM of each primer and 200 µM dNTPs

PCR reaction conditions

The PCR had 40 cycles and 55^{o}C was the annealing temperature. The first step was initial denature done at 95 ^{o}C for 2 minutes. Forty cycles involved denaturation for 20 seconds at 95^{o}C, annealing at 55^{o}C for 20 seconds and polymerisation at 72 ^{o}C for 1 minute per kb. After the forty cycles, the PCR reaction was held at 72°C for five minutes and then kept at 10°C until removal to a freezer or analysis on agarose gel.

Scoring Single Nucleotide Polymorphisms (SNPs) in *TaFT3-D1*

Scoring of SNPs in *TaFT3-D1* was done as described for *Vrn-A1* by Dı´az *et al.*, (2012). The KBioscience KASP reagents (www.kbioscience.co.uk) were used in reactions containing distilled water (2 µl), KASPar mix (4 µl), primers (0.1 µl), 50 mM $MgCl_2$ 0.064 ml) and DNA (2 µl). An activation time (94°C, 15 min) was followed by 20 cycles of [94°C for 10 sec; 57°C for 5 sec; 72°C for 10 sec] followed by 24 cycles of [94°C for 10 sec; 57°C for 20 sec; 72°C for 40 sec]. Fluorescence was read as an end point reading at 25°C. Primer combinations were; Exon4_A/G SNP specific). primers: gaaggtgaccaagttcatgctAGGCGGAAGAAGGTTTAG**A** gaaggtcggagtcaacggattGGCGGAAGAAGGTTTAG**G** (0.16 mM). Generic primer ATGGTCAGTACTCTGTACTATCTAGTCC (0.4 mM

2.3 Chapter 2 Results

In the previous study (Griffiths *et al*., 2009), the 1DL QTL was detected by the analysis of DH lines grown in the filed only. In contrast, the current study developed and evaluated NILs grown under controlled environments and in the field (Fig. 2.2 and Fig. 2.3). In both field and controlled environments, the NILs carrying the spark 1DL segment were consistently early flowering than the Rialto (Fig. 2.2, Fig. 2.3 and Fig. 2.4). The statistical significance of the results was checked using the Student t-test for both field and controlled environment grown NILs (Table 2.1). All NIL pairs had significant differences in mean heading date in both the field and controlled environments except NIL pair two (A6, A7, B8 and B9 which had a non-significant p-value under short days but significant p-values for LD and VLD (Table 2.1)

The results validate the existence and chromosome position of the flowering time QTL as marker assisted introgression of the Spark 1DL region caused early flowering in the relatively late flowering Rialto background (Fig. 2.2, Fig. 2.3, Fig. 2.4 and Fig. 2.6b). The results also show that the 1DL heading QTL is an *eps* effect given that the NILs with the Spark allele are early flowering independent of photoperiod (Fig. 2.4). This was suggested but not proven by the field study of Griffiths *et al*., (2009).

Genotype of 1DL NILs at loci known to regulate heading date in Spark x Rialto

The NILs used in this study were created with the recurrent parent Rialto. In cases were the donor parent carried Rialto alleles there was no issue with potential Spark background effects in the BC2 NILs. This is of particular importance in the regions where it is known that heading date QTLs are likely to segregate. The genotype of the NILs at ear emergence QTL loci on 1BL, 2A, 3A, 3B, 4B, 4D, 5AL 5B, 6A, 6B, 7A and 7D was checked using KASPar markers since Spark and Rialto were reported to segregate for ear emergence at these loci (Griffiths *et al*., 2009). The donor parent SR9 was already fixed for Rialto chromosome arms 3B, 4B and 4D, 5B hence the NILs A10, A11, B12, B13, B14, A15, A16, B17, B18 developed from SR9 were all fixed Rialto at 3B, 4B, and 4D since Rialto was the recurrent parent. We confirmed this when we genotyped the NILs (Table 2.2). SR23, the other donating parent had fixed Rialto chromosome arms at 1B, 3A, 4B, 5B hence the NILs, A1, A2, B3, B4, B5 A15, A6, A7, B8 and B9 were all fixed Rialto at 1B, 3A, and 4B since Rialto was the recurrent parent for backcrossing. This was confirmed in NILs using KASPar markers (Table 2.2). The recurrent parent SR9 had Spark Chromosome arms at 1B, 2A and

3A, 6AL while the recurrent parent SR23 had Spark chromosome arm at 2A, 4D, 6AL while chromosome. These loci were ckecked using KASPar markers as they were likely to cause some background noise if these areas were fixed with spark alleles in the background of the NILs. At 1B, NILs A10, A11, B12, B13 and B14 had the Spark allele while the rest had the Rialto allele (Table 2.1). At 2A, NILs A6 and B9 had Spark alleles in the QTL region while the rest had Rialto alleles. At 3A, NILs A10, A11, B12, B13 and B14 had the Spark allele while the rest had Rialto. At 4D, all the NILs had the Rialto allele. 5AL, all the NILs A6, A7, B8 and B9 were heterozygous but the rest were fixed Rialto. All the NILs were fixed Rialto at 5BL, 6B and 7D while NILs A7 and B8 had Spark alleles and NILs B9 was heterozygous at 7A and the rest were fixed Rialto (Table 2.2). These differences in the NILs background can be speculated to account for some of the variations in heading observed between the NILs.

Differences in heading date among NILs

The results show that there are some differences in heading date among the Nils (Fig. 2.2, Fig. 2.3 and Fig. 2.4) but these differences are less in the parental lines (Fig. 2.5). This maybe speculated to be due to different backgrounds between the Nils and parental lines. The parental lines are more homogenous than the NILs which have heterozygous segments (Table 2.2). Furthermore, NIL pair 2 (A6, A7, B8 and B9) is heterozygous at 5AL loci and this NIL pair is the only one which had non-significant p – value under short days (Table 2.1). It is possible that the short day effect at 5AL locus (described in chapter 6) may interact with the 1DL locus. It is described in chapter 6 that the 5AL locus is linked to the *XBarc 151* marker which is known to be linked to genes that affect flowering time like *Vrn-A1*, *PHYC* (Diaz *et al.*, 2012; Distelfeld and Dubcovsky 2010).

Interaction between 1DL and photoperiod

The analysis of variance (ANOVA) was carried out to determine if there was an interaction between the 1DL genotype and photoperiod but there was no significant interaction between 1DL genotype and photoperiod ($p = 0.10851$) and the F value was 2.2516 which was less than the F critical value 3.051.

Possibility of *TaFT3* as a candidate for 1DL

The results (Fig. 2.6b) show that *Triticum aestivum FLOWERING LOCUS T 3* (*TaFT3*), the wheat homologue of barley gene *FLOWERING LOCUS T 3* (*HvFT3*), a candidate for *PHOTOPERIOD H2* (*Ppd-H2*) (Faure *et al*., 2007), is not a candidate for the 1DL *eps* effect.

A single nucleotide polymorphism (SNP) in exon 4 which is a silent mutation in the D copy of *TaFT3* (*TaBradi2g19670*) allowed the development of a KASPar marker (X*TaBradi2g19670*) which distinguishes Spark *TaFT3-D1* GenBank accession number KJ661739 from Rialto *TaFT3-D1* GenBank accession number KJ661740. All the NILs at this locus have the Rialto allele except NIL10, 11 and 12 (Fig. 2.6b). NILs 11 and 12 have both alleles of *TaFT3* (Fig. 2.6b) but NIL 11 is early flowering relative to NIL 12 (Fig. 2.3 and Fig. 2.4). Given that all the early flowering NILs have the Spark allele at *Xgdm111* (Fig. 2.6b), it can be concluded that the 1DL *eps* effect is downstream of *TaFT3-D1* and hence *TaFT3-D1* is not a candidate for the 1DL *eps* effect.

The background of the 1DL NILs

The results also show that the NILs have more than 90% Rialto background (Fig. 2.6a), the average for the 18 NILs was 95%. The expected Rialto background from two backcrosses was about 90% given that backcrossing started with around 60% Rialto background for the donating parents SR9 and SR23 (Fig. 2.1). A possible explanation is that even though the 173 markers were selected to represent as much of the chromosomes as possible, they are not adequate to give an accurate estimation given the big size of the bread wheat genome. Spark and Rialto also have close lineage from their pedigrees and the 248 monomorphic markers from a total of 421 (data not shown) also shows their close relatedness. Taken all together, the results suggest that the background of the NILs was very similar. NIL pair 1 (A1, A2, B1, B2, B3) and NIL pair 4 (A15, A16, B17 and B18) have Rialto background at all the loci that Griffiths *et al*., (2009) reported to segregate for flowering time between Spark and Rialto (Table 2.2). These two NILs pairs (Nil pairs 1 and 4) also have the highest Rialto background (Fig. 2.6a). It is worth noting that the NIL pairs have the same alleles in the background whether it is Spark or Rialto hence comparing the NIL pairs at1DL should give comparable results. However, there are some minor differences within the NILs themselves for example NIL B5 flowers 2 days later than NILs B3 and B4 and NIL B8 and B9 have a difference of 2 days in the field. It is possible that there are other QTL that could not be detected by the DH lines whose effect is now observable. Again the KASPar markers used cannot detect copy number variations which could be causing these differences in heading within NILs.

It is also shown that the NILs segregate for ear emergence when fully vernalized for eight weeks (Fig. 2.3). A recent report by Dı´az *et al.,* (2012) showed that wheat segregates for heading when inadequately vernalized (less than 8 weeks) and grown under LD. This study used Claire, Malacca and Hereward which require short, intermediate and long exposure to vernalization, respectively, as controls (Fig. 2.5). Hereward flowers more than 30 days later than Claire and Malacca when inadequately vernalized for four weeks (Dı´az *et al.*, 2012). In the current study, the three varieties all flower at the same time when vernalized for 8 weeks, showing that the experiment was exposed to adequate vernalization, hence the segregation of the NILs can be attributed to an *eps* gene(s). There is also a separate effect that causes Rialto to be early flowering under short days and the 1DL effect is independent of this (Fig. 2.5).

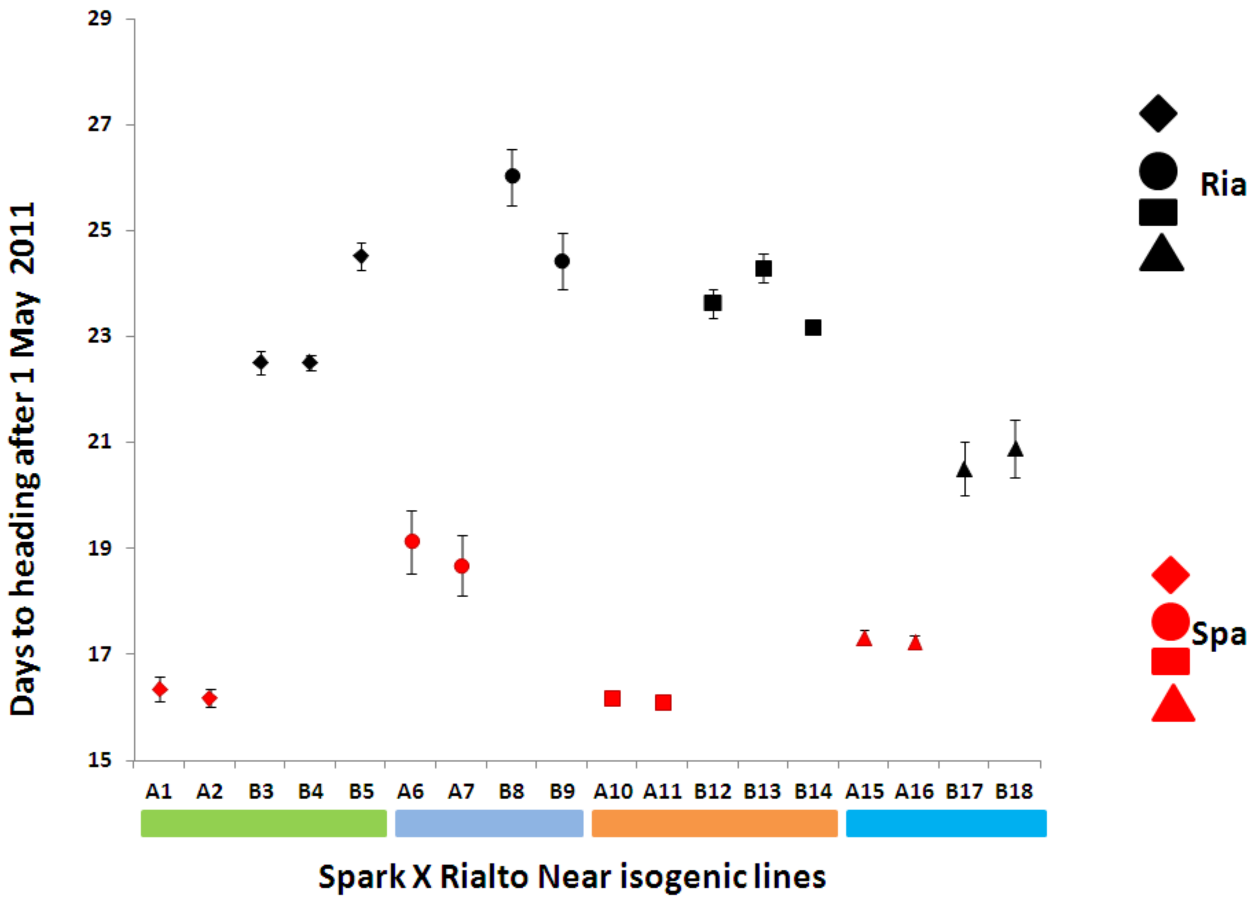


Fig. 2.2 GS55 for leading tillers of field grown (UK) Spark (Spa) X Rialto (Ria) NILs. The NILs with the Spark allele are always early (red). These are four independent NIL pairs showing consistent segregation of early and late phenotypes (p value < 0.0001). The red and black colours are used for the NILs carrying the Spark and Rialto alleles at 1DL respectively. The different shapes are used to distinguish between NIL pairs. Diamonds are used for the first NIL pair (A1-B5), circles are used for the second NIL pair (A6-B9), rectangles are used for the third NIL pair (A10-B14) and triangles are used for the fourth NIL pair (A15-B18). The error bars are the standard error of the mean.

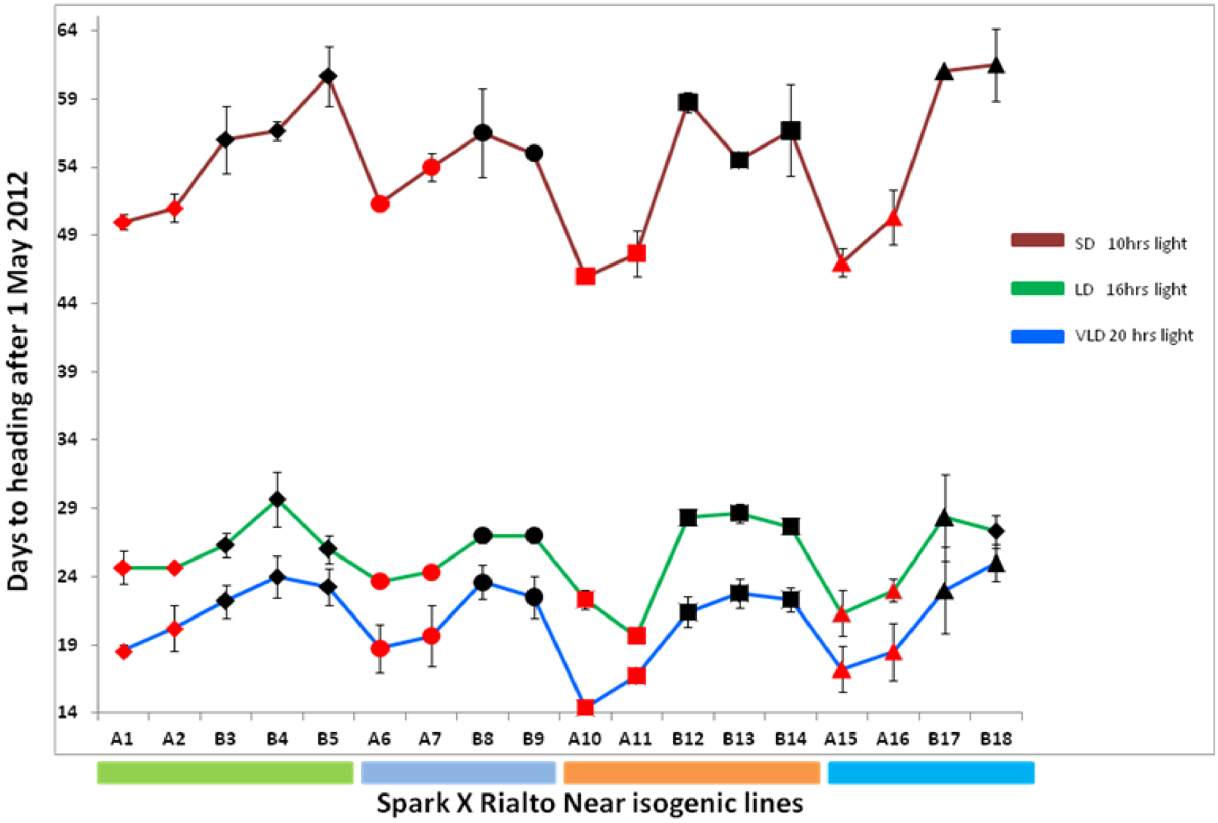


Fig. 2.3 GS55 for leading tillers of controlled environment grown Spark X Rialto NILs. The NILs with the Spark allele are always early independent of day length. The red and black colours are used for the NILs carrying the Spark and Rialto alleles at 1DL respectively. The different shapes are used to distinguish between NIL pairs. Diamonds are used for the first NIL pair (A1-B5), circles are used for the second NIL pair (A6-B9), rectangles are used for the third NIL pair (A10-B14) and triangles are used for the fourth NIL pair (A15-B18). The error bars are the Standard error of the mean.The red green and Blue lines connecting the symbols are for the purpose of distinguishing the three photoperiod treatments.

Table 2.1 Mean heading date after 1 May and Student T-test values of 1DL NILs grown in the field (Fig. 2.2) and controlled environments (Fig. 2.3). The mean heading date are the average days to ear emergence of NILs carrying the Spark or Rialto allele at 1DL for each NIL pair. The ear emergence was measured at GS55 using the scale by Zadoks *et al*., (1974).

		Field		Controlled environment					
				VLD (20 hrs light		LD (16 hrs light)		SD (10 hrs light)	
NIL pairs	1DL QTL interval genotype	Mean Heading date	Student T –test p-value	mean	Student T –test p-value	mean	Student T –test p-value	mean	Student T –test p-value
A1, A2 B3, B4, B5	Spark	16.3	0.0001	19.3	0.0037	24.3	0.032	50.5	0.012
	Rialto	23.3		23		26.1		56.4	
A6, A7 B8, B9	Spark	18.9	0.0001	19.1	0.035	24	0.0001	52.4	0.2
	Rialto	25		23.3		27		54	
A10, A11 B12-14	Spark	16.1	0.0001	15.4	0.001	21	0.0001	46.8	0.0001
	Rialto	23.7		22.2		28.2		56.8	
A15, A16 B17, B18	Spark	17.3	0.0001	17.9	0.0028	22	0.0001	48.7	0.0002
	Rialto	20.7		24.3		27.8		60.2	

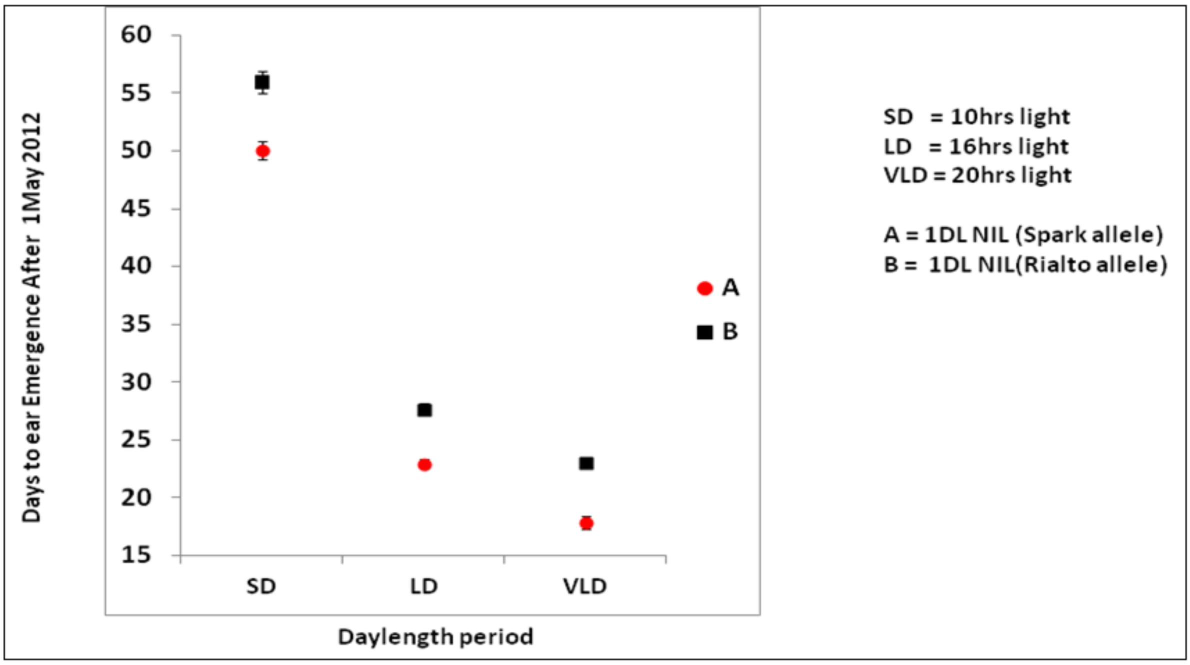


Fig. 2.4 GS55 for leading tillers of Spark X Rialto NILs grown under controlled environments. The heading days are the mean of 24 plants for the Spark (A) NIL and 30 plants for the Rialto (B) NIL. The additive effect is about five days in the three photoperiod treatments. Student's t-test was carried out for the mean heading days and all the four NILs pairs have a p value < 0.0001, which is highly significant. The error bars are the Standard error of the mean.

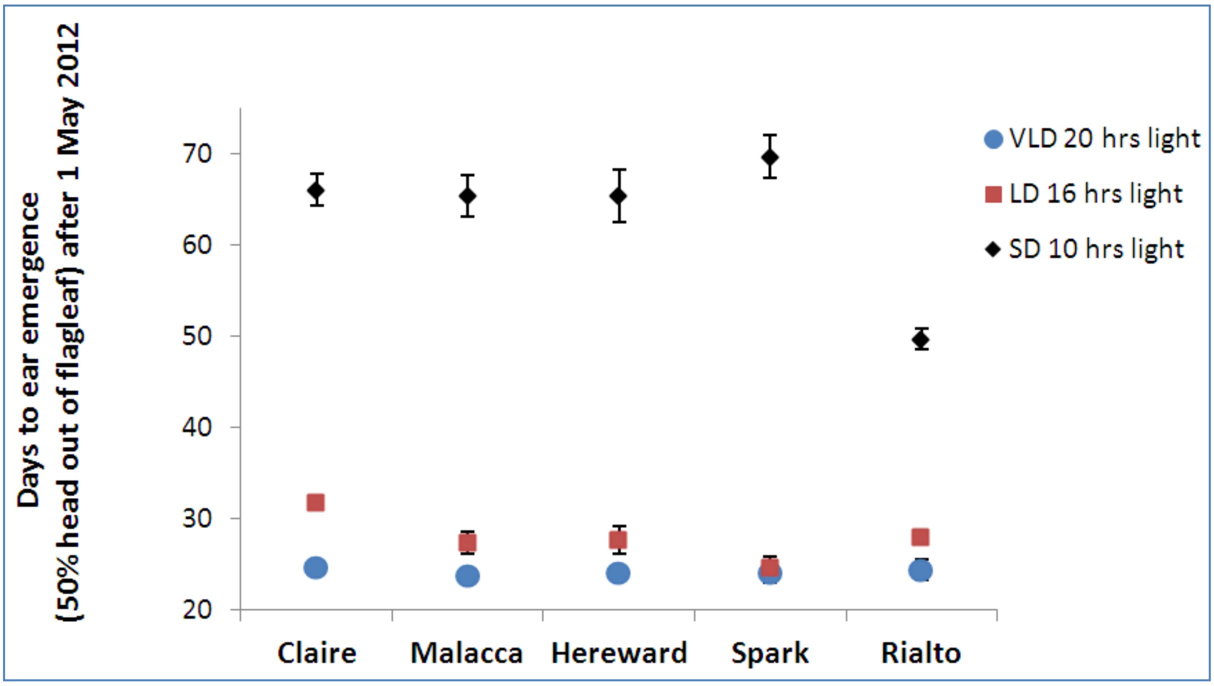


Fig. 2.5 GS55 for leading tillers average days to ear emergence of controlled environment grown elite UK wheat varieties. Rialto is relatively earlier flowering under short days than the rest of the varieties which flower almost at the same time under short days except Spark which is slightly late. The error bars are the Standard error of the mean.

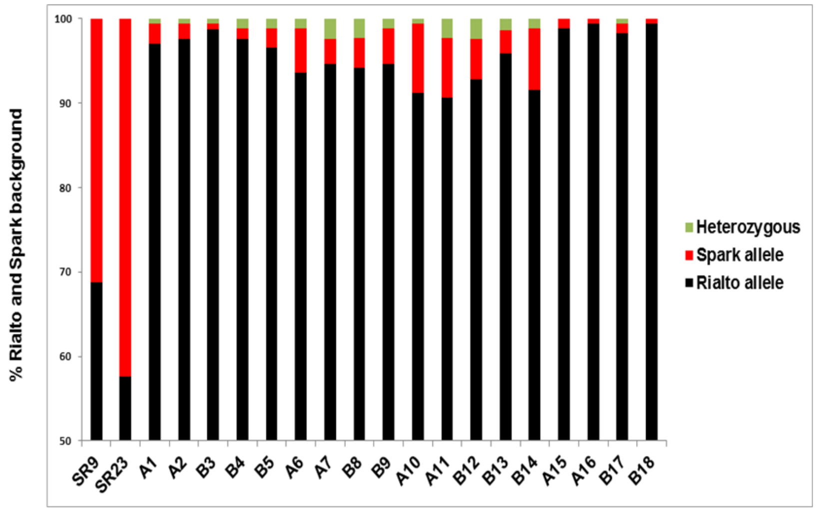


Fig. 2.6a Estimation of the background genotype of the 1DL NILs and the parental donor lines SR9 and SR29 using a total of 173 KASPar markers. The average was 95% Rialto background for all the 18 NILs which is 5% above the expected 90% that is theoretically obtained from two backcrosses. NIL pairs A1-B5 and A15-B18 had more than 95% Rialto background while NIL pairs A6-B14 had Rialto background closer to the expected 90% Rialto background

NIL	*Xcfd63*	*XTaBradi2g19670*	*Xgdm11*	*XTaBradi2g14790*	*XBarc62*
A1	b	b	a	a	a
A2	b	b	a	a	a
B3	b	b	b	b	b
B4	b	b	b	b	b
B5	b	b	b	b	b
A6	b	b	a	a	a
A7	b	b	a	a	a
B8	b	b	b	b	b
B9	b	b	b	b	b
A10	a	a	a	a	a
A11	a/b	a/b	a	a	a
B12	a/b	a/b	b	b	b
B13	b	b	b	b	b
B14	b	b	b	b	b
A15	b	b	a	a	a
A16	b	b	a	a	a
B17	b	b	b	b	b
B18	b	b	b	b	b

Fig. 2.6b The genotype of the 1DL NILs (a = Spark allele and b = Rialto allele). The *eps* effect is distal to the *Xgdm111* marker and it is the Spark allele which confers early heading since NILs A1, A2, A6, A7, A10, A11, A15 and A16 are early flowering (Fig. 2.2 and 2.3). The marker *XTaBradi2g19670* (*TaFT3*) a homologue of the barley gene *HvFT3* the suggested candidate for *Ppd-2* in barley is not a candidate for the 1DL *eps* effect since all the NILs except one have the Rialto allele at this locus and early heading is downstream of this marker.

Table 2.2. The genotype of the 1DL NILs at loci reported by Griffiths *et al*., (2009) to segregate for flowering time QTLs between Spark and Rialto. Het means heterozygous alleles between Spark and Rialto.

NILs	Wheat chromosome genotype at known Spark X Rialto flowering time QTL loci										
	1B	2A	3A	3B	4B	4D	5AL	5BL	6B	7A	7D
A1	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
A2	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
B3	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
B4	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
B5	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
A6	Rialto	Spark	Spark	Rialto	Rialto	Rialto	Het	Rialto	Rialto	Rialto	Rialto
A7	Rialto	Rialto	Spark	Rialto	Rialto	Rialto	Het	Rialto	Rialto	Spark	Rialto
B8	Rialto	Rialto	Spark	Rialto	Rialto	Rialto	Het	Rialto	Rialto	Spark	Rialto
B9	Rialto	Spark	Spark	Rialto	Rialto	Rialto	Het	Rialto	Rialto	Het	Rialto
A10	Spark	Rialto	Spark	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
A11	Spark	Rialto	Spark	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
B12	Spark	Rialto	Spark	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
B13	Spark	Rialto	Spark	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
B14	Spark	Rialto	Spark	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
A15	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
A16	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
B17	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto
B18	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto	Rialto

2.4 **Discussion**

The data validate the existence and chromosome position of the flowering time QTL as marker assisted introgression of the Spark 1DL region caused early flowering in the relatively late flowering Rialto background (Fig. 2.2-2.3). This shows that this effect is amenable to marker assisted selection in breeding. The results also showed that the 1DL heading QTL is an *Eps* gene given that the NILs with the Spark allele are early flowering independent of photoperiod (Fig. 2.3). This was suggested but not proven by the field study of Griffiths *et al*., (2009).

It is also demonstrated that the NILs segregate for ear emergence when fully vernalized for eight weeks (Fig. 2.3). A recent report by Diaz *et al*., (2012) showed that wheat segregates for heading when inadequately vernalized (less than 8 weeks) and grown under long days. This study used Claire, Malacca and Hereward which require short, intermediate and long exposure to vernalization, respectively, as controls (Fig. 2.5). Hereward flowers more than 30 days later than Claire and Malacca when inadequately vernalized for four weeks (Diaz *et al*., 2012). In the current study, the three varieties all flower at the same time when vernalized for 8 weeks, particularly under short and very long days, with Claire (which is earliest flowering when inadequately vernalized) flowering 5 days later than the other two under long days (Fig. 2.5) showing that the plants had been exposed to adequate vernalization, hence the segregation of the NILs can be attributed to an *Eps* gene(s). It is also evident that there is a separate effect that causes Rialto to be early flowering under short days. The 1DL effect is independent of this (Fig. 2.5).

The results show that the NILs used segregate for flowering time due to an *Eps* locus. This thesis follows on the study by Griffiths *et al*., (2009) who carried out META QTL analysis using doubled haploid populations and suggested that there was an *Eps* effect on the distal end of chromosome 1DL. An aim of this thesis is to contribute towards the fine maping of the gene and the validation of NILs segregating for the QTL is a necessary first step. A 20 hour photoperiod satisfies the photoperiod requirements of most photoperiod sensitive wheat given that wheat is a long day plant (flowering rapidly in long days of about 16 hours light but very late in short days of about 10hrs light), unless they carry photoperiod insensitive *Ppd1* alleles (Beales *et al*., 2007, Wilhelm *et al*., 2009, Diaz *et al*., 2012).

The wheat varieties used are UK winter wheat varieties which are photoperiod sensitive (Worland *et al*., 1998). The eight weeks vernalization treatment satisfied the vernalization requirement given that Hereward, which flowers very late relative to Malacca when inadequately vernalized for four weeks (Diaz *et al*., 2012), flowered at the same time as Malacca when vernalized for eight weeks (Fig. 2.5.). Since the segregation of the NILs cannot be accounted for by photoperiod or vernalization requirements, it falls in the *Eps* group of genes that affect flowering (Bullrich *et al.,* 2002; Appendino *et al.,* 2003; Lewis *et al.* 2008) possibly through other developmental pathways.

The segregation of the NIL pairs, which have a common background, should enable further study to determine the genetic basis of the *Eps* given that the region that is flanked by the markers used to develop the NILs is known. The study included both field grown and controlled environment grown material and both environments gave consistent results where the NILs carrying the Spark allele were early flowering relative to the NILs carrying the Rialto allele.

A similar *Eps* study of the effect of the distal end of *T. monococcum* chromosome 1 (Lewis *et al*., 2008), suggested that the gene responsible had pleiotropic effects on spikelet number and grains per spike in addition to the heading time effect. The late flowering allele in *T. monococcum* was associated with increased number of spikelets per spike (Lewis *et al*., 2008). The study done in *T. monococcum* (Lewis *et al*., 2008) did not report on grain yield. However, there is a trade-off between number of grains and grain size. Having more spikelets on a spike can lead to smaller grains relative to having fewer spikelets and this may result in no overall yield gain. Our study only validated the heading differences between NIL pairs.

An important question which remains unanswered from our work is whether the 5 day differences in flowering time will cause a significant yield difference between the two NILs pairs and if that will be dependent on variable environments. If the 1DL *Eps* effect is yield neutral, the two alleles can be used to breed wheat for an environment that requires earlier flowering (Spark allele) to avoid stress like late drought, or an environment that is favourable to late flowering wheat (Rialto allele) to take advantage of a long growing season, without a significant yield penalty. The validation of grain yield of the NILs will answer this question. The Spark allele can be deployed at different latitudes because it is not photoperiod sensitive as shown by the NILs.

Given that the late flowering allele in *T. monococcum* was associated with increased number of spikelets per spike (Lewis *et al*., 2008) and that an earlier study (Griffiths *et al*., 2009) suggested that the same gene was likely responsible for *Eps* in both species, it is vital to clone this gene so as to prove if it is the same gene that is responsible in both species. Successful cloning the gene maybe a step towards increasing yield, because a delicate combination of genes responsible for grain size and spikelet number would eventually lead to overall yield increase. This validation study is a step towards cloning the gene and fine tuning flowering adaptation in wheat and possibly other cereals.

3 Chapter 3

3.1 New marker development for 1DL region

3.2 Methodology

3.2.1 Finding more markers on 1DL

There were not enough markers in the region containing the *Eps* QTL on 1DL (Griffiths *et al*., 2009) to enable fine mapping of the gene(s) responsible. For the Savannah X Rialto doubled haploid (DH) population, the marker *Xwmc609* was the most distal (Fig. 3.1), for Spark X Rialto *Xbarc62* was the most distal (Fig. 3.1) and *XBJ544902* was the most distal for Avalon X Cadenza (Fig. 3.1). More markers around this QTL region were needed to enable the fine mapping of the gene(s) responsible for the observed heading variation in the three doubled haploid populations (Griffiths *et al*., 2009).

Synteny between wheat, rice (Valarik *et al*., 2006; Faricelli *et al*., 2010), brachypodium, barley (Higgins *et al*., 2010) and sorghum (Zakhrabekova *et al*., 2012) was used to design new markers for 1DL (Fig. 3.2) around the *Eps* QTL.

When Fig. 3.1 and Fig. 3.2 are compared, it is evident that the marker X*AL503851* from the gene vacuolar ATP synthetase subunit **C** (*vatpC*) a homologue of the Brachypodium gene *Bradi2g14400* (Table 3.1) is shared between the *T. monococcum Eps* region (*Eps* A^{m} 1) and the *T. aestivum* (1DL) *Eps* regions suggesting a possibility that the same gene may be responsible for the flowering variation observed for both species. Given the overlap between the markers flanking the 1DL heading QTLs particularly for Avalon X Cadenza and Spark X Rialto DH populations (Fig. 3.1) it was necessary to design common markers that would be used to compare the two populations.

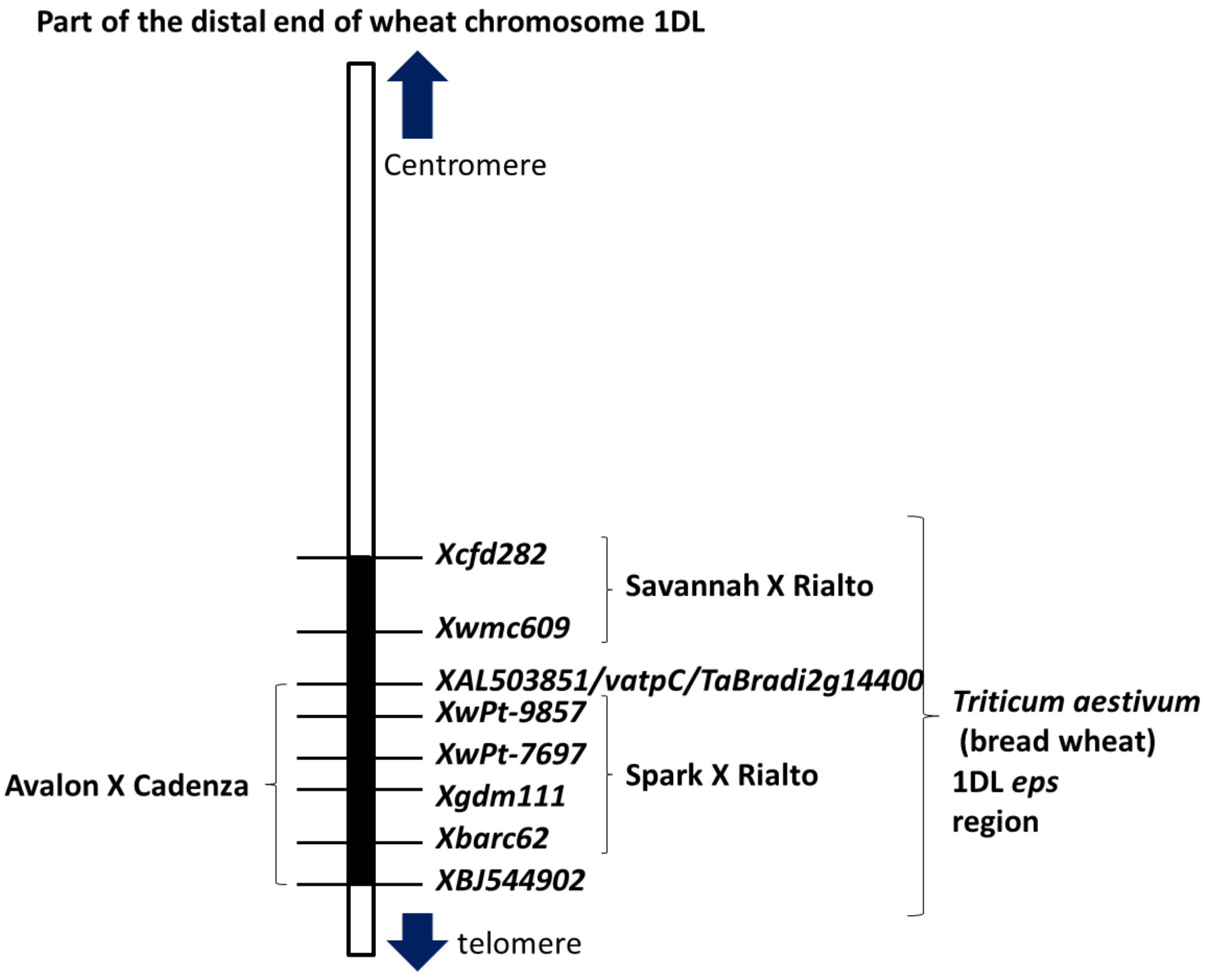


Fig. 3.1 The *Triticum aestivum Eps* region on the distal end of chromosome 1DL mapped using three independent doubled haploid populations (Avalon X Cadenza, Savannah X Rialto and Spark X Rialto) by META QTL analysis (adapted from Griffiths *et al*., 2009). The marker *XAL503851* is from the gene *vatpC* and will be used in Fig. 3.2 to link the synteny among *Triticum monococcum, Oriza sativa, Brachypodium distachyon, Hordeum vulgare and Sorghum bicolor*.

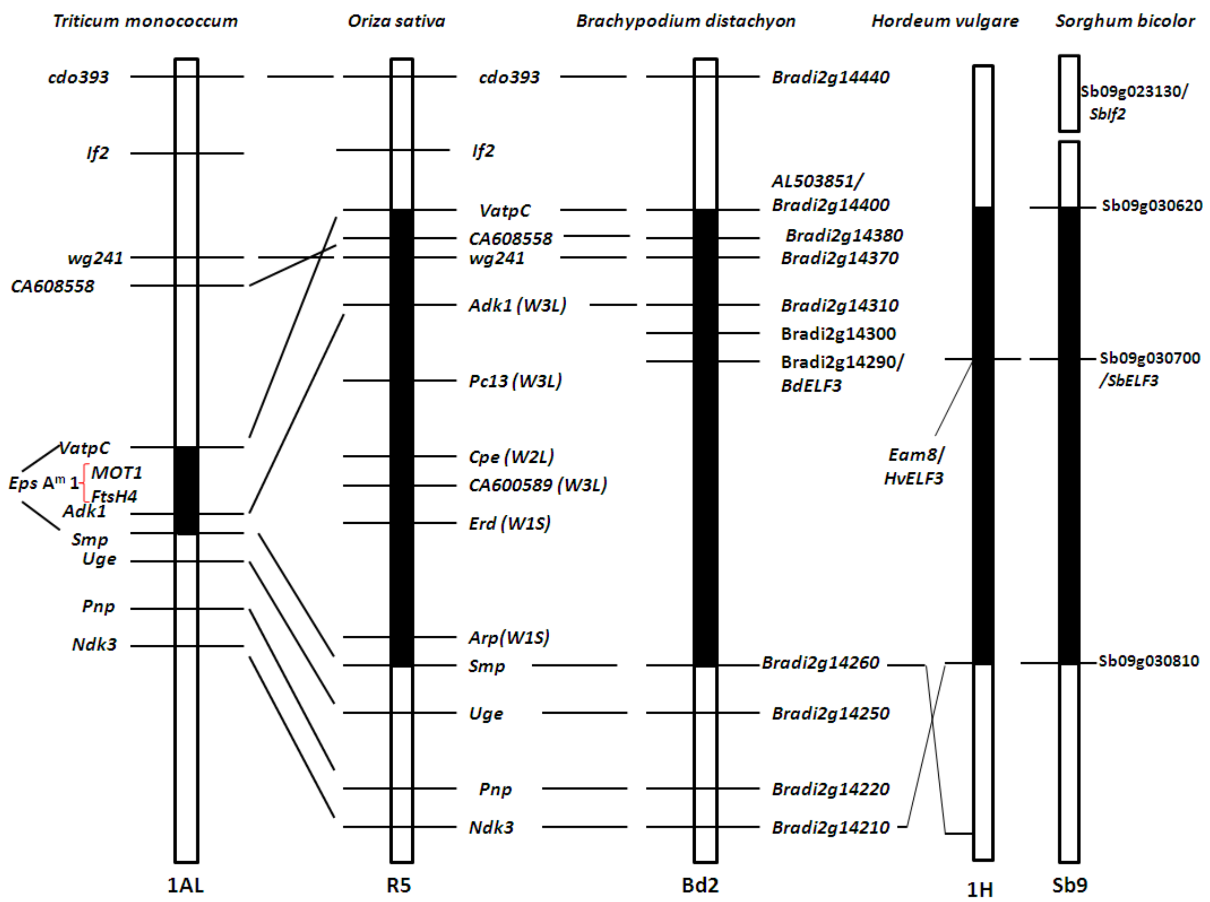


Fig. 3.2 The co-linearity and partial conservation of gene order among five grass species *Triticum monococcum* (*T. monococcum*) group one chromosome and rice chromosome 5 (Valarik *et al*., 2006; Faricelli *et al*., 2010), *Brachypodium distachyon* (*B. distachyon*) chromosome 2, barley (Higgins *et al*., 2010), and *Sorghum bicolor* (Zakhrabekova *et al*., 2012). The horizontal lines link syntenous genes and all horirontal lines at the same level indicate the same gene in the different species. The marker *XAL503851* from the gene *vatpC* is used here to show the synteny among *T. monococcum* (*VatpC*), *Oriza sativa* (*VatpC*), *Brachypodium distachyon* (*AL503851/Bradi2g14400*), *and Sorghum bicolor* (*Sb09g030620*). Rice (*Oriza sativa*) has the *ELF3* gene on two different chromosomes but not on chromosome 5 hence it is absent from this syntenous region. The gene order *Smp* (*Bradi2g14260*), *Uge* (*Bradi2g14250*), *Pnp* (*Bradi2g14220*) and *Ndk3* (*Bradi2g14210*) is reversed for *Hordeum vulgare* but the order is similar for *Triticum monococcum*, *Oriza sativa*, *Brachypodium distachyon* and *Sorghum bicolor* although only *Sb09g030810* (*Smp/Bradi2g14260*) only is shown here.

Markers were designed by sequencing syntenous genes around the *Eps* QTL on 1DL for Avalon, Cadenza, Spark, Rialto and Savannah. Since the study was being carried out using hexaploid wheat, it was essential to assemble the syntenous genes and identify the three wheat homoeologues (A, B and D genomes) in order to design D genome specific primers because the QTLs under investigation were all on the D genome (Griffiths *et al.*, 2009). At the beginning of this study, the flow sorted chromosome arm sequence data and the *Aegilops tauschii* sequence data were both not available. The only data available was the unassembled "Chinese Spring" 454 sequences (http://www.cerealsdb.uk.net/CerealsDB/Documents/DOC searchreads.php). The quotation marks on "Chinese Spring" will be used in this thesis to distinguish the "Chinese Spring" wheat variety from the "Chinese Spring" season as suggested by Diaz *et al*., (2012).

3.2.2 Homology searching the "Chinese Spring" unassembled reads database

The draft "Chinese Spring" 454 unassembled sequence reads database was used to assemble the three homeologous sequences. The database which is publicly available was made using the Roche 454 sequence technology by the wheat genome sequencing consortium. The "Chinese Spring" 454 unassembled sequence reads database was blast searched using the messenger RNAs (mRNAs) of the syntenous genes. The retrieved reads were assembled using Vector NTI, and to a limited extent phredprap sequence alignment programmes. The putative three homoeologues were then manually identified from the assembled contigs and designated (X, Y and Z) and analysed further to distinguish the A, B and D genomes.

3.2.3 Identification of the A, B and D genome homoeologues using nulli tetrasomic lines

"Chinese Spring" wheat variety nulli tetrasomic lines [AAAABB (tetra A null D), AAAADD (tetra A null B), BBBBAA (tetra B null D), BBBBDD (tetra B null A), DDDDAA (tetra D null B), DDDDBB (tetra D null A)] were then sequenced using non genome specific primers (primers were designed to bind to areas of identical sequence match among the A, B and D genomes). The diploid wheat *Triticum urartu* (*T. urartu*) which is similar to the A genome of hexaploid wheat, and *Aegilops tauschii* (*A. tauschii*), which is similar to the D genome of hexapoid wheat were also sequenced using the same non genome specific primers. Sequences from the diploid wheat species and the "Chinese Spring" nullisomic lines enabled one to accurately assign the assembled sequences into the three wheat genomes of hexaploid wheat (A, B and D). Primers specific to the D genome were then designed and used to amplify fragments of genes for Spark, Rialto, Avalon, Cadenza and Savannah.

This method was used to assemble the full length ***T**riticum* ***a**estivum* ***E**arly* ***F**lowering 3* (*TaELF3*) homologue of the *Hordeum vulgure ELF3* (*HvELF3/eam8/Mat-a*) as well as identifying the three genomes. The full length barley *eam8* (gene bank accession number HQ850272) sequence (Faure *et al*., 2012), which Dr David Laurie provided before publishing his work done in barley, was used to blast search the "Chinese Spring" 454 unassembled sequence database. The retrieved reads were assembled using phredprap and Vector NTI sequence alignment programmes. Three different sequences, the three putative A, B and D were clearly identifiable in the different contigs. A few contigs had all sequences coming from one of the homoeologues and these helped in joining the contigs together as they were overlapping segments between contigs. Upon manually grouping similar reads from the different contigs, the sequences were joined together and aligned using the free online multiple sequence alignment tools gene doc and clustalw2 (http://www.ebi.ac.uk/Tools/msa/clustalw2/).

3.2.4 Identification of the A, B and D using the *Aegilops tauschii* unassembled reads database

When the *Aegilops tauschii* draft sequence was made publicly available, it was no longer economic or necessary to resequence nulli tetrasomic lines or the diploid species *A. tauschii and T. urartu* to distinguish the three homoeologues. Instead, one of the putative A, B and D genome homoeologues designated X, Y and Z was used to blast search the *A. tauschii* sequence database made using the Roche 454 sequence technology (You *et al*., 2011) and the *A. tauschii* sequences were assembled and aligned with the three putative wheat homoeologues. The D genome from the putative wheat homoeologues would have the highest sequence identity match with the *A. tauschii* (98-100%) while the other two sequences usually had lower (about 95-97%) sequence identity with the *A. tauschii* sequence. In less conserved gene segments like introns there was between 90 and 95% sequence identity between the *A. tauschii* sequence and the other two putative wheat homoeologues while there was 96-100% identity between the putative D wheat homolog and the *A. tauschii* sequence.

One of the genes that was assembled using this method was the wheat homolog of the *B. distachyon* gene *Bradi2g14210* designated *TaBradi2g14210*. The prefix *Ta* was used to indicate the *Triticum aestivum* (*Ta*) homologue of the Brachypodium gene. The *TaBradi2g14210* is a homologue of the rice gene *Ndk1* which was used to make the distal marker *XNdk3* (Fig. 3.2) for the *T. monococcum Eps* A^m 1 region (Valarik *et al*., 2006; Faricelli *et al*., 2010). It was assumed at that time that this marker would be distal to the 1DL *Eps* QTL.

The full length *Bradi2g14210* cDNA was used as a query sequence to homology search the "Chinese Spring" 454 sequence database. The retrieved "Chinese Spring" 454 reads were assembled using vector NTI sequence alignment programme. Three putative homoeologues were then aligned using clustalw2 sequence alignment programme. The D genome homolog was identified using the *Aegilops tauschii* 454 sequence data which became available at the end of January 2011 (You *et al*., 2011). There was 100% sequence match between the *A. tauschii* sequence read GB5Y7FA02HVRZD and the D genome homolog of the three assembled putative homoeologues of *TaBradi2g14210*. In addition to *TaBradi2g14210*, this method was used to assemble portions of the genes listed in table 3.1 whose chromosomal locations for *T. monococcum* and synteny with rice, brachypodium, barley and sorghum are shown in Fig. 3.2.

1.1.1 Genome specific primer development

Sections of the partially assembled genes listed in table 3.1 were used to design D genome specific primers (Table 3.2). The D genome specific primers were used to perform polymerase chain reactions (PCRs) and the PCRs selectively amplified overlapping portions of the D genome copies of each of the genes listed in table 3.1 while competitively excluding the A and B copies of the genes. At least one non-specific (amplified from all the three genomes) primer pair was designed for each gene and this was used as a control to check for presents of DNA in all the samples used so as to distinguish failed PCR from failed amplification due to the 1DL deletion. The melting temperature (Tm) of the primers as well as the presence of primer dimers and formation secondary structures like hair pins was checked using the online SIGMA DNA calculator tool. Only those primers that had no primer dimers and at most moderate secondary structures were used. The Tm of the primers was around 63^{o}C while GC content was between 40% and 70% with a few exceptions.

Table 3.1 Genes that were used to design new markers for 1DL *Eps* locus

Marker name	**Gene name**	**Homologue**
[α]*BJ544902*		*Bradi2g14460*
**Xcdo393*		*Bradi2g14440,* [μ]*Sb09g030620*
[α]*XAL503851*(**vatpC*)	**v**acuolar **ATP** synthetase subunit **C**	*Bradi2g14400*
**Xwg241*		*Bradi2g14370*
**XCA608558*		*TaBradi2g14380*
TaMOT1	[β]***Mo****lybdenum* ***T****ransporter* ***1*** *(MOT1)*	*Bradi2g14340*
**XADK1*	***Ad****enylate* kinase ***1***	*Bradi2g14310*
[α]*XBarc62*	***T****riticum* ***a****estivum* ***E****arly* ***F****lowering* ***3*** *(TaELF3)*	*Bradi2g14290,* [γ]*HvELF3/*[δ]*eam8/*[μ]*Mat-a, AtELF3, OsELF3, ZmELF3, Sb09g030700* (3'UTR)
**XNdk3*	**N**ucleoside **d**iphosphate **k**inase **3**	*Bradi2g14210,* [μ]*Sb09g030810*

*Valarik *et al*., 2006; [α]Song *et al*., 2005; [β]Faricelli *et al*., 2010; [γ]Higgins *et al*., 2010; and [μ]Zakhrabekova *et al*., 2012; [δ]Faure *et al*., 2012.

3.2.5 PCR Reaction mixture

The PCR reactions were done as described by Diaz *et al*., (2012) with a few modifications. 50 ng genomic DNA in 20 µl reactions comprising 1X PCR Buffer and 0.4 units Taq polymerase with 2 mM MgCl2, 250 nM of each primer and 200 µM dNTPs.

3.2.6 PCR reaction conditions

The PCR had 40 cycles and 55^{o}C was the annealing temperature. The first step was initial denature done at 95 ^{o}C for 2 minutes. Forty cycles involved denaturation for 20 seconds at 95^{o}C, annealing at 55^{o}C for 20 seconds and polymerisation at 72 ^{o}C for 1 minute per kb. After the forty cycles, the PCR reaction was held at 72^{o}C for five minutes and then kept at 10^{o}C until removal to a freezer or analysis on agarose gel.

3.2.7 Detection of PCR amplicons by agarose gel electrophoresis

The PCR amplicons were separated on a 2% weight/volume agarose gel in 1 X **T**ris-**a**cetate-**E**thylenediaminetetraacetic acid (TAE) buffer. The gels were made by dissolving 2g of agarose for every 100ml of buffer. After dissolving the agarose, 0.5 µg/ml of ethidium bromide stain was prepared by dissolving 5µl of 10mg/ml ethidium bromide solution in 100ml of 1 X TAE buffer. Into each well on the agarose gel was put 5µl of PCR product mixed with 1µl of cresol red. The PCR fragments were separated on the agarose gel for 2 hours at 100Volts. The 2-log DNA ladder (New England Biolabs Ltd) was used to estimate the PCR fragment sizes.

3.3 Chapter 3 Results

Nine PCR based markers that distinguished Spark and Rialto, Avalon and Cadenza as well as Charger and Badger were designed. These markers were X*Adk1* (*TaBradi2g14310*), *Xwg241* (*TaBradi2g14370*), and *Xcdo393* (*TaBradi2g14440*), *XBJ44902* (*TaBradi2g14460*), *XAL50385/vatpC* (*TaBradi2g14400*), *XTaMOT1*, *XTaELF3* (*TaBradi2g14290*), *XBarc62* (*TaBradi2g14290* 5'UTR) and *XNdk3* (*TaBradi2g14210*). These markers will now be described in detail.

3.3.1 Assembly of *TaELF3* gene from "Chinese Spring" 454 unassembled sequence database

The three putative homoeologues were clearly present in some contigs (Fig. 3.3).

Having identified the putative three homoeologues, A, B and D reads were identified using homoeologous SNPs (Fig. 3.3). The three homoelogues were then aligned using a combination of Clustalw2 and gene doc (appendix 3.1).

3.3.2 Identification of the three wheat homoeologues of the *TaELF3* gene

A single nucleotide polymorphism of either C or T was found at position 814bp (Fig. 3.4) which was diagnostic for the B genome. The D genome and the A genome both have T at this position. In addition to the interpretation from the tetrasomic nullisomic sequences, the D genome can be confirmed to have a T at this position as *A. tauschii* has a T at this position (Fig. 3.4).

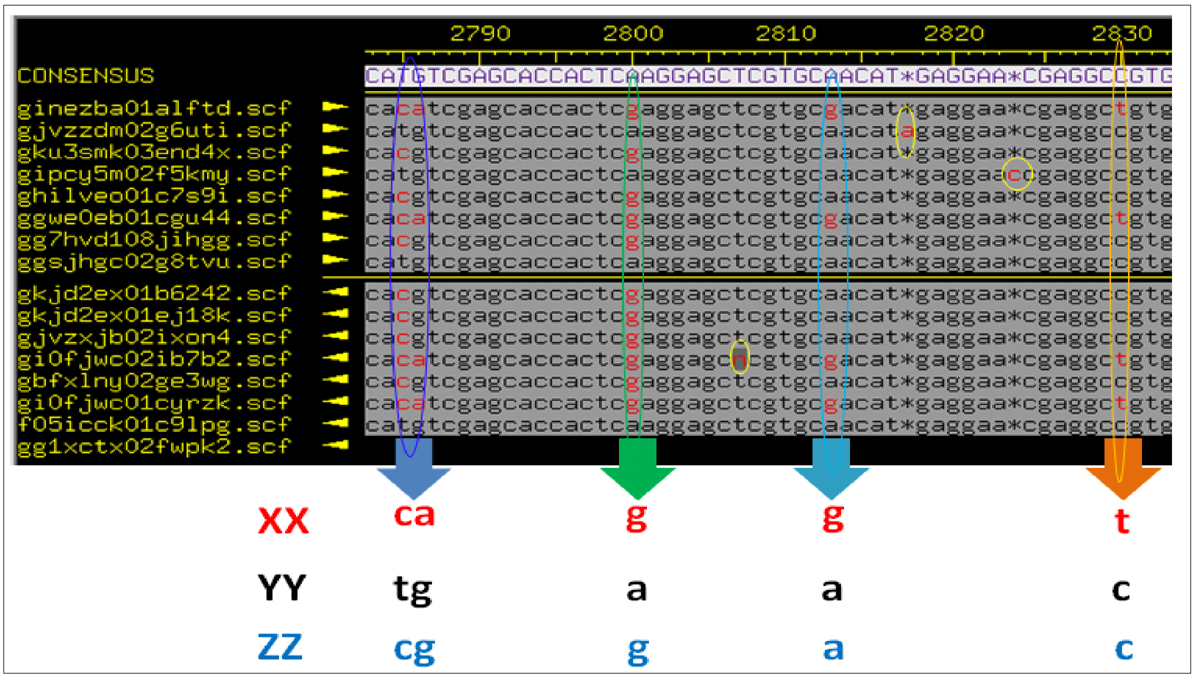


Fig. 3.3 Identification of the *TaELF3* homoeologues from retrieved "Chinese Spring" 454 sequence reads. The putative A, B and D genomes were not distinguishable at this stage and hence they were designated XX, YY, and ZZ. The bases circled in yellow are probably misreads due to PCR artefacts and were ignored at these points. For example the circled n (Fig. 3.3) was assumed to be thymine (t) as confirmed by three other reads sharing the same haplotype at the polymorphic sites shown by arrows while the circled a and c (Fig. 3.3) were regarded as miscalls again as confirmed by three other reads sharing the same haplotype at positions labelled by arrows.

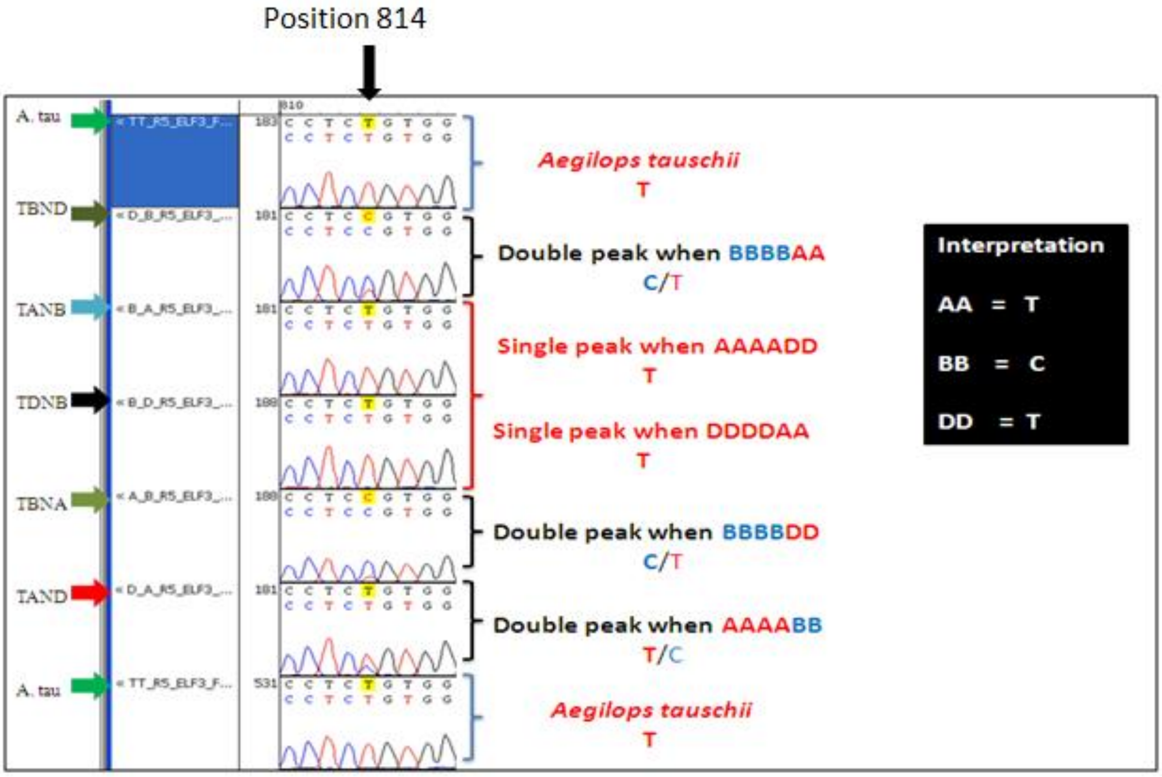
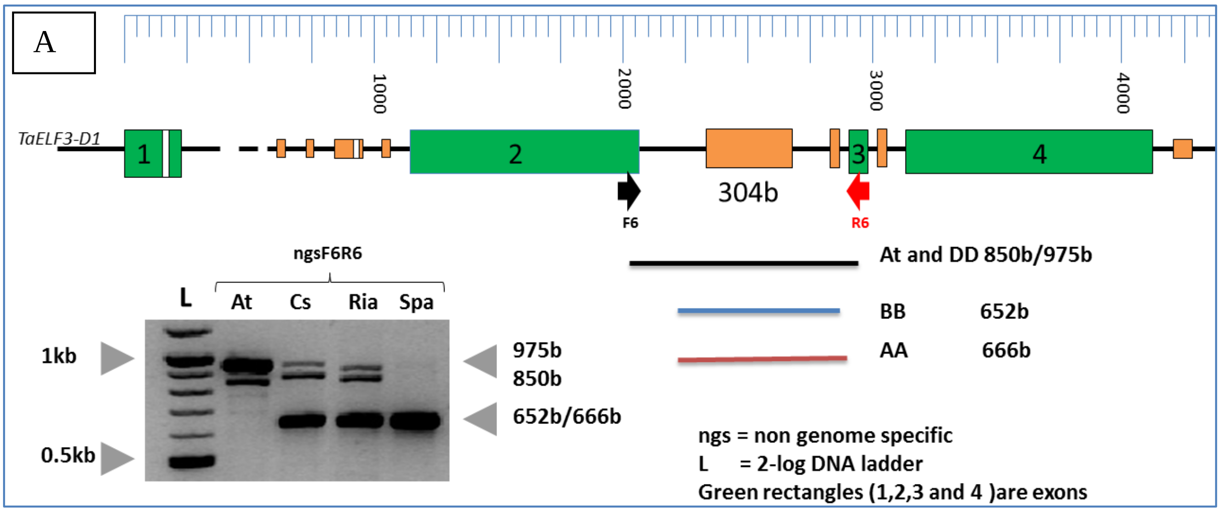


Fig. 3.4 Determination of genome specific sequences of *TaELF3* homoeologues using "Chinese Spring" nullisomics and *Aegilops tauschii* (A. tau) DNA. The size of the peaks corresponded with the copy number for example BBBBAA (Tetra B nulli D (TBND)), has the C peak bigger than the T peak and when that is reversed to Tetra A nulli D (TAND) (AAAABB), the T peak became bigger than the C peak because of the differences in copy number. This analysis was done at several positions along the gene and the three homoeologues were then assigned to the A, B and D genomes (appendix 3.1). The *TaELF3* marker will be discussed in this chapter while the *TaELF3* gene will be described in later chapter.

3.3.3 The *TaELF3* marker

Due to insertion/deletion events in this part of the gene, A, B and D amplicons were different sizes and could be resolved on agarose gel. From the non genome specific primers, a marker which scored the presence and absence of the D copy of Ta*ELF3* was developed (Fig. 3.5). *Aegilops tauschii* (At), and *Triticum urartu* (ura) were used as controls to show possible positions of the D copy band 975b which is the same as the *A. tauschii* larger band (Fig. 3.5 A) and the A genome copy band 666b was the same as the *T. urartu* band (Fig. 3.5 B). The A and B genomes could not be separated on the agarose gel because the two bands have a small size difference 666b and 652b respectively (Fig. 3.5 A). The 850b band (Fig. 3.5 A) is likely a second copy of the D genome given that it is the same size as the *A. tauschii* band and is absent from *T. urartu.* Both the A and B genomes lack the 304b insertion (Fig. 3.5 A) that is present on the D copy. This was confirmed by sequencing. The presence/absence marker ngsF6R6 (Fig. 3.5) was used to score the doubled haploid populations made from a cross between Spark and Rialto (Fig. 3.6) as well as the Avalon X Cadenza (Fig. 3.7). The same pattern of either presence of both bands or absence of both bands was observed (Fig. 3.6 and Fig. 3.7).



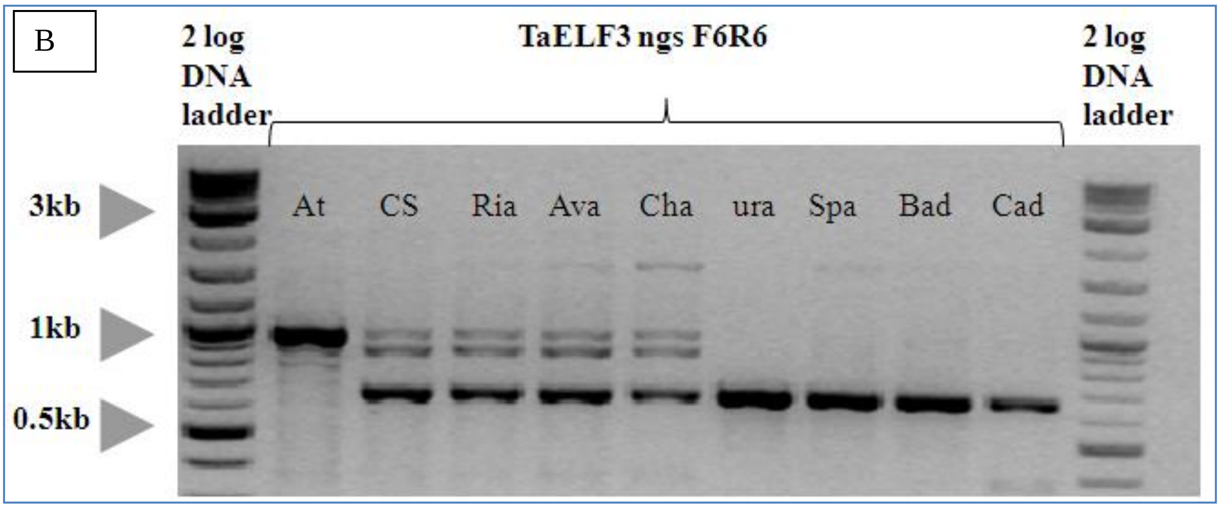


Fig. 3.5 The presence and absence of the D copies (A) of the *TaELF3* gene divided the analysed UK wheat varieties into two groups (B). The first group comprising Rialto (Ria), Avalon (Ava), and Charger (Cha) had the intact gene (A/B) like “Chinese Spring” (CS) while Spark (Spa), Badger (Bad) and Cadenza (Cad) did not amplify as shown by absence of the two bands with sizes 975b and 850b (A/B) suggesting a deletion of the gene.

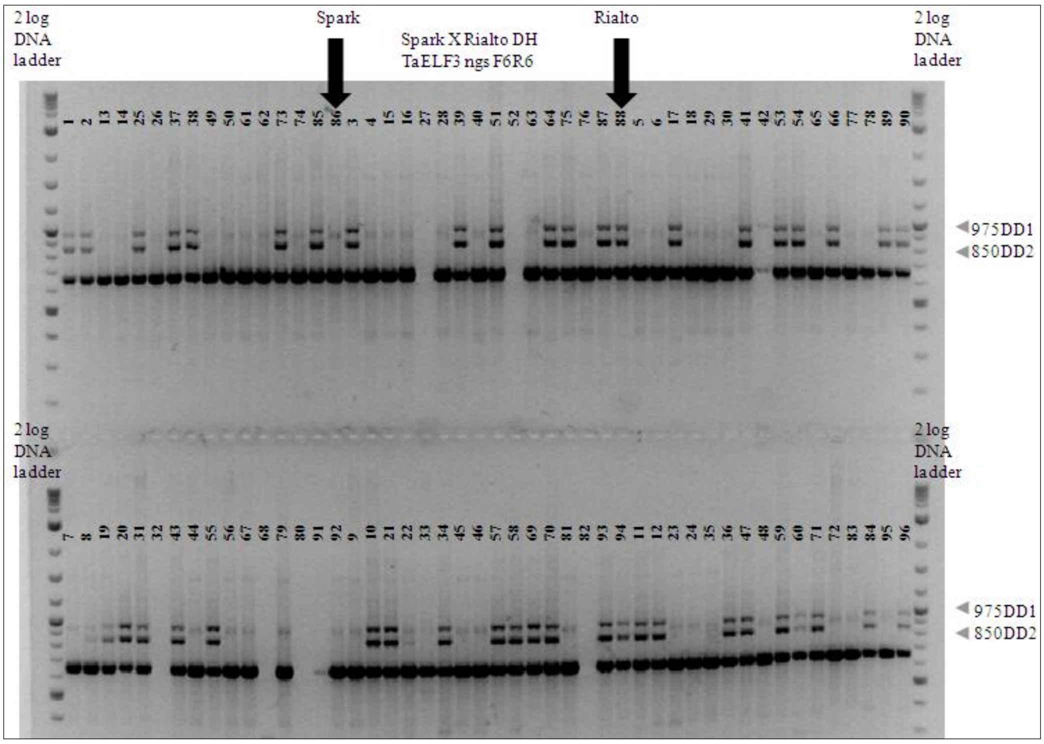


Fig. 3.6. Use of the *TaELF3* D copy insertion/deletion as a marker in Spark X Rialto DH population. Spark parent is number 86 and Rialto parent is number 88. The 850bp and 975bp bands are absent in Spark. Co segregation of the double band (Fig. 3.6, and Fig. 3.7) suggests that the two copies are closely linked; tandem duplication would be a possibility. It is also possible that the population size is not big enough to separate the two copies.

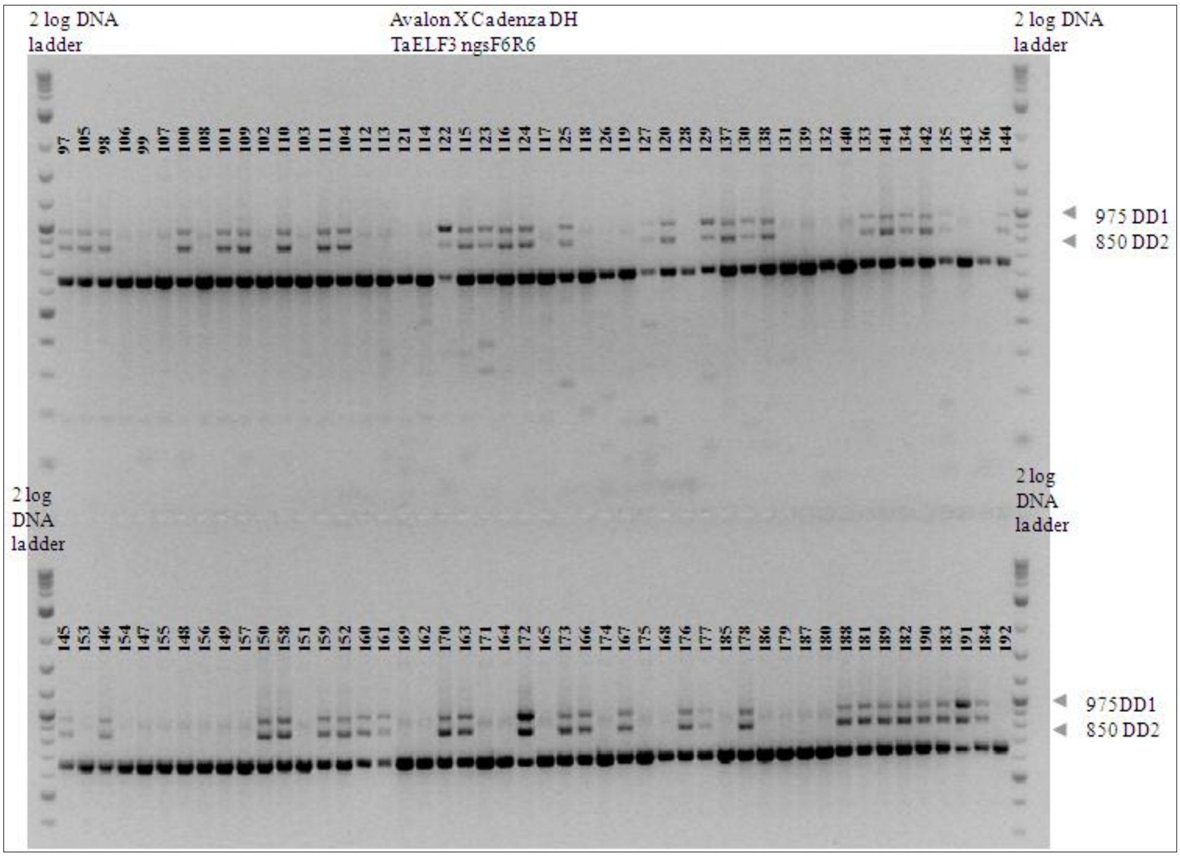


Fig. 3.7 Segregation of the presence/absence of the *TaELF3-D* copy in an Avalon X Cadenza DH population. The same pattern that was observed in Spark and Rialto (Fig. 3.5) as well as Spark X Rialto DH (Fig. 3.6) was observed for Avalon X Cadenza DH population where the D copies are co-segregating. A doubled haploid population derived from a Charger X Badger was also scored using the *TaELF3* non genome specific marker and the same pattern observed for Spark X Rialto and Avalon X Cadenza DH populations was observed for Charger X Badger (data not shown). The QTL analysis done earlier in the Griffiths group did not detect a QTL in the Charger X Badger cross (Griffiths *et al*., 2009). It is possible that the map used for the Charger X Badger QTL analysis did not cover 1DL or there may be a loss of function mutation in Charger for the gene responsible for the 1DL QTL.

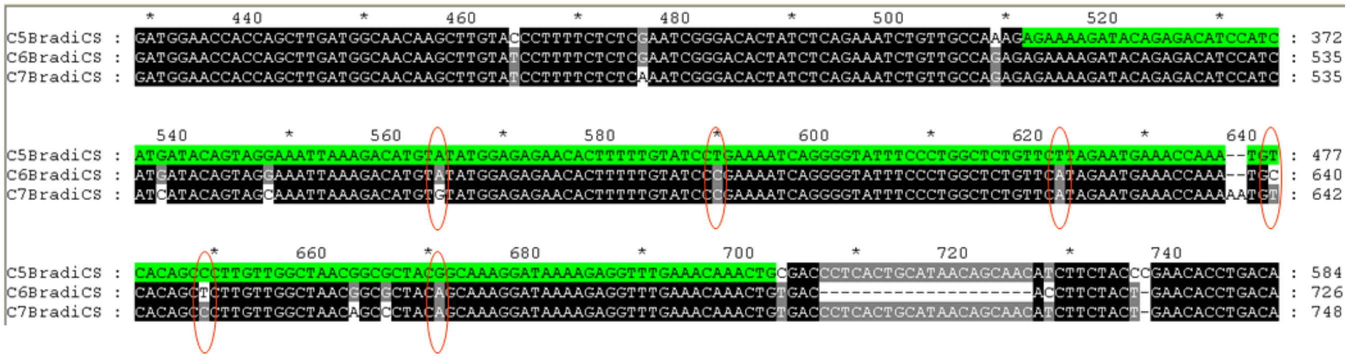


Fig. 3.8 Identification of the D homoeologue of *TaBradi2g14210* in an assembly of the putative A, B and D genomes (C5BradiCS, C6BradiCS and C75BradiCS) of "Chinese Spring" from the 454 sequence database. The *A. tauschii* sequence read GB5Y7FA02HVRZD from the *A. tauschii* 454 sequence database matched the segment highlighted in green for C5BradiCS. Of the three putative homoeologues (C5BradiCS, C6BradiCS and C75BradiCS), the C5BradiCS which matched 100% the GB5Y7FA02HVRZD sequence from *A. tauschii* was taken to be the D genome.

3.3.4 Assembly and amplification of *TaBradi2g14210* gene

The query sequence used to retrieve GB5Y7FA02HVRZD sequence from the *A. tauschii* 454 database was C6BradiCS. The C5BradiCS sequence was interpreted to be the D homolog given that it is identical (100% match) to the *A. tauschii* sequence (Fig. 3. 8 green segment). It was not necessary to assign C6BraiCS and C7BradiCS into A or B genomes.

The D genome specific primers designed from the assembled sequences of the *TaBradi2g14210* (table 3.2) were used to amplify segments of the gene in six UK varieties as well as *A. tauschii* (Fig. 3.9). “Chinese Spring” was also amplified as a control. The theoretical expected band size for F3R4 (Fig. 3.9) was about 0.5kb which again was absent for Spark, Badger, and Cadenza (Fig. 3.9). This result again showed a possible *TaBradi2g14210* deletion for Spark, Badger, and Cadenza just as was the case with *TaELF3*.

The two Rialto amplicons produced by primers DDF3R4 (Fig. 3.9 and the single Spark amplicon produced by primers DDF3R4 (Fig. 3.9) were gel purified and directly sequenced. There was no polymorphism between the Spark and Rialto (smaller band) although the sequence did not match any of the assembled *TaBradi2g14210* sequences. There were no matches from the *Aegilops tauschii* 454 database when it was blast searched with the sequence derived from the PCR sample that produced the smaller band (Fig. 3.9). The *Bradi2g14210* DDF3R4 marker was used to score Spark X Rialto and Avalon X Cadenza doubled haploid populations (Fig. 3.10 and Fig. 3.11).

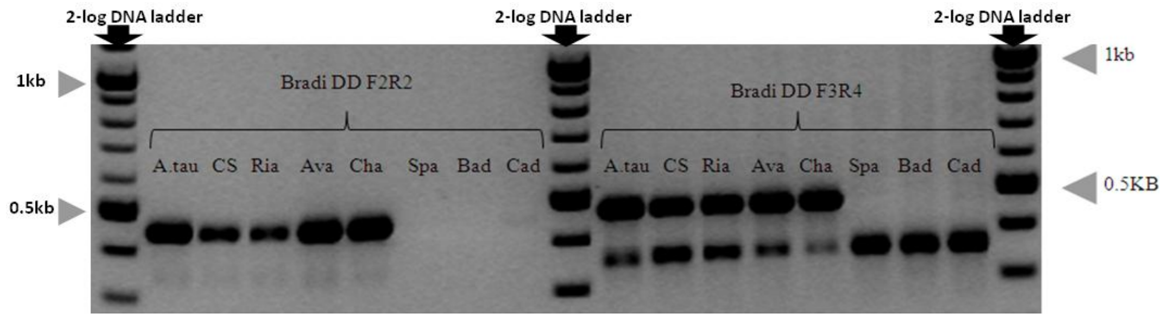


Fig. 3.9 Possible deletion for Spark, Badger, and Cadenza at *TaBradi2g14210*, the wheat homologue of *Bradi2G14210*. Key: *Aegilops tauschii* (A.tau) “Chinese Spring” (CS), Rialto (Ria), Avalon (Ava), Charger (Cha), Spark (Spa), Badger (Bad), and Cadenza (Cad). The primers F2R2 and F3R4 (Fig. 3.9) were both D genome specific.

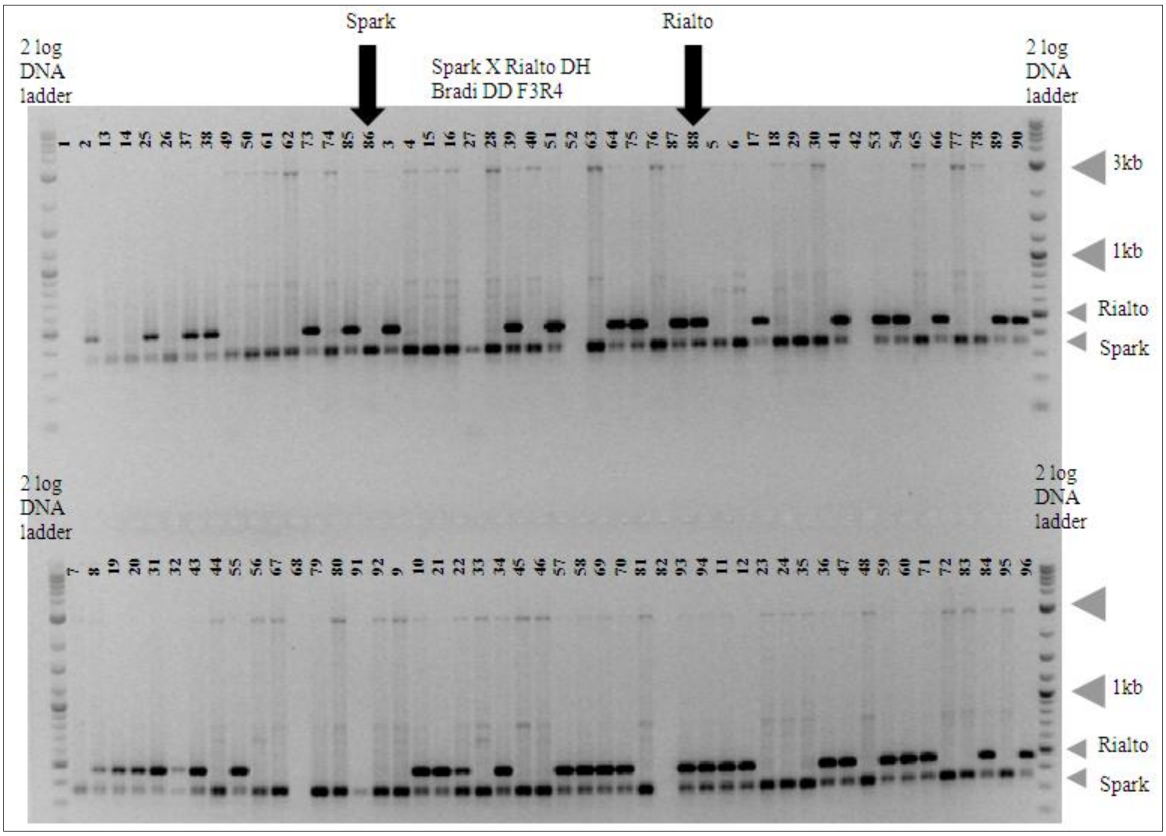


Fig. 3.10 scoring of a Spark X Rialto doubled haploid population with a marker from a wheat homologue of Brachypodium (*Bradi2G14210*). Number 86 and number 88 are Spark and Rialto respectively. Rialto has two bands and Spark has one band. The band labelled Rialto is unique to Rialto (Fig. 3.10). While the one labelled Spark is also available in Rialto although it is consistently faint in Rialto apart from DH line 22. The common band is faint in Rialto types may be due to quantitative drop in product probably due to primer binding at two sites.

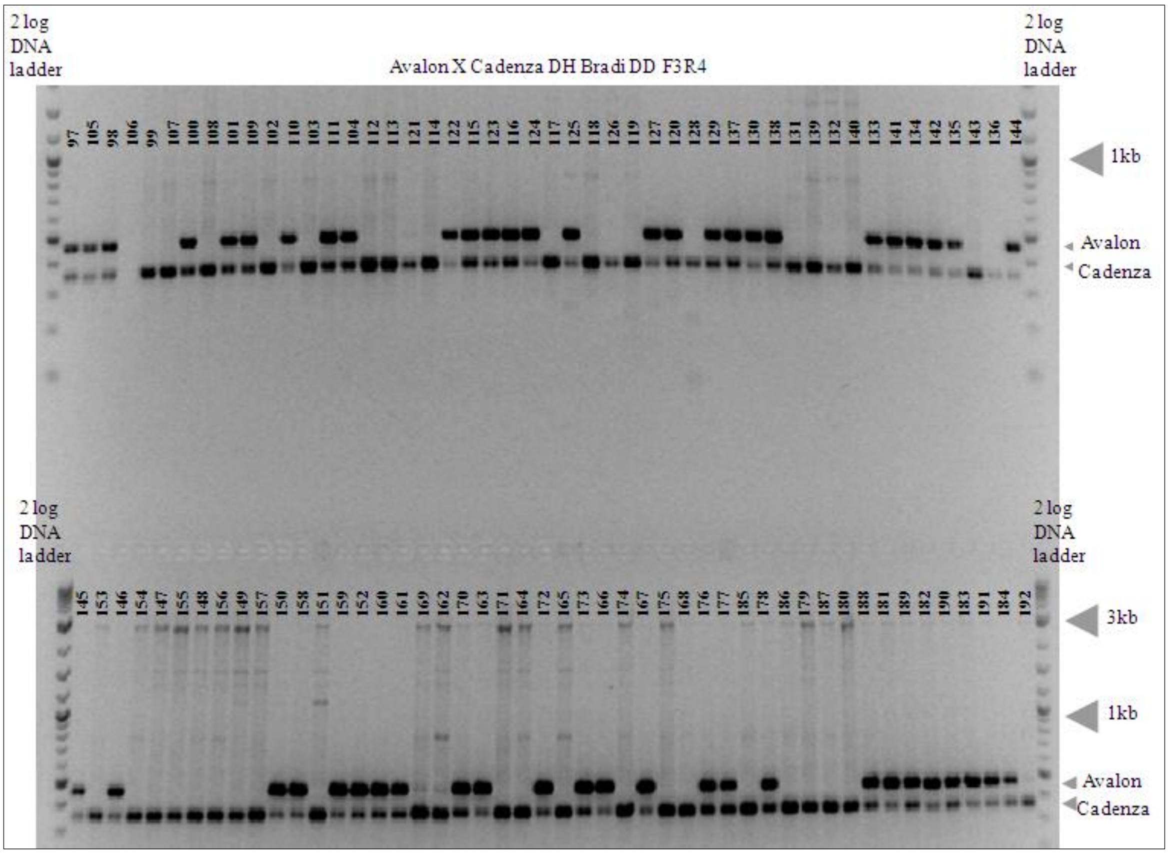


Fig. 3.11 scoring of an Avalon X Cadenza doubled haploid population with a marker from a wheat homologue of gene *Bradi2G14210*. Avalon has two bands and Cadenza has only one.

3.3.5 *XBarc62* marker development

When the *A. tauschii XBarc62* sequence including the repeat (Song *et al*., 2005) retrieved from Grain Genes database was used to homology search the "Chinese Spring" (CS) 454 sequence database, the three homoeologues (A, B, and D) could be assembled (Fig. 3.13). The *XBarc62* sequence matched one of the three assembled sequences. D genome specific (MZ DD) primers were designed to end on a base that was specific to the D genome (Fig. 3.13). The genome specific primers together with the primers *XBarc62* SSR primers (Song *et al*., 2005), shown by the blue arrows (Fig. 3.13) were then used to amplify fragments from *A. tauschii* (Tau), "Chinese Spring" (CS), Savannah (Sav), Spark (Spa), Badger (Bad), Cadenza (Cad), Rialto (Ria), Avalon (Ava) and Charger (Cha) and the fragments analysed on a 2 % agarose gel (Fig. 3.12).

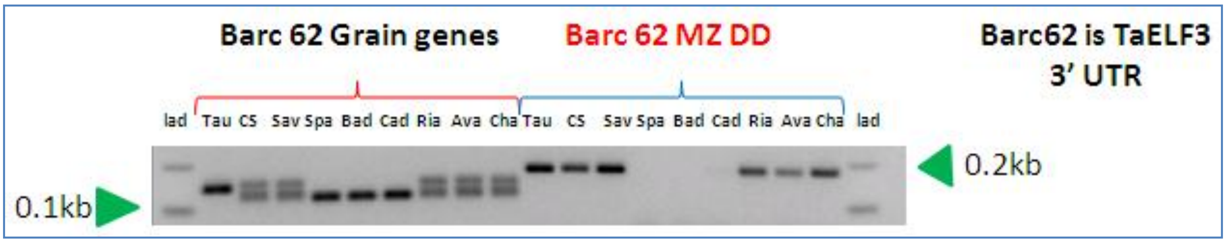


Fig. 3.12 Deletion of the Barc62 marker in Spark (Spa), Badger (Bad) and Cadenza (Cad). The *XBarc62* primers designed by Song *et al*., (2005), shown here as Barc 62 Grain genes, are not D genome specific as evidenced by the production of two PCR bands when these primers were used to amplify "Chinese Spring" (CS), Savannah (Sav), Rialto (Ria), Avalon (Ava) and Charger (Cha) as shown in Fig. 3.12. Sequencing revealed that the smaller size fragment (Fig. 3.12, absent from *A. taiuschii*) was from the A genome copy.

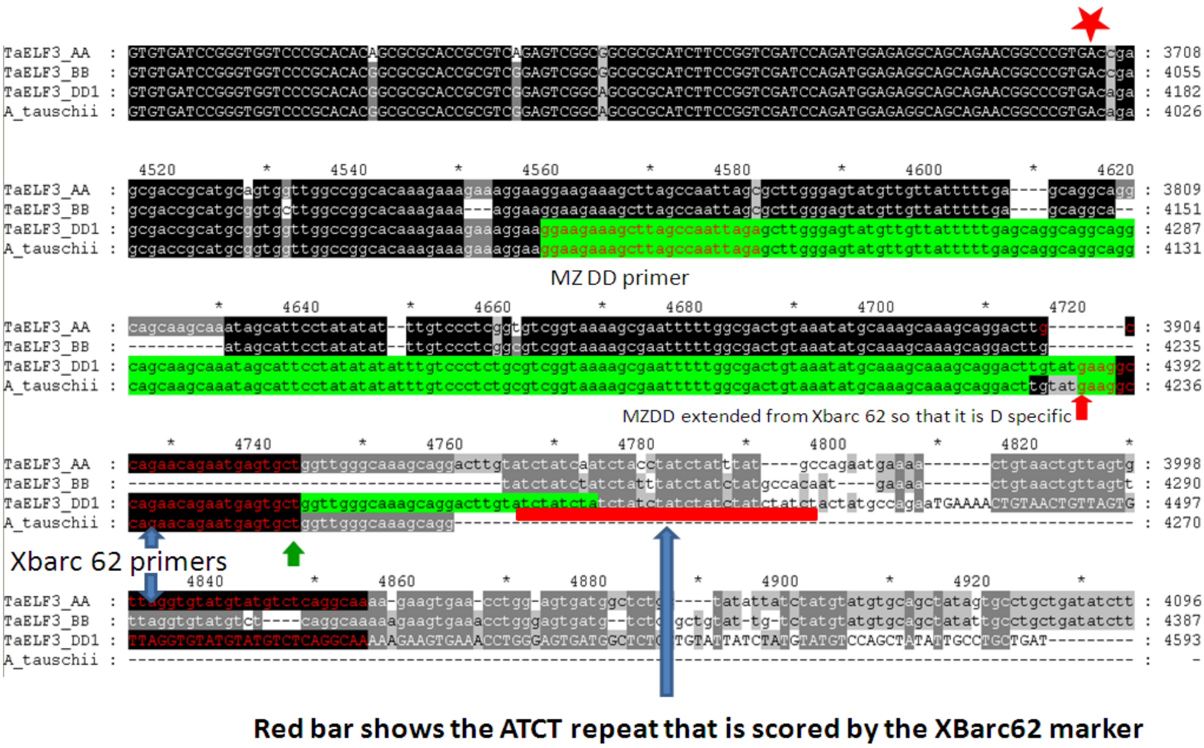


Fig. 3.13. The position of the *Xbarc62* marker in the 3'UTR of *TaELF3* gene. The region highlighted in green is the *Xbarc62* sequence from the grain genes database (Song *et al*., 2005), and it matches the 3' end of the D genome of *TaELF3* The two regions with red text in a black background show the position of *Xbarc62* primers (shown by blue arrows) from Grain genes database designed by Song *et al*., (2005). Red text in a green background shows the position of the primers when they are designed to be D genome specific (barc 62 MZ DD). The red arrow shows the end of the reverse primer for barc 62 MZ DD which begins at the position marked by the green arrow. The 11b deletion in the A genome of the region spanned by the primers designed by Song *et al*., (2005), is the cause of the size differences between the A genome fragment (smaller fragment, about 120b) and the D genome fragment (larger fragment, about 132b) as shown on Fig. 3.12. The red star shows the position of the stop codon (TGA) of the *TaELF3* gene. The red bar indicates the position of the SSR (ATCT repeat) detected by the *XBarc62* SSR primers Song *et al*., (2005). It is evident that the *XBarc62* SSR primers (Song *et al*., 2005) amplify both the A and D genomes (but do not amplify the B genome.

When these primers are used they amplify two fragments in "Chinese Spring" (CS), Savannah (Sav), Rialto (Ria), Avalon (Ava) and Charger (Cha), but only one fragment in Spark (Spa), Badger (Bad), Cadenza (Cad) as shown in Fig. 3.12. Sequencing of the Spark, Badger and Cadenza PCR fragments that produced the smaller size band on (Fig. 3. 12) confirmed that it was the *TaELF3* A genome and this fragment is absent from *A. tauschii* (Fig. 3.12). The *XBarc62* SSR marker using the primers by Song *et al*., (2005), scored Spark as a null (data not shown) because of the absence of the D genome sequence in Spark as confirmed by use of D specific primers (Fig. 3.12) which shows no amplification for Spark.

It was also shown that the *XBarc62* SSR marker is downstream of the stop codon of the *TaELF3* gene. The *XBarc62* SSR (ATCT) begins 255 bases downstream from the *TaELF3* stop codon (Fig. 3.13). In addition, the smaller size PCR fragment band produced by *XBarc62* SSR primers (Song *et al*., 2005), shown on Table 3.2 was from the A genome of *TaELF3* because the marker did not amplify the B genome since one of the primer positions is deleted in the B genome (Fig. 3.13).

3.3.6 Additional genes deleted from 1DL in Spark, Badger and Cadenza

Sequencing the D copies of the genes *Adk1*, *wg241*, and *cdo393* which were developed in the same way as the other markers also showed the absence of the D copy in Spark, Badger and Cadenza while Rialto, Avalon and Charger did not have the deletion (Fig. 3.14). This was consistent with the results observed for *TaELF3* (Fig. 3.5), *TaBradi2g14210* (Fig. 3.9), and *XBarc62* (Fig. 3.12). This suggested that Spark, Badger and Cadenza likely have a deletion of several genes at this locus. The same DNA that was used to amplify with the D genome specific primers was used to amplify with the non genome specific (ngs) primers on the same PCR plate and the same PCR master mix. The ngs primers amplified from Spark, Badger and Cadenza for all the three genes *Adk1*, *wg241* and *cdo393* (Fig. 3.14) suggesting that the absence of bands when D specific primers were used for Spark, Badger and Cadenza (Fig. 3.14) was due to absence of the D sequences for these genes in these varieties possibly due to deletion of several genes (Fig. 3.15). The wheat pedigrees of the varieties used in this study were analysed to determine how closely related these varieties were (Fig .3.16). The pedigree suggests that the deletion came from Tonic considering that both Spark and Cadenza share Tonic as one of the parents (Fig.3.16).

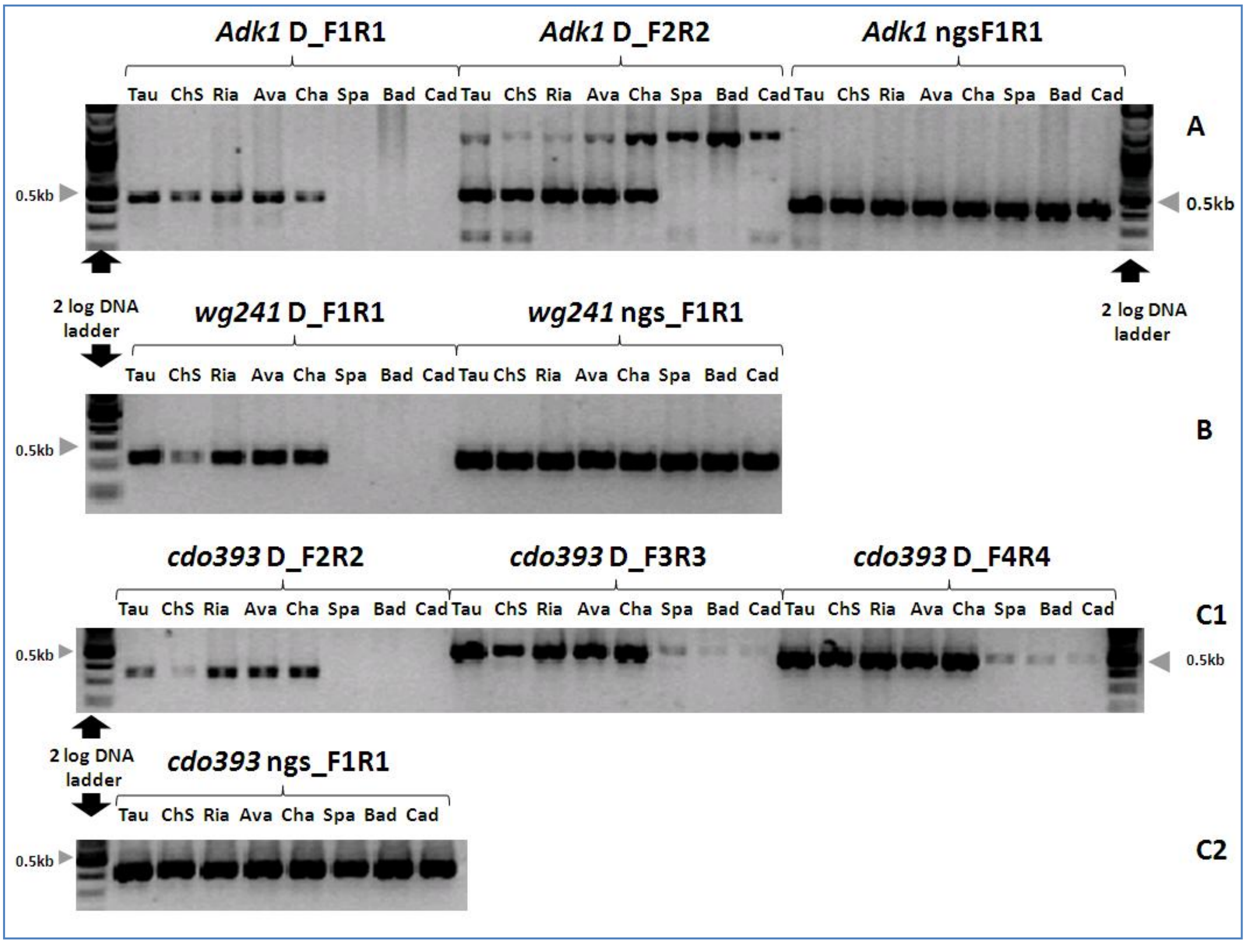


Fig. 3.14 The possible deletion of D genome copies of the genes *Adk1* (A), *wg241* (B), and *cdo393* (C1/C2) in Spark, Badger and Cadenza chromosomes while Rialto, Avalon and Cadenza seem to have intact 1DL chromosomes. The faint bands observed for Spark, Badger and Cadenza for cdo393 F3R3 and F4R4 (Fig. 3.14, C1) are possibly due to inefficient amplification from either the A or B genomes because some of these primers had only one genome specific base and there is no competition from the D genome for Spark, Badger and Cadenza. The *Adk1* D_F2R2 primers amplify an additional band for all the varieties including Spark, Badger and Cadenza which have the deletion. However the expected PCR fragment sizes produced by the D specific F1R1 and F2R2 primers for *Adk1* are both absent Spark, Badger and Cadenza. The abbreviation ngs denotes non genome specific primers.

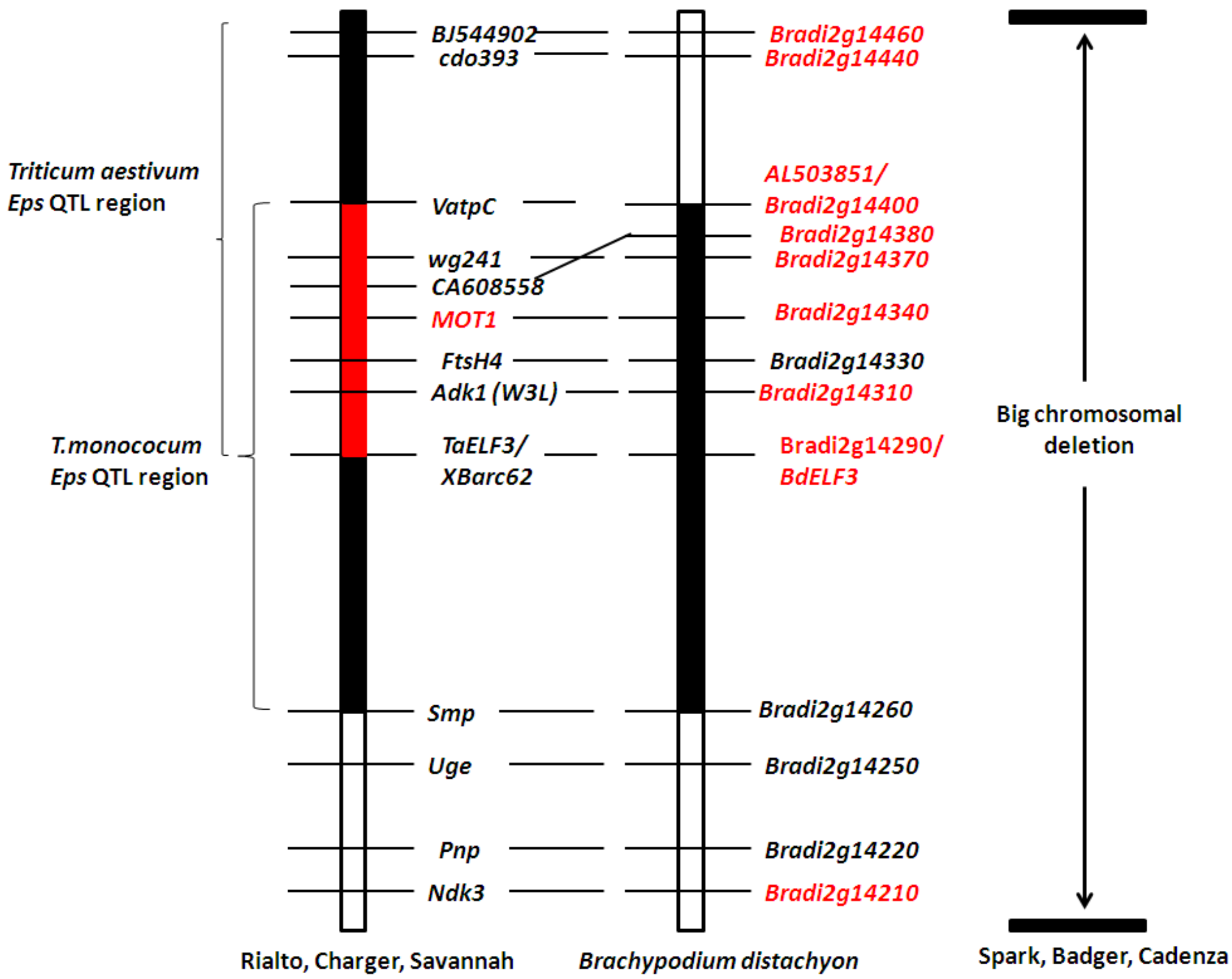


Fig. 3.15 A deletion in the 1DL genome of the group one chromosome in Spark, Badger and Cadenza spans the entire *T. monococcum Eps* region. The genes in red were all shown to be deleted from Spark, Badger and Cadenza. The gene order for Rialto, Charger and Savannah (Fig. 3.15) was assumed to be the same as that reported in *T. monococcum* (Valarik *et al*., 2006; Faricelli *et al*., 2010) given the synteny reported for this region among *Brachypodium distachyon* (*B. distachyon*) chromosome 2, barley (Higgins *et al*., 2010), *Sorghum bicolor* (Zakhrabekova *et al*., 2012), rice and wheat (Faricelli *et al*., 2010),

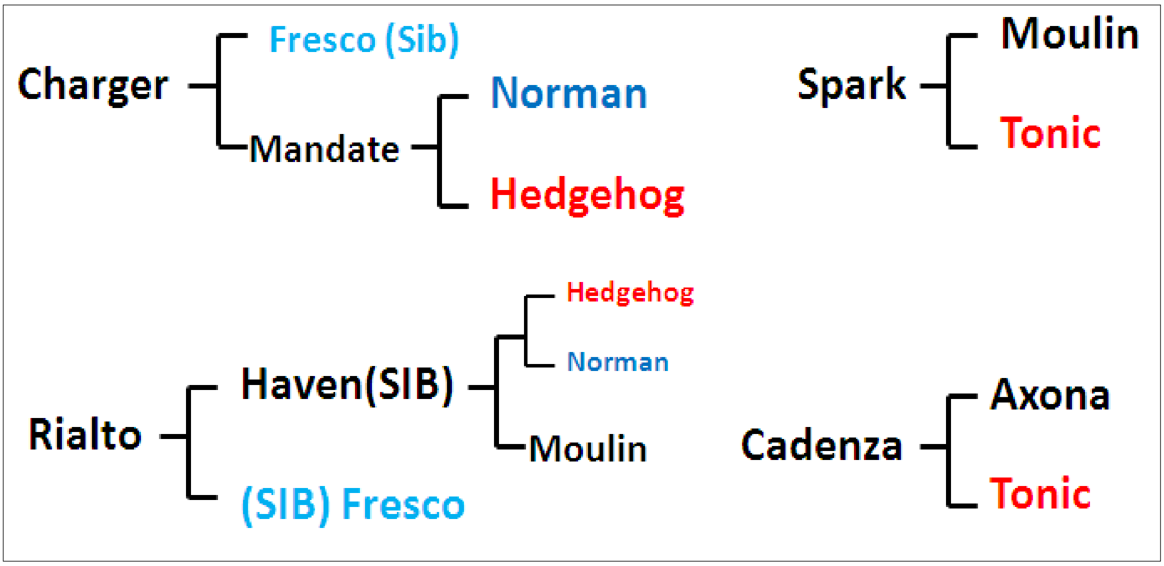


Fig. 3.16 Pedigree of Charger, Rialto, Spark, and Cadenza. Charger has a nearly identical pedigree to Rialto the only difference being the presence of Moulin in Rialto pedigree. Spark and Cadenza share Tonic, which is spring wheat. It is likely that the Spark and Cadenza alleles at 1DL *Eps* locus came from the spring wheat variety Tonic as both varieties have Tonic as one of the parents (Fig. 3.16).

Table 3.2 The primers used to reveal the 1DL deletion

marker/gene name	**Primer sequence 5'-3'**	**Tm$^{\alpha}$**	**%GC$^{\beta}$**	**SecStr$^{\gamma}$**	**Dimer$^{\delta}$**
TaELF3_F6_ngs*	CGGTGCTATTGGTCCAAAG	63	52.63	vweak$^{\psi}$	no
TaELF3_R6_ngs	CAGTCGATGCAGCTCAAAC	62.3	52.63	no	no
Adk1_DD$^{\mu}$_F1	AGGGCCTAGTAGTGGTTCCTGTTGTCGTCA	75	53	weak	no
Adk1_DD_R1	TGTAAGTTGTCAAGAGTTGCTGT	60	39	no	no
Adk1__DDF2	ACCGTCGAAGTTGAGGCCTTGA	70	54	vweak	no
Adk1__DDR2	CCTGGCCAAACAGAAGTCA	63	52	weak	no
Adk1_ngsF1	GTGGACTCGTAGTTCTTGGC	61	55	vweak	no
Adk1_ngsR1	CAGACATGACCAATCCACCTC	64	52	no	no
wg241_DD_F1	CTTTGTTGCATCATCATTCTCTGA	65	37	vweak	no
wg241_DD_R1	CGGTAATAAAGCGTCAACAG	59	45	no	no
wg241_ngsF1	CTTTGTTGCATCATCATTCTCTG	63	39	no	no
wg241_ngsR1	CACCTCAGCCTGGGAATC	63	61	no	no
cdo393_DD_F1	GAACTTTCAATTGGAACTATTGATGAC	63.5	33	weak	no
cdo393_DD_R1	CGAGCAGCTAATCATGGAGCAACCG	74	56	weak	no
cdo393_DD_F2	CCTCTCGACCAATACGAATG	62	50	weak	no
cdo393_DD_R2	CATTTAGAGAATAGACAGCTCCTTTC	61	38	weak	no
cdo393_DD_F3	GGATGGAAGGTTGCAATTAATC	63	40	weak	no
cdo393_DD_R3	ATTCTTGCGCACAGTGAAG	61	47	vweak	no
cdo393_DD_F4	GTCAGGCCAATGACCAATGTTCTCT	69	48	mod	no
cdo393_DD_R4	TGACGTCTTCTTGTCGTTGTGGAAT	69	44	weak	no
cdo393_ngs_F1	GAATGAACAAGCACGGCG	65	55	no	no
cdo393_ngs_R1	GCAAATACAAGGATCCGGC	64	52	no	no
Barc62_DD_F1 (GG)	TTGCCTGAGACATACATACACCTAA	63	40	no	no
Barc62_DD_R1 (GG)	GCCAGAACAGAATGAGTGCT	62	50	no	no
Barc62_DD_F2	CTCATTCTGTTCTGGCCTTC	61	50	no	no

Barc62_DD_R2	GGAAGAAAGCTTAGCCAATTAGA	61	39	vweak	no
Barc62_ngs_F1	CAAGTCCTGCTTTGCTTTG	61	47	vweak	no
Barc62_ngs_R1	GATGGAGAGGCAGCAGAAC	62	57	no	no
TaBradi2g14210_DDF2	GCAGTTTGTTTCAAACCTCTTTTATCC TTTGCC	73.6	39.3 9	weak	non
TaBradi2g14210_DDR2	GAATATGGAACAGATTAATAAACTGA AAG	61	27.5 9	weak	non
TaBradi2g14210_DDF3	GTGTTTGCCGCCAACTTT	63.7	50	vweak	non
TaBradi2g14210_DDR4	TGCGATCTCGTCCTTGGCC	71	63.1 6	non	non
TaBradi2g14210_ngsF6	CCCCCATGTCAGGTGTTC	64.1	61.1 1	non	non
TaBradi2g14210_ngsR6	CCTGGCTCAGATTTCGATG	63.4	52.6 3	weak	non

$^{\alpha}$ = melting temperature, $^{\beta}$= guanine: cytosine content, $^{\gamma}$ = secondary structure, δ= primer dimer,

*= non genome specific primer, $^{\psi}$= very weak (secondary structure), $^{\mu}$ = D genome specific primer.

Table 3.2 The primers used to reveal the 1DL deletion continued

marker/gene name	Primer sequence 5'-3'	Tm[α]	%GC[β]	SecStr[γ]	Dimer[δ]
TaBradi2g14460_DD_F1	CTTGCTAGGCTGGCTTATTG	61.4	50	No	no
TaBradi2g14460_DD_R1	TGCCCTACAAAAGACTTATGTAGA	60.5	37.5	Mod	no
TaBradi2g14460_DD_F2	CCTTGGAGCAGCAGAAAC	61.2	55.56	No	no
TaBradi2g14460_DD_R2	CACTTATACATAGTCAGCTTGCAAAT	61.2	34.62	vweak[ψ]	no
TaBradi2g14460_DD_F3	TCTATAGGTCCAAATGTTTGTGAAT	61.3	32	No	no
TaBradi2g14460_DD_R3	GTCAGTCGTAAACATTTCCATT	59.4	36.36	No	no
TaBradi2g14460_DD_F4	CTCATCAAACGCTTCATGTT	60.3	40	Vweak	no
TaBradi2g14460_DD_R4	AAGGTTAGCATTTTGCACATC	60.5	38.1	Weak	no
TaBradi2g14460_DD_F5	AGCCATTTTTAACCTTCTTGCAGTT	65.5	36	Vweak	no
TaBradi2g14460_DD_R5	CCAATTAATCTTTGCTTCAGTTTTC	62.6	32	No	no
TaBradi2g14460_DD_F6	CCGAAAACTGAAGCAAAGATT	62	38.1	No	no
TaBradi2g14460_DD_R6	TGGGACACGAGTTCCAGA	63.1	55.56	Weak	no
TaBradi2g14460_DD_F7	CAAACACGGACTACTATCTGGAA	61.8	43.48	No	no
TaBradi2g14460_DD_R7	ATGTACAGTGCGTGCACAACA	65.3	47.62	Weak	no
TaMOT1_DD_F1	TGATTGTAATATACCTACATATGTGGC ATGGTGCAAT	73.1	35.14	Weak	no
TaMOT1_DD_R1	CCGCGTCAATGTCCATAAG	64	52.63	No	no
TaMOT1_DD_F2	ATATACCTACATATGTGGCATGGTGCA AT	67.9	37.93	Weak	no
TaMOT1_DD_R2	ATCCTTATCCGCGTCAATGTCCATAAG	70.6	44.44	Weak	no
TaMOT1_DD_F3	GCATTTCTAGATTTCAGGATGGA	63	39.13	Vweak	no
TaMOT1_DD_R3	GGGTATCAATTCATACATCAACAA	61.2	33.33	Weak	no
TaMOT1_DD_F4	GGATGGACATGCTTATATATCCTTTTCT TGGTTGCC	75.2	41.67	Mod	no
TaMOT1_DD_R4	CAGATCTTTAAGCATTTCCTGGC	64.7	43.48	Weak	no
TaMOT1_ngs_F1	GCTTCTGACACAGTTGCAGATG	64.9	50	Mod	no
TaMOT1_ngs_R1	TTCTCCTCTTCCATATGTCTCTC	60.2	43.48	No	no
TaMOT1_ngs_F2	TGCAGGTATGTGTTGTAGTTATCTGT	62.4	38.46	Weak	no
TaMOT1_ngs_R2	GGCTTAGGTCATCAAGGTCAAG	63.7	50	Vweak	no
TaMOT1_ngs_F3	GTACTCGTGTATGAAGAATTGGGAG	63.5	44	Weak	no
TaMOT1_ngs_R3	GTAGTCAATCACATAACAGCGC	61.1	45.45	No	no

[α] = melting temperature, [β]= guanine: cytosine content, [γ] = secondary structure, δ= primer dimer, [ψ]= very weak (secondary stricture), [μ] = D genome specific primer, F and R = forward and reverse primers.

3.4 Chapter 3 Discussion

The results show that there is possibly a large deletion in Spark, Badger, and Cadenza that extends from at least *TaBradi2g14460* to at least the *TaBradi2g14210* on the long arm of the group1 D genome chromosome (Fig. 3.15). Interestingly, this deletion spans the entire *T. monococcum Eps* locus (Fig. 3.15) (Valarik *et al*., 2006; Faricelli *et al*., 2010). Furthermore, the markers that coincide with the 1DL *Eps* QTL peak for the doubled haploid populations Spark X Rialto (*XBarc62/TaBradi2g14210*) and Avalon X Cadenza (*XBJ544902/TaBradi2g14460*) are all in the deletion for Spark and Cadenza (Fig. 3.14 and Fig. 3.15). This may suggest that the candidate genes are in the deletion. Further evidence for the possibility of the deletion containing the *Eps* gene(s) also comes from the overlap of the *T. monococcum Eps* (*Eps* A^m1) locus (Valarik *et al*., 2006; Faricelli *et al*., 2010) and the *T. aestivum* (1DL) *Eps* locus (Griffiths *et al*., 2009) as shown in (Fig. 3.15).

The Spark/Badger/Cadenza deletion is approximately 5.6Mb based on estimates done on *T. monococcum* (Faricelli *et al*., 2010). This complicates the detection of posible candidates as there are several genes in this region in the Brachypodium syntenic colinear region. However, this deletion spans the entire *T. monococcum Eps* region (Fig. 3.15) where *MOT1* and *FtsH*4 have been suggested as possible candidates (Faricelli *et al*., 2010) hence these genes are possible candidates for the 1DL *Eps* QTL.

Another study by Lin *et al*., (2008) detected a significant flowering time QTL on the distal end of chromosome 1BL. This 1BL QTL was suggested to be an orthologue of the *T. monococcum Eps* region (Lin *et al*., 2008) reported earlier by Bulrich *et al.*, (2002) and Faricelli *et al*., (2010). Lin *et al*., (2008) also identified another significant QTL on 1DL tightly linked with the *XBarc62* marker. This 1DL QTL is likely to be the same locus as the one reported by Griffiths *et al.*, (2009) given that they share the common marker *XBarc62*. It is also interesting to note that Lin *et al*., (2008) detected the QTL using spring wheat because the variety Cadenza used in our study is spring wheat while Spark is winter wheat and both share the spring variety Tonic in their respective pedigree (Fig. 3.16) and both have the 1DL deletion (Fig. 3.14 and Fig. 3.15).

Another interesting result was the linking of the *Xbarc62* marker with the *TaELF3* gene (Fig. 3.13). The *TaELF3* gene is an orthologue of the *Arabidopsis thaliana ELF3* (*AtELF3*). In

Brachypodium distachion there is only one gene between *Adk1* (*Bradi2g14210*) the distal marker for the *Eps* A^m1 locus (Faricelli *et al*., 2010), and *Bradi2g14290* (*Brachypodium distachion ELF3* (*BdELF3*)) and this region has conserved gene order with the 1DL *Eps* region. According to (Fig. 3.15), *TaELF3* would be between the markers *Adk1*and *Smp* (*Bradi2g14260*) which falls in the region highlighted in black as the *T. monococcum Eps* region (Valarik *et al*., 2006) although this region has however been narrowed to begin at *Adk1* instead of *Smp* (Faricelli *et al*., 2010). There is only one gene between *Adk1* (*Bradi2g14310*) and *BdELF3* (Bradi2g14290). The involvement of *ELF3*, a circadian clock gene, in flowering is well known in *Arabidopsis thaliana*, barley and temperate cereals (Kim *et al*., 2005; Higgins *et al*., 2010; Faure *et al*. 2012).

The *ELF3* gene is known to cause flowering variation in *Arabidopsis thaliana* where the loss of function mutation results in early flowering (Zagotta *et al*., 1992). In Barley, *HvELF3*/*eam8/Mat-a* mutations have been shown to adapt barley to short growing seasons by causing early maturity and range extension (Faure *et al*., 2012; Zakhrabekova *et al*., 2012). In rice, research in China using TDNA insertion showed that loss of *ELF3* function results in late flowering (Fu *et al*., 2009). A recent report of a study in Japan revealed that natural variation in heading date 17 [(*Oriza sativa ELF3* (*OsELF3*)] caused flowering variation in Japanese rice (Matsubara *et al*., 2012). The flowering variation was only observed under long days but not under short days (Matsubara *et al*., 2012). The reason why rice with loss of function mutation *ELF3* gene is late flowering could be explained by its flowering pathway (Fig. 3.17). ***H****eading* ***d****ate* ***1*** (Hd1) the rice ***co****nstans* (*CO*) gene is a suppressor of FT (Fig. 3.17), hence if *ELF3* loses its function there will be more GI and subsequently more *Hd1* which suppresses FT resulting in late flowering (Higgins *et al*., 2010).

However, loss of function mutations at *ELF3* gene in Arabidopsis, barley and wheat have a different effect of causing early flowering as opposed to late flowering in rice. This is because *CONSTANS* (*CO*) is a promoter of *FT* in Arabidopsis, barley and wheat (Fig. 3.17) hence when *ELF* 3 loses function in Arabidopsis, barley and wheat, there will be more GI which promotes CO and leading to early flowering relative to the wild type. Spark is the donor of the early allele in the 1DL *Eps* QTL (Griffiths *et al*., 2009). Spark is also early flowering in long days relative to Rialto.

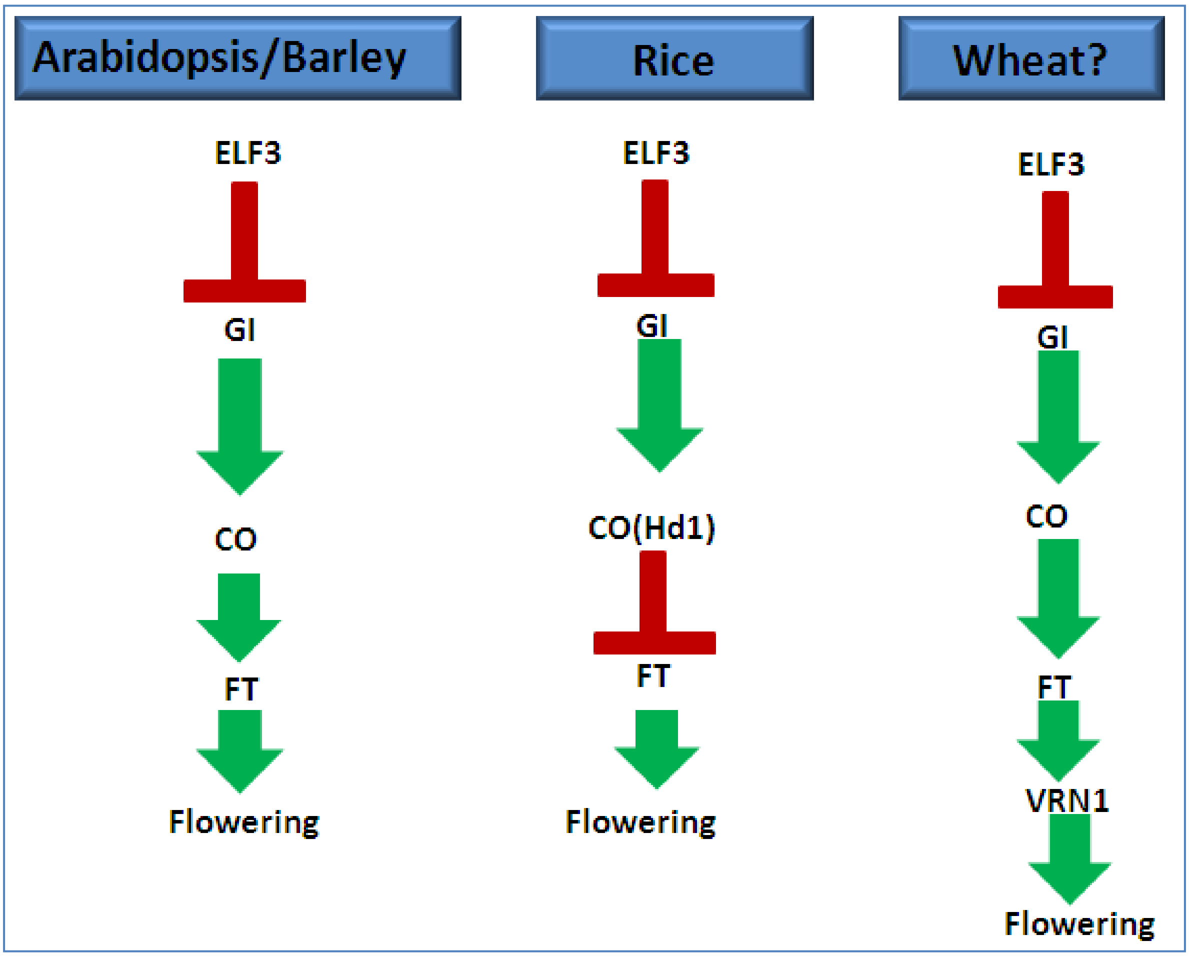


Fig. 3.17 Simplified *Arabidopsis thaliana*, barley, rice and wheat flowering time pathways that involve circadian clock gene *ELF3* (Higgins *et al*., 2010).

Furthermore, Cadenza is also early flowering in long days and is the donor of the early allele in the 1DL Eps QTL (Griffiths *et al*., 2009). Since both Spark and Cadenza have the 1DL deletion (Fig. 3.15) it is plausible to suggest *TaELF3* as a possible candidate gene that is responsible for the *Eps* QTL in addition to *TaMOT1* and *FtSH4* suggested for *T. monococcum*. These three candidates will be discussed in chapter 7.

The other reason why *TaELF3* is suggested as a candidate of the *Eps* gene in the 1DL deletion is that independent studies have had flowering time QTLs linked to this marker (Lin *et al*., 2008; Griffiths *et al*., 2009) and this thesis has shown that the barc62 marker is the 3'UTR of *TaELF3* only 253 bases from the *TaELF3* stop codon (Fig. 3.13). Only the Savannah X Rialto QTL markers *Xwmc609* and *Xcfd282* are outside the deletion because Savannah does not have the 1DL deletion. Given that the most distal marker for Savannah X Rialto is *Xwmc609*, populating this area with more markers may reveal that the Savannah X Rialto QTL is likely the same locus as that of Spark X Rialto and Avalon X Cadenza QTLs.

All the PCR markers described in this chapter including the two agarose gel markers for *TaELF3* (Fig. 3.5) and *TaBradi2g14210* (Fig. 3.9) whose primers are summarised in Table 3.2 cannot be used for fine mapping the 1DL effect because all the markers are in the deletion and it is not possible to have recombination in a deletion. The Spark/Badger/Cadenza 1DL deletion will be defined to determine where it begins and ends so that markers outside the deletion can be used to identify recombinants. These recombinants will confirm if the deletion has the candidate gene or if the candidate gene is outside the deletion. Defining the 1DL deletion is the subject of the next chapter.

4 Chapter 4

4.1 Defining the 1DL deletion

4.2 Determining extent of the 1DL deletion using Brachypodium collinear genes

Given the evidence of a likely deletion of several genes in the region containing *Eps* QTL on 1DL, it was essential to determine the size of the deletion. Defining the deletion would enable development of co-dominant markers flanking the deletion along the QTL confidence interval.

4.3 Methodology

Genome assemblies were made by homology searching the Chinese Spring 454 sequence database using Blastn (Altschul *et al*., 1990) as well as the chromosome arms sequence database with expressed sequence tags (ESTs) from chromosome bin maps known to be on group one chromosomes. The ESTs that also matched the Brachypodium collinear region with 1DL were used to determine the genes defining the 1DL deletion. The genes *TaBradi2g28010*, *TaBradi2g25820*, *TaBradi2g19670* were assembled using the "Chinese Spring" 454 sequence unassembled reads database described in chapter 3 because the flow sorted chromosome arm sequences were not yet available when the work was done. The flow sorted chromosome arm sequence data confirmed that these genes together with those described in chapter 3 were accurately assembled and the homoeologues were also correctly assigned.

4.3.1 The flow sorted chromosome arm sequence database

The flow sorted chromosome arm sequences hosted by Institut National de la Recherche Agronomique (INRA) in France (http://wheat-urgi.versailles.inra.fr/Seq-Repository) enabled rapid assembly of genes on the distal and proximal side of the 1DL deletion described in chapter 3. The wheat varieties Spark and Rialto were used to define the 1DL deletion because the Spark X Rialto near isogenic lines (NILs) were already available in the Griffiths group. Furthermore, there were four independent Spark X Rialto BC_2F_3 populations that were grown by single seed descent (SSD) to BC_2F_5 in this study which were used for fine mapping the flowering time QTL on 1DL. The markers developed in this chapter and the previous one were then used to genotype the NILs and SSD populations (described in the next chapter).

Forty wheat homologues of Brachypodium genes were used to define the deletion that contains several genes that was described in chapter 3. These genes were checked by BLAST homology searching (Altschul *et al*., 1990) the flow sorted chromosome arm sequence database (http://wheat-urgi.versailles.inra.fr/Seq-Repository) with the mRNAs (exons) of the *B. distachyon* collinear genes. The genes that only matched the group one chromosome and were on the long arm of group one chromosomes were selected. There was no need to identify the three wheat homoeologues of each gene as these were all assigned to 1AL, 1BL, and 1DL from the flow sorted chromosome arm sequence database. A few genes would have certain segments missing and for such genes, the unassembled "Chinese Spring" 454 sequence database (described in chapter 3) was used to fill the gaps using the method described in chapter 3 for the assembly of genes and identification of homoeologues. In addition to the use of the unassembled "Chinese Spring" 454 sequence database, the *A. tauschii* sequence database (http://n61225.nbi.bbsrc.ac.uk/blast.html) and the *T. urartu* sequence database (http://n61225.nbi.bbsrc.ac.uk/blast.html) were also used for those genes that were not complete on the flow sorted chromosome arm sequence database (http://wheat-urgi.versailles.inra.fr/Seq-Repository).

A total of 214 primers (107 primer pairs) from 13 genes *TaBradi2g28010*, *TaBradi2g25820*, *TaBradi2g15630*, *TaBradi2g14970*, *TaBradi2g14940*, *TaBradi2g14830*, *TaBradi2g14790*, *TaBradi2g14730*, *TaBradi2g14190*, *TaBradi2g14130*, *TaBradi2g14790*, *TaBradi2g14750*, and *TaBradi2g19670* (*TaFT3*) were designed as described in chapter 3 and these were used to define the 1DL deletion and to develop some markers that were outside the 1DL deletion.

4.4 **Chapter 4 Results**

A total of forty Brachypodium genes were used to define the 1DL deletion and they are listed in Table 4.1. The PCR primers which are specific to 1DL used to define the 1DL deletion are listed in Table 4.2. The primers that have ngs indicate the non genome specific primers that were used as controls for each gene. Of the forty genes, eight have been described in chapter 3 and these are *Bradi2g14440*, *Bradi2g14400*, *Bradi2g14380*, *Bradi2g14370*, *Bradi2g14340*, *Bradi2g14310*, *Bradi2g14290 and Bradi2g14210*, they were all shown to be part of the segment that has several genes deleted from Spark, Badger and Cadenza (Fig. 3.15) and they are shown in blue colour (Table 4.1). Twelve other genes on the equivalent region of Brachypodium chromosome 2 region that has partial co-linearity with the wheat group 1 chromosome had no matches with wheat group one chromosomes and these are written in red colour on Table 4.1. Of these twelve genes, five matched the wheat group three chromosomes and these are *Bradi2g14070*, *Bradi2g13870*, *Bradi2g13820*, *Bradi2g13810*, and *Bradi2g13800*.

The genes *Bradi2g14770*, *Bradi2g14740*, *Bradi2g14120*, *Bradi2g14110* (Table 4.1), matched homologues on both group 1 and group3 wheat chromosomes and these were not used to define the deletion because amplification from group 3 would not be distinguishable from group1 in the absence of polymorphism that can be used to differentiate the locations. The genes *Bradi2g14780*, *Bradi2g14750*, and *Bradi2g14440* (Table 4.1), matched genes on both group1 and group3 chromosomes but none of the three had sequence match with the group 3 D genome chromosome of "Chinese Spring" and hence *Bradi2g14440* was used to define the deletion as previously described in chapter 3. The gene *Bradi2g14730* matched both group1 and group 3 but when the genes were aligned, the group1 genes were sufficiently different from the group3 genes hence primers were designed to be specific to the group1 D genome chromosome and this gene was also found to be among the deleted genes (Fig. 4.2, I). Thirteen genes in addition to the 8 described in chapter 3 matched group1 chromosomes only and all these were used to define the deletion (bold black Table 4.1) and these genes are described in this chapter.

Table 4.1 The *B. distachyon* genes used to define the 1DL deletion

B. distachyon Chromosome 2 Gene number	Match with *T. aestivum* Group1	Match with *T. aestivum* Group3	Gene or marker name or EST accession number
Bradi2g28010	yes	no	serine/threonine-protein kinase TOR-like (BF485305)
Bradi2g25820	yes	no	peptide methionine sulfoxide reductase B3, chloroplastic-like
Bradi2g19670	yes	no	*Barley **F**lowering **T**ime **3*** ([ψ]*HvFT3*)
Bradi2g15630	yes	no	chloroplast unusual positioning1(CHUP1) chloroplastic-like
Bradi2g14970	yes	no	Glucose-1-phosphate adenylyltransferase large subunit, chloroplastic/amyloplastic-like
Bradi2g14940	yes	no	uncharacterised
Bradi2g14830	yes	no	probable indole-3-acetic acid-amino synthetase GH3.5-like
Bradi2g14790	yes	no	*RNA polymerase sigma factor rpoD-like*
Bradi2g14780	no	partial 3B	
Bradi2g14770	Yes (**1DS**)	yes	
Bradi2g14760	no	no	
Bradi2g14750	no	partial 3B	
Bradi2g14740	yes	yes	
Bradi2g14730	yes	yes	CTP synthase-like
Bradi2g14460	yes	no	[α]*BJ544902*
Bradi2g14440	yes	3A and 3B	**Xcdo393* ([μ]*Sb09g030620*)
Bradi2g14400	yes	no	**v**acuolar **ATP** synthetase subunit **C** (**vatpC*) ([α]*XAL503851*)
Bradi2g14380	yes	no	**XCA608558*
Bradi2g14370	yes	no	**Xwg241*
Bradi2g14340	yes	no	[β]***Mo**lybdenum **T**ransporter **1** (MOT1)*
Bradi2g14310	yes	yes	***Ad**enylate kinase **1** (*XADK1)*
Bradi2g14290	yes	no	*AtELF3/Eam8/Mat-a* (early maturity)/ [α]*XBarc62*
Bradi2g14290 3'UTR	yes	no	[α]*XBarc62*
Bradi2g14250	yes	no	UDP-glucose 4-epimerase GEPI48-like (LOC100838089), mRNA
Bradi2g14210	yes	no	**N**ucleoside **d**iphosphate **k**inase **3** (**Ndk3*) [μ]*Sb09g030810*
Bradi2g14190	yes	no	uncharacterised
Bradi2g14130	yes	no	uncharacterised
Bradi2g14120	yes	partial	Histone deacetylase HDT2-like
Bradi2g14110	yes	yes	rho GDP-dissociation inhibitor 1-like
Bradi2g14090	yes	no	uncharacterised
Bradi2g14080	no	no	
Bradi2g14070	no	yes	
Bradi2g13870	no	yes	
Bradi2g13860	no	no	
Bradi2g13850	no	no	
Bradi2g13840	no	no	
Bradi2g13820	no	yes	
Bradi2g13810	no	yes	
Bradi2g13800	no	yes	
Bradi2g13790	yes	no	probable inactive leucine-rich repeat receptor-like protein kinase (At1g66830-like)
Bradi2g13750	yes	no	*Adaptor protein complex 3 subunit delta (AP-3)-like*

*Valarik *et al*., 2006; [α]Song *et al*., 2005; [β]Faricelli *et al*., 2010; [γ]Higgins *et al*., 2010; and [μ]Zakhrabekova *et al*., 2012; [δ]Faure *et al*., 2012; [ψ]Faure *et al*., 2007.

Table 4.2 The primers used to define the deletion including several genes on 1DL deletion.

marker/gene name	Primer sequence 5'-3'	Tm[α]	%GC[β]	SecStr[γ]	Dimer[δ]
TaBra2g28010_F1_*ngs	ATGAATGTTGTGAATTTGTTTTTG	61.35	25	no	no
TaBra2g28010_R1_ngs	GATGGAGTATATAATATTGGCCAGG	62.14	40	weak	no
TaBra2g28010_F1_ D µ	CACATTGACTTTGGAGACTGTTTC	63.58	41.67	vweak	no
TaBra2g28010_R1_D	CAGGCAAAGGTGCTACG	60.59	58.82	weak	no
TaBra2g28010_F1_A	GGAGATTGTTTTGAGGCG	60.78	50	no	no
TaBra2g28010_R1_A	CAGGCAATGGTGCTACAA	60.88	50	weak	no
TaBra2g28010_F1_B	TTTGATGCTATAGTTTTGTTGAGTCTTG	64.04	32.14	no	no
TaBra2g28010_R1_B	GGAGTATCTAATAAGCACTATATTTTGGTAT	60.2	29.03	vweak	no
TaBra2g25820_F1_DD	GAGCACAACATGCTGAGTTCG	65.92	52.38	mod	no
TaBra2g25820_R1_DD	CCTGAAGAATGCAGCTCAT	60.54	47.37	weak	no
TaBra2g25820_F2_DD	AAGAATATTTGCAACATCACAAC	59.42	30.43	vweak	no
TaBra2g25820_R2_DD	CGATGCCTTTCTTTTCCTCTATT	63.29	39.13	no	no
TaBra2g25820_F3_DD	CACAACTTGTAGTGTGCTTTGACT	62.08	41.67	mod	no
TaBra2g25820_R3_DD	ACGGATGTGCTGGCTGT	63.19	58.82	no	no
TaBra2g25820_F4_DD	CAATTCTAATAAATGTCGGCTGTA	60.72	33.33	no	no
TaBra2g25820_R4_DD	ATGGTAGTCTGTTAAACTAACAATAACA	59.02	28.57	weak	no
TaBra2g25820_F1_ngs	CTAGATTGGATGTTTCAAATATTACTTG	60.78	28.57	vweak	no
TaBra2g25820_R1_ngs	TGGAACAGGTGAATATGACAAG	61.35	40.91	no	no
casTaBradi2g15630_DF1	GCTTCATATACAAAAACCACTCC	60.26	39.13	non	non
casTaBradi2g15630_DR1	GAGCGAGAAATTCAGATGG	59.9	47.37	non	non
casTaBradi2g15630_DF2	GTGGTGTTCGTTGGCTCA	63.6	55.56	non	non
casTaBradi2g15630_DR2	CTCCCTCACCAGGCCA	63.83	68.75	weak	non
casTaBradi2g15630_DF3	ACTATTGGTTCTGCGTCTTGT	60.2	42.86	non	non
casTaBradi2g15630_DR3	ATCCAGCTTCACCATGAGA	60.83	47.37	vweak	non
casTaBradi2g15630_DF4	GGACGCCGAGATCGAA	63.84	62.5	non	non
casTaBradi2g15630_DR4	CAGGTCCTCGTTTGTATGTCTC	62.43	50	non	non
casTaBradi2g15630_DF5	CAATTCCAGAAGTTCCACAAAT	61.64	36.36	non	non
casTaBradi2g15630_DR5	CCAGGTTCAGAATTAACTGCA	61.6	42.86	weak	non
casTaBradi2g15630_DF6	CAGTTGATGTCGAAGAATGTG	60.74	42.86	non	non
casTaBradi2g15630_DR6	CAGGATTTTTATGCAAGGC	59.65	42.11	non	non
casTaBradi2g15630_DF7	CAAAAACATCGAATGTTTCTGAC	62.15	34.78	weak	non
casTaBradi2g15630_DR7	CACTCTGTCAGAAGTATGACACTAATTA	60.5	35.71	mod	non
casTaBradi2g15630_DF8	GAACAAGGCCACATCCTTT	61.49	47.37	mod	non
casTaBradi2g15630_DR8	GGCGAACCGTAAGCTCTC	62.52	61.11	non	non
casTaBradi2g15630_DF9	GGCATCCGTTCAGCTT	59.88	56.25	non	non

casTaBradi2g15630_DR9	CACAAGTTACTCCGGTTTTG	63.27	47.62	non	non
casTaBradi2g15630_DF10	GTTTGTTTGTTCGGCTGC	61.89	50	non	non
casTaBradi2g15630_DR10	CCGTCTACGCCGCCT	63.86	73.33	non	non
casTaBradi2g14970_DF1	CTGGCGAGGAGGGAA	61.14	66.67	non	non
casTaBradi2g14970_DR1	AAATCACTGATGAATTTACAGGTC	59.79	33.33	weak	non
casTaBradi2g14970_DF2	CTTTGAGTTCAGAAGAGGAAACAGCG	68.8	46.15	vweak	non
casTaBradi2g14970_DR2	AACTCACAAGGGTGTCTGCT	61.36	50	weak	non
casTaBradi2g14970_DF3	GTCATGTGCCTTCCATGC	62.9	55.56	mod	non
casTaBradi2g14970_DR3	ACACAATGCAGAAAACTTGG	60.17	40	non	non
casTaBradi2g14970_DF4	GATAGTTTGACACTAGTACATCTCAGTTC	60.4	37.93	weak	non
casTaBradi2g14970_DR4	CGGTGAATGTGACGATTAAGA	62.43	42.86	non	non
casTaBradi2g14970_DF5	TATTCCCATGAGCAACTGCTTCAAT	68.18	40	weak	non
casTaBradi2g14970_DR5	TCTGACACAGTGAGGTAAGACC	60.78	50	weak	non
casTaBradi2g14970_DF6	GAACTGGCTGACCAAGCTTATT	63.25	45.45	weak	non
casTaBradi2g14970_DR6	ACATAAGCCTGACAAAAACAGA	60.18	36.36	weak	non
casTaBradi2g14970_DF7	CCTTCTAAAGTAAGAACCTGCTCTC	61.53	44	weak	non
casTaBradi2g14970_DR7	GCGAAAAAGCATACCTTGAGT	62.04	42.86	vweak	non
casTaBradi2g14970_DF8	AGAACCAACCTGCCATTG	61.13	50	non	non
casTaBradi2g14970_DR8	GTTTGAACTCTGAAGGAGGGC	63.91	52.38	weak	non
casTaBradi2g14970_DF9	CGGCGCAAGTGAGACAG	64.74	64.71	non	non
casTaBradi2g14970_DR9	CCGAGGCTTCACAGTTCTAAAT	63.23	45.45	non	non
casTaBradi2g14970_ngs_F1	GGAAGAACGCCAGCCAC	64.63	64.71	non	non
casTaBradi2g14970_ngs_R1	CGTCCGGAGAACCTGC	63.27	68.75	non	non
casTaBradi2g14970_ngs_F2	TGTGGTGCATGTCAACTGT	61.35	47.37	non	non
casTaBradi2g14970_ngs_R2	CCCCCGGGAGTTTGTT	63.45	62.5	non	non
casTaBradi2g14940_DF1	GTCGGTGGTAGAACCAAGAC	61	55	mod	non
casTaBradi2g14940_DR1	CATTTTTGTCCCCTGGAAA	62.22	42.11	weak	non
casTaBradi2g14940_DF2	CGCAAGAAGTTGGTCGAAT	62.77	47.37	non	non
casTaBradi2g14940_DR2	CCTCGATCGACAATTACTTCTATAC	60.72	40	non	non
casTaBradi2g14940_DF3	GTTTTCGCTATTTTGTGGTGC	63.17	42.86	non	non
casTaBradi2g14940_DR3	CTGACGTCGTCCGCG	64.43	73.33	weak	non
casTaBradi2g14940_DF4	GCGACGCAAAAGGGACGG	71.21	66.67	non	non
casTaBradi2g14940_DR4	GCACAGCCATGGCGA	64.92	66.67	non	non
casTaBradi2g14940_DF5	CTCCGCCCCCACACAAAGT	69.53	63.16	non	non
casTaBradi2g14940_DR5	CTTTTCTGCCCGCTAGTCA	63.02	52.63	non	non
casTaBradi2g14940_DF6	TCGCCATGGCTGTGC	64.92	66.67	non	non
casTaBradi2g14940_DR6	ACTCATGATCTCTAATGCCTCTAC	59.31	41.67	vweak	non

casTaBradi2g14940_ngs_F1	AGGCGTTGGCGGTG	63.48	71.43	non	non
casTaBradi2g14940_ngs_R1	ATGGAGTCATGGACACCAT	60.22	47.37	mod	non
casTaBradi2g14940_ngs_F2	TTGTGTGATCAGGTTGAAGC	61.33	45	vweak	non
casTaBradi2g14940_ngs_R2	TCTCTCCATTGATATGGACAT	58.35	38.1	mod	non
casTaBradi2g14830_DF1	GTGGACACTGCTATTACTTTCCTATTA	61.37	37.04	weak	non
casTaBradi2g14830_DR1	GGAAAACCATGGCCACTC	62.98	55.56	non	non
casTaBradi2g14830_DF2	CTGCAAAAGGTGAGGATCA	61.42	47.37	vweak	non
casTaBradi2g14830_DR2	CATTGCGGTGTTGCC	60.9	60	non	non
casTaBradi2g14830_DF3	CGGTTCTTTGGTGTCCACT	62.61	52.63	weak	non
casTaBradi2g14830_DR3	CCATAGGACAACAAGATAACACATC	62.19	40	vweak	non
casTaBradi2g14830_DF4	GGCAGTTTGGCCTCGAT	63.92	58.82	mod	non
casTaBradi2g14830_DR4	ACCATCTCTTATATCAGCACATAGC	61.21	40	non	non
casTaBradi2g14830_DF5	GCTCTGTGGGTTGATATACTCAGAT	63.23	44	mod	non
casTaBradi2g14830_DR5	ATTTACCCCACCATTAATCTAAGTG	61.76	36	weak	non
casTaBradi2g14830_DF6	CACTGATCAGTGCCGACTAT	60.31	50	mod	non
casTaBradi2g14830_DR6	AGTAGTATTCAGAGATCAAAATTAAAATCATA	60.65	21.88	vweak	non
casTaBradi2g14830_DF7	GTGTAGTTTTCAGTGTAAATTCAGACTTA	60.7	31.03	vweak	non
casTaBradi2g14830_DR7	CAGCTCCCAGAAAATCACATAG	62.44	45.45	non	non
casTaBradi2g14830_DF8	GGACCTGCAGCTGGCT	63.02	68.75	non	non
casTaBradi2g14830_DR8	GCGACATTCCGGTTCAGT	63.81	55.56	non	non
casTaBradi2g14830_DF9	CGGGCCGCTATGTGATT	64.69	58.82	non	non
casTaBradi2g14830_DR9	ATTACATGCCTGGGGCT	60.48	52.94	mod	non
casTaBradi2g14830_DF10	TGCAGATACTGAACCGGAAT	62.03	45	weak	non
casTaBradi2g14830_DR10	CTGCATGTAAATTACAAAGCATACATAT	61.83	28.57	weak	non
casTaBradi2g14830_ngs_F1	AACTGGCCTCACAGATTTG	60.27	47.37	weak	non
casTaBradi2g14830_ngs_R1	AGGTGATGGGCTTCCC	61.09	62	mod	non
casTaBradi2g14830_ngs_F2	GCGCTTCCACAACTCG	61.89	62.5	non	non
casTaBradi2g14830_ngs_R2	TCTGTCATAGCCCATACGC	61.25	52.63	non	non
casTaBradi2g14790_DF1	GAATCGGTAATGTCTTCAGTGTTTTA	62.94	34.62	vweak	non
casTaBradi2g14790_DR1	CGAGAAACCAAAGACATGCATA	63.72	40.91	non	non
casTaBradi2g14790_DF2	CTTTTATCGTCCAGGAGAGACAA	63.21	43.48	weak	non
casTaBradi2g14790_DR2	GACCGAGATATATAAAGATAATTTCACATA	60.52	26.26	non	non
casTaBradi2g14790_DF3	GACAAGAGATCAACAGGGCT	60.84	50	non	non
casTaBradi2g14790_DR3	CTTTAAATCCACCCCATACTGT	60.49	40.91	non	non
casTaBradi2g14790_DF4	CTTTGGTTTCTCGTTGTTGAC	61.12	42.86	non	non
casTaBradi2g14790_DR4	CTAAAGTCATTTAATTGGCACCAT	61.73	33.33	vweak	non
casTaBradi2g14790_DF5	TTATATATCTCGGTCGCGCACGTG	70.2	50	non	non

casTaBradi2g14790_DR5	CGGAGCCCAACATACATCCAG	68.52	57.14	weak	non
casTaBradi2g14790_DF6	ATGACCGTTCCTGCATGT	61.65	50	weak	non
casTaBradi2g14790_DR6	GAACTTCTTATCATGTGGGGTG	62.07	45.45	non	non
casTaBradi2g14790_ngs_F1	GAGGAGCTGTCGTTCGAG	61.36	61.11	non	non
casTaBradi2g14790_ngs_R1	TCGTACTTGCGCACCATC	63.61	55.56	non	non
casTaBradi2g14790_ngs_F2	AGATGGCATAGACTCATCATTG	60.52	40.91	mod	non
casTaBradi2g14790_ngs_R2	CTTTATGGGGTGAAATTAGCC	61.04	42.86	non	non
TaBradi2g14730_DDF1	CAACCTTTTATTTCGCCTGT	60.51	40	no	no
TaBradi2g14730_DDR1	CAAATCCACCTGCAACAATA	60.93	40	no	no
TaBradi2g14730_DDF2	TGGCGAGGTATTGGGATT	62.85	50	no	no
TaBradi2g14730_DDR2	ATTAATAACAGACTGCAATAAAAATATATTAATA	59.15	14.71	vweak	no
TaBradi2g14730_DDF3	GGATAATGTTCATGCTGAATCG	63.03	40.91	weak	no
TaBradi2g14730_DDR3	AGAGACATGGTAAGTTGGACG	60.59	47.62	no	no
TaBradi2g14730_DDF4	GTGAGCAGGTAAGTAAACTTCTCAT	60.59	40	mod	no
TaBradi2g14730_DDR4	CAGATAAAACAATTGAAAAGGACG	62.31	33.33	no	no
TaBradi2g14730_DDF5	GAGGTTTTCTTCCAAAGATGC	61.5	42.86	weak	no
TaBradi2g14730_DDR5	CTGCATGCCAAGGCATATA	62.18	47.37	mod	no
TaBradi2g14730_DDF6	AAATTTACAATTTGTACCTGTCTGACAG	63.05	32.14	mod	no
TaBradi2g14730_DDR6	GGCGAAACCGACGGTA	63.42	62.5	weak	no
TaBradi2g14730_DDF7	GTGTGGGCAGCTGGAT	60.9	62.5	no	no
TaBradi2g14730_DDR7	AACCCAGGCTCTGTCTCGACAAG	69.73	56.52	weak	no
TaBradi2g14730_DDR8	GTGCTGTACTGCCATGTGAT	61.24	50	no	no
casTaBradi2g14190_DF1	CAGCGCCAAGAAAGCAG	63.58	58.82	non	non
casTaBradi2g14190_DR1	TGTTGTGTTTGCTGACAGTGT	61.92	42.86	vweak	non
casTaBradi2g14190_DF2	TACCTACCAACCCCATCTCA	61.74	50	non	non
casTaBradi2g14190_DR2	CACCCCTGGAACTGGAG	61.8	64.71	non	non
casTaBradi2g14190_DF3	CTTATCTGACAGACACGACATACAT	60.86	40	vweak	non
casTaBradi2g14190_DR3	TGTAATGGTATATCTTCTCTCTGAACTG	61.5	35.71	vweak	non
casTaBradi2g14190_DF4	AACACTGTCAGCAAACACAAC	60.28	42.86	vweak	non
casTaBradi2g14190_DR4	GGGCATTGCTTACAACAAAAAT	63.56	36.36	vweak	non
casTaBradi2g14190_DF5	CCTGGAAGAAACCGGC	61.86	62.5	non	non
casTaBradi2g14190_DR5	CGGCATACTCTCTGAATAGTTTCAAT	64.18	38.46	weak	non
casTaBradi2g14190_ngsF1	CCTCACCGGCCAGAAG	63.25	68.75	non	non
casTaBradi2g14190_ndsR1	AGGCTTTCTTGGCTCTCTC	60.25	52.63	non	non
casTaBradi2g14130_DF1	GCCACGGAAGATCAGGTC	63.39	61.11	non	non
casTaBradi2g14130_DR1	GGCACGGATATGACGGT	62.05	58.82	non	non

casTaBradi2g14130_DF2	CGTGTCCGCCATGAGC	65.68	68.75	non	non
casTaBradi2g14130_DR2	CCATATCTGCAAGCACCG	62.91	55.56	non	non
casTaBradi2g14130_DF3	CATCCATATTTCAACGCATTAAA	62.21	30.43	non	non
casTaBradi2g14130_DR3	GCATAATATAGGGAAGAAACAGCAT	62.07	36	non	non
casTaBradi2g14130_DF4	AATGTTGAAACTGAATGGTAGTCTAAT	60.85	29.63	vweak	non
casTaBradi2g14130_DR4	GTAGAAGGGGCAATCTGCTC	62.64	55	weak	non
casTaBradi2g14130_DF5	GACAAAGAAGAGGTACACTACCCC	62.79	50	mod	non
casTaBradi2g14130_DR5	GGATCAGCCAGAGAAAAAATAAA	62.06	34.78	non	non
casTaBradi2g14130_DF6	GGATCAGATTGGACCTGAA	60.01	47.37	mod	non
casTaBradi2g14130_DR6	GCATTGCACTTGAGATTGTAC	59.76	42.86	non	non
casTaBradi2g14130_DF7	CGCTTGTTTACTACCTCATTGC	62.41	45.45	non	non
casTaBradi2g14130_DR7	TTGCTCAAGTGGTCGGC	63.87	58.82	non	non
casTaBradi2g14130_DF8	CATCCTAAGAAACAGTATGTATGTAAGC	60.96	35.71	vweak	non
casTaBradi2g14130_DR8	GGTTCATCAGAATCCTCCTACA	61.81	45.45	vweak	non
casTaBradi2g14130_DF9	GTGTGCGAGTGTTGTTTCG	63.08	52.63	weak	non
casTaBradi2g14130_DR9	CAAACGCGCTCAAAACC	63.05	52.94	non	non
casTaBradi2g14130_DF10	GCCAGCGATGCAATAGTAAC	62.13	50	non	non
casTaBradi2g14130_DR10	GCCACTTCAATCACCCAC	61.62	55.56	non	non
casTaBradi2g13790_F1	AACACGAAACTACAACGTAGTACAG	60.1	40	mod	non
casTaBradi2g13790_F1b	CATAAACGCAACGACTCG	60.44	50	non	non
casTaBradi2g13790_R1	GATGGCGCCGGAGAG	64.6	73.33	non	non
casTaBradi2g13790_F2	GGACCTTTCCTCCAACAA	60.03	50	weak	non
casTaBradi2g13790_R2	GACCCGCACCATGTCCT	64.95	64.71	weak	non
casTaBradi2g13790_F3	CAACCGTGGCCCCACA	68.45	68.75	weak	non
casTaBradi2g13790_R3	CAAAACTAATCAATGTCGAAGTACATTAT	62.09	27.59	weak	non
casTaBradi2g13790_F4	GGTGAGGCGACTCGGT	62,7	68.75	weak	non
casTaBradi2g13790_R4	CCTTTGCTAGCAAAGAACTACC	60.79	45.34	weak	non
casTaBradi2g13790_F5	AATTGTTTTGATACAGTACTGTCTCAG	60.38	33.33	weak	non
casTaBradi2g13790_R5	CATTTCGAGCAAGATCACG	62	47.37	non	non
casTaBradi2g13790_F6	GGACAATGACATTCACACCAC	62.77	47.62	vweak	non
casTaBradi2g13790_R6	ACCGCCCTTTCGTGGTC	66.26	64.71	weak	non
casTaBradi2g13790_F6a	CTCACTGCAATGTTGAACCTA	60.32	42.86	vweak	non
casTaBradi2g13790_R6b	CTTGTTAAAGGCCCCGAAAT	63.74	45	vweak	non
casTaBradi2g13790_F7	CCCTCTTGTGAGCAAAGAAA	61.9	45	weak	non
casTaBradi2g13790_R7	ATTCATTCTCACACAGAGTACTACAGT	60.07	37.04	weak	non
casTaBradi2g13790_F8	TCATGTGTTAGCTTTTCTTCTTTG	61.15	33.33	non	non
casTaBradi2g13790_R8	ACACTAGTGGCAATATACATACATGAC	60.81	37.04	non	non
casTaBradi2g13790_ngs_F1	CTAATGAGTGCCGCCG	61.61	62.5	non	non

casTaBradi2g13790_ngs_R1	CTCGAGCCTGGACAGG	60.73	68.75	weak	non
casTaBradi2g13790_ngs_F2	TGGGACAATGACATTCACAC	61.94	45	vweak	non
casTaBradi2g13790_ngs_R2	CGCTCCAAGGTTTCTGTG	62.08	55.56	non	non
casTaBradi2g13750_DF1	CGCGCCTAGCTGCG	64.69	78.57	mod	non
casTaBradi2g13750_DR1	GGAGATTGTTCCCAAGCAAG	63.46	50	weak	non
casTaBradi2g13750_DF2	GTTTGCAAATGACATTCTTGGT	62.58	36.36	non	non
casTaBradi2g13750_DR2	GAGCTCCACGACCCGT	62.7	68.75	weak	non
casTaBradi2g13750_DF3	GATGAGTTAGCTGTTGATCAAACTGTC	64.85	40.74	weak	non
casTaBradi2g13750_DR3	GTGCTCTTCTCTTTAGTAAGATCGG	62.32	44	weak	non
casTaBradi2g13750_DF4	CTTTTTGAGCACCGTAAACGA	63.83	42.86	non	non
casTaBradi2g13750_DR4	GGCACTTTCATGCACCAA	63.45	50	weak	non
casTaBradi2g13750_DF5	GGTCTTTGTATACTATCCCAAAGGTT	62.16	38.46	weak	non
casTaBradi2g13750_DR5	GAAAAAAAGAAAATGTGCAAAAG	60.49	26.09	non	non
casTaBradi2g13750_DF6	GCTGTAGGATGGTTTGGAGC	63.5	55	weak	non
casTaBradi2g13750_DR6	CGATCAGGTGAAATCCCGC	67.77	57.89	vweak	non
casTaBradi2g13750_DF7	CTGTAGCTGCCTCTGCATAAGT	62.39	50	weak	non
casTaBradi2g13750_DR7	CCATCTGATCGCAGTGGT	62.45	55.56	weak	non
casTaBradi2g13750_ngsR1	GCCAGCTCCTCACTCG	60.92	68.75	non	non
casTaBradi2g13750_ngsR1	AGCAGCAGAAAGAACAGAGC	61.45	50	non	non

$^{\alpha}$ = melting temperature, $^{\beta}$= guanine: cytosine content, $^{\gamma}$ = secondary structure, δ= primer dimer, *= non genome specific primer, $^{\psi}$= very weak (secondary structure), $^{\mu}$ = D genome specific primer. F and R = forward and reverse primers

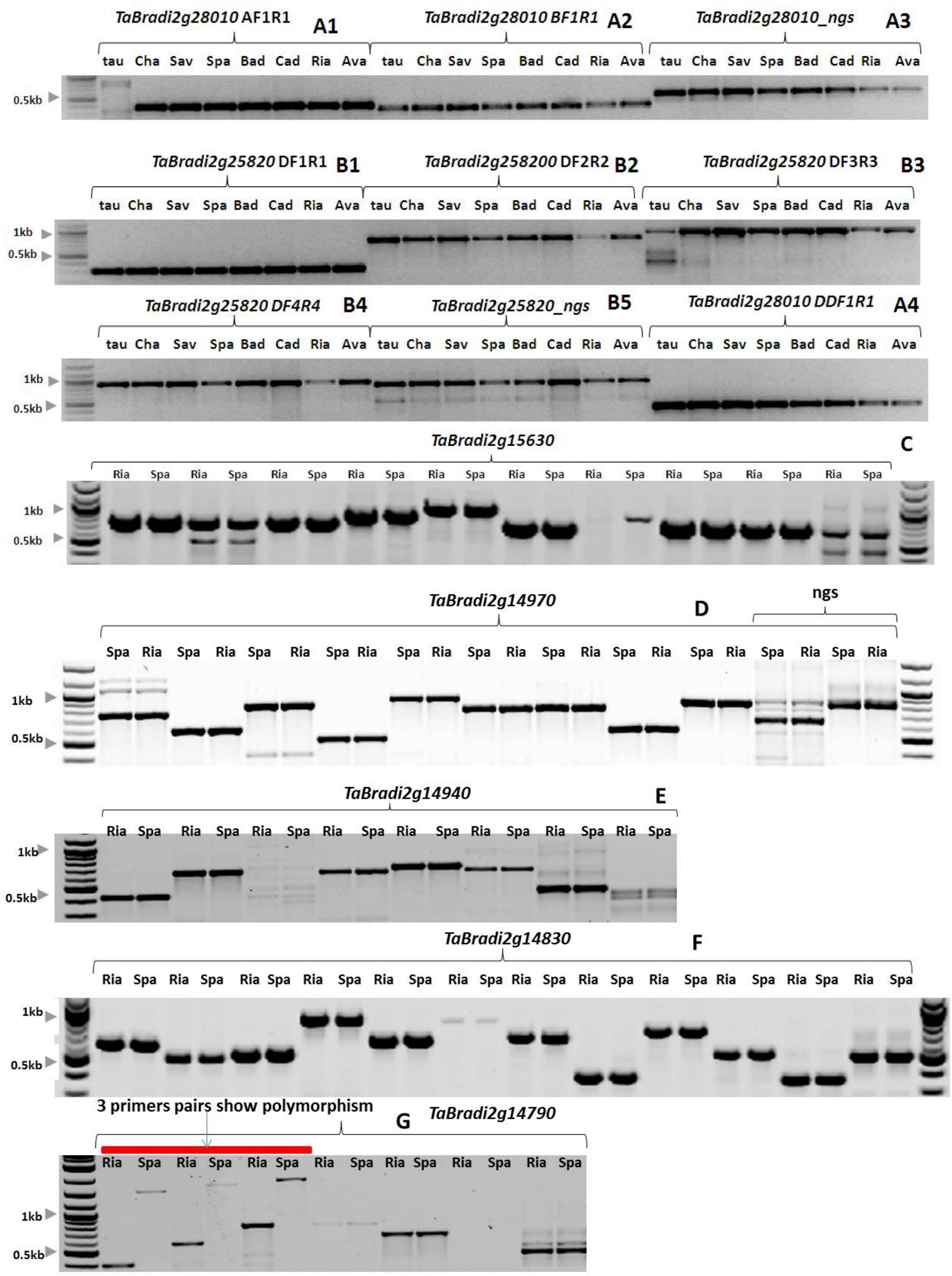


Fig.4.1 The 1D genes that match the *B. distachyon* chromosome 2 genes that were used to define the 1DL deletion on the proximal end of the deletion. Three codominant PCR markers were developed from *TaBradi2g14790* shown by the red bar (fig.4.1, G). The primer pairs for each gene are from the 5’-3’ end and the order is as listed on Table 4.2. Non genome specific primers are shown as ngs. Key: tau = *A. tauschii*, Cha = Charger, Sav = Savannah, Bad = Badger, Cad = Cadenza, Ria= Rialto, Ava = Avalon.

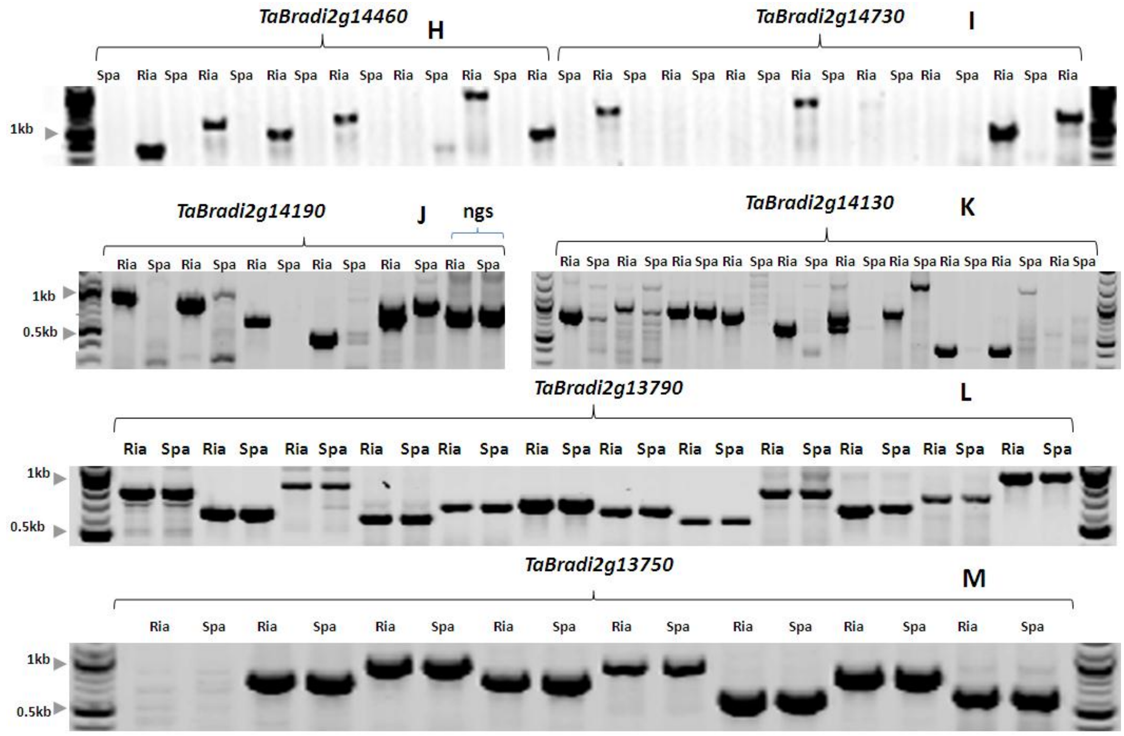
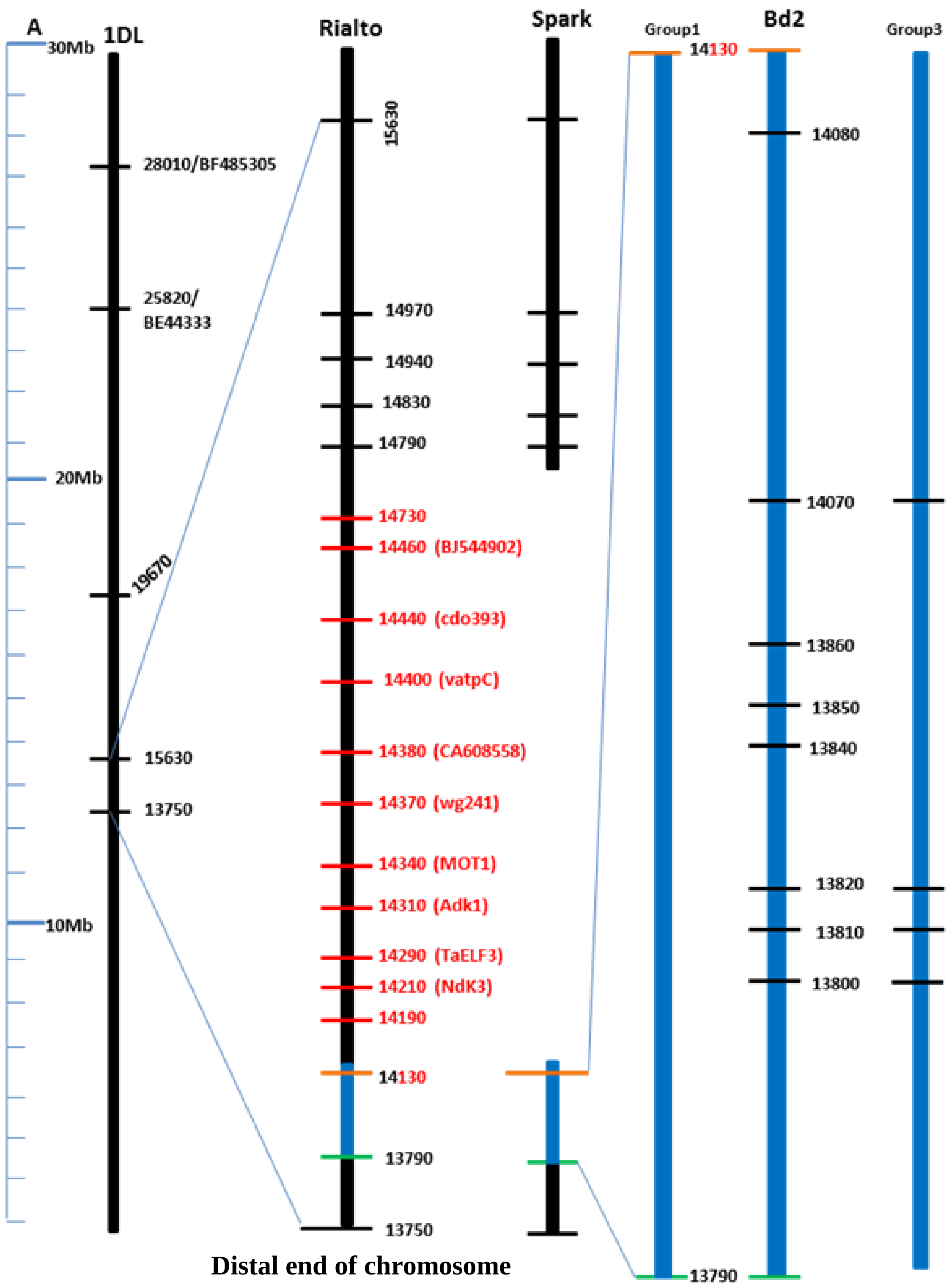


Fig. 4.2 The wheat chromosome 1D genes that match the *B. distachyon* chromosome 2 genes that were used to show that deletion goes beyond *TaBradi2g14440* deletion to include *TaBradi2g14460* (H) and *TaBradi2g14730* (I), *TaBradi2g14190* (J) and *TaBradi2g14130* (K). Key: Spa = Spark, Ria = Rialto. The primer pairs for each gene are from the 5'-3' end and the order on the gel (left to right) is as listed on Table 4.2.

The genes *TaBradi2g1379*0 and *TaBradi2g13750* define the 1DL deletion on the distal end of the deletion. The gene *TaBradi2g14130* amplifies on the 5' end for both Spark and Rialto and about 1Kb of this gene was sequenced from both varieties using the primer pair (*TaBradi2g14130* DF3R3 shown on Table 4.2) that gave the bold band for both Spark and Rialto (Fig. 4.2k) (appendix 4.10b), but the rest of the gene is not amplified from Spark suggesting that the distal deletion breakpoint maybe within this gene.



Distal end of chromosome

Fig. 4.3 Schematic presentation of the deletion of several genes on 1DL of Spark. Line A represents the approximate chromosome length in mega bases (Mb) in the equivalent region of the Brachypodium, based on the physical map of chromosome 2. The red or black numbers next to the black or red horizontal bars indicate the Brachypodium chromosome 2 gene numbers. The red numbers indicate the wheat orthologues deleted from Spark while the black numbers show those genes outside the deletion. The black vertical (Fig. 4.3, 1DL, Rialto, and Spark) bars indicate the 1DL region that is collinear with Brachypodium chromosome 2. The blue vertical bars (Fig. 4.3, Bd2, Group1 and group3) are used to illustrate that all the 8 brachypodium genes (13800, 13810, 13820, 13840, 13850, 13860, 14070 and 14080) between the predicted genes Bradi2g13790 (designated 13790 on Fig. 4.3) and 14130 do not match the wheat group 1 genes but four of these genes match the group three chromosome genes. The gene *TaBradi2g14130* (14130) is labelled in black and red because part of this gene was amplified and sequenced from Spark while the rest of the gene seems deleted (Fig. 4.2, K).

From Fig. 4.3 and fig. 4.2 as well as Table 3.1, the distal end of the deletion has the greater part of *TaBradi2g14130* deleted and the next two genes *TaBradi2g13790* and *TaBradi2g13750* are intact for Spark.

4.4.1 Other markers that show the 1DL deletion (Allen *et al*., 2011)

The KASPar marker BS00010669 is not genome specific (Fig. 4.5) as the reverse primer amplifies from at least two genomes and the forward primer highlighted in yellow (Fig. 4.5) can amplify from the other two genomes (cdo393_X and cdo393_Y). Cdo393_D (Fig. 4.5) was identified to be the D genome as it matches a sequence from Aegilops tauschii using a method described in chapter 3. When D specific primers were designed for cdo393 (done before the availability of KASPar markers by Allen *et al*., 2011), one of the primer pairs MZ DD F4R4 spans the region where BS00010669 marker is (Fig. 4.5). MZ DDF4R4 does not amplify any fragment in Spark, Badger and Cadenza (Fig.3.14 C1 designated cdo393 D_F4R4). This means the KASPar markers in this 1DL region appears to score allelic polymorphism because the D genome is absent in Cadenza hence it scores Avalon as having a G and Cadenza as having a T (from the A or B genome) as illustrated in Fig. 4.5.

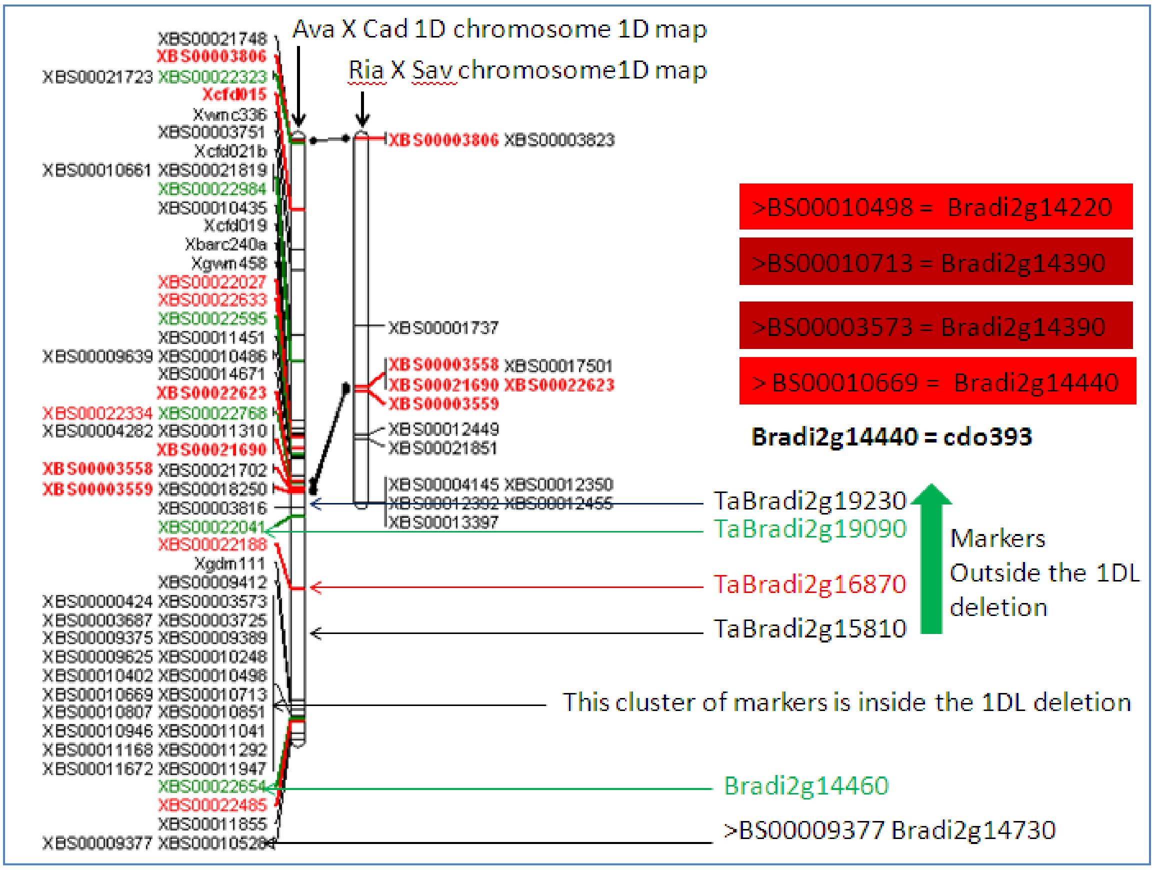


Fig. 4.4 Comparison of the Avalon X Cadenza (Ava X Cad) and the Rialto X Savannah (Ria X Sav) chromosome 1D map (Allen *et al*., 2011). The cluster of markers that map on the distal end in Avalon X Cadenza map are in the 1DL deletion. Markers BS00010498, BS00010713, BS00003573 and BS00010669 (highlighted in red) have sequences identical to those of the genes in the 1DL deletion region. Markers *XBS00022654* (*TaBradi2g14460*) and *XBS00009377* (*TaBradi2g14730*) are both deleted from Cadenza (*TaBradi2g14460* deletion in Cadenza is shown in Fig. 3.15). The green vertical arrow shows the markers outside the 1DL deletion (data not shown). Savannah and Rialto do not have the 1DL deletion hence none of the 20 markers in the Avalon X Cadenza cluster of markers (Fig 4.4) is polymorphic in the Rialto X Savannah map (Fig. 4.4). The gene order in Brachypodium is also shown to be conserved in the Avalon X Cadenza map (Fig. 4.4). The KASPar marker BS00010669 will be used to illustrate why the markers by Allen *et al*., (2011) suggest allelic variation Avalon X Cadenza when these genes are deleted from Cadenza (Fig. 4.5).

```
                    MZ DDF4
cdo393_D          GTCAGGCCAATGACCAATGTTCTCTTTTCTTGAGCAGCATGAGGAGAGTGCGATTGAAG
cdo393_X          ATCAGGCCAATGACCAGTG-TCTCATTTTCTTGAGCAGCATGAGGAGAGTGCGATTGAAG
cdo393_Y          ATCAGGCCAATGACTAATGTTCTCCTTTTCTTGAACAGCATGAGGAGAGTGCGATCGAAG
                  .************* *.** **** *********.******************** ****

cdo393_D          AGCTCGCTCGGGACTACAACGCGAACTGGATGACTGCAGTTGAGATGATTGACGATGACA
cdo393_X          AGCTCGCTAGGGACTACAATGCGAACTGGATGACTGCAGTTGAGATGATTGACGATGACA
cdo393_Y          AGCTTGCTAGGGACTACAACGCAAACTGGATGACTGCAGTTGAGATGATTGATGACGACA
                  **** ***.********** **.***************************** ** ****

cdo393_D          TCTACGTCGGTGCAGAGAACAGCTACAACCTCTTCACTGTGCGCAAGAATAGCGACGCGG
cdo393_X          TCTATGTTGGTGCAGAGAACAGCTACAACCTTTTCACTGTGCGCAAGAACAGCGACGCGG
cdo393_Y          TCTATGTCGGTGCAGAGAACAGCTACAACCTTTTCACCGTGCGCAAGAACAGCGATGCAG
                  **** ** *********************** ***** *********** ***** **.*

cdo393_D          CCACAGACGAGGAGAGGGGTAGGCTGGAGGTGGTCGGGGAGTACCACCTCGGAGAGTTTG
cdo393_X          CCACAGACGAGGAGAGGGGCGAGGCTGGAGGTAGTCGGGAGTACCACCTCGGAGAGTTTG
cdo393_Y          CCACAGATGAGGAGAGGGGCAGGCTGGAGGTGGTCGGGGAGTACCACCTCGGAGAGTTTG
                  ******* *********** ..*   *..*  .   ************************
Bristol BS00010669 Forward primers            GTGATGCGCCTCCCTGACTCT
cdo393_D          TCAACAGATTCCGGCACGGCTCGCTGGTGATGCGCCTCCCTGACTCGGAGATGGGCCAGA
cdo393_X          -TGACAGGTTCCGGCATGGCTCGCTGGTGATGCGCCTCCCCGACTCTGAGATGGGCCAGA
cdo393_Y          TGAACAGGTTCCGGCACGGGTCGCTTGTGATGCGCCTCCCGGACTCTGAGATGGGCCAGA
                    .****.******** ** ***** ************** ***** *************
                  Bristol BS00010669 common primer
cdo393_D          TCCCCACGGTCATCTTTGGCACCATCAATGGGGTCATCGGCATCATCGCCTCCCTGCCCC
cdo393_X          TCCCCACGGTCATCTTTGGCACCATCAACGGGGTCATTGGCATCATCGCCTCCCTGCCCC
cdo393_Y          TCCCCACGGTCATCTTCGGCACCATCAACGGGGTCATCGGCATCATCGCCTCCCTGCCCC
                  **************** *********** ******** **********************

cdo393_D          ACGACCACTATGTGTTCCTGGAGAAGCTCCAGACAACCCTGGTCAAGTTCATCAAGGGTG
cdo393_X          ACGACCACTATGTGTTCCTGGAGAAGCTCCAGACAACCCTGGTCAAGTTCATCAAGGGTN
cdo393_Y          ACG-CCACTATGTGTTCCTGGAGAAGCTCCAGACAACCCTGGTCAAGTTCATCAAGGG-C
                  *** ******************************************************
                                                          MZ DD R4
cdo393_D          TGGGCAGCCTGAGCCACGAGCAGTGGCGGTCATTCCACAACGACAAGAAGACGTCAGAGG
cdo393_X          TGGGCAGCCTGAGCCACGAGCAGTGGCGGTCGTTCCACAACGACAAGAAGACGTCGGAGG
cdo393_Y          TGGGCAGCCTGAGCCACGAGCAGTGGCGGTCGTTCCACAACGGCAAGAAGCGTCGGAG-
                  *******************************.**********.**********.**
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Fig. 4.5 Part of the *cdo393* “Chinese Spring” gene assembled from the 454 unassembled sequence database showing the position of the KASPar SNP marker BS00010669 (highlighted in purple). The BS00010669 is not specific to the D genome as it also amplifies from the genome labelled X (the putative A or B genome) as well. When D specific markers MZ DD4 highlighted in green and MZ DDR4 highlighted in red are used, there is no amplification from Cadenza Suggesting that this portion of the chromosome is deleted.

4.5 Chapter 4 Discussion

It was shown earlier (chapter 3) that several genes from *TaBradi2g14440* to *TaBradi2g14210* (*Ndk3*) were deleted on 1DL for Spark, Badger and Cadenza and this deletion covers the entire *Eps* region in *T. monococum*. It is now shown that additional genes *TaBradi2g14190* and part of *TaBradi2g14130* on the distal end of 1DL and *TaBradi2g14460* and *TaBradi2g14730* on the proximal end of 1DL deletion are also deleted (Fig. 4.2, H. I. J, K). The allele specific (KASPar) markers by Allen *et al*., (2011) also reveal the 1DL deletion. Comparing the maps for Avalon X Cadenza and Rialto X Savannah (Fig. 4.4) shows that Rialto X Savannah map has no polymorphism on all the 25 markers on the distal end of the chromosome including the 20 markers that all map to a single point labelled as cluster of markers in Fig. 4.4.

This chapter and the previous one showed that neither Savannah nor Rialto has the 1DL deletion and that the markers that that map to the same position in Avalon X Cadenza (Fig. 4.4 and Fig. 4.5) are likely in the 1DL deletion for Avalon X Cadenza DH population (Fig. 4.4). Fig.4.5 also illustrates how the KASPar markers by Allen *et al*., (2011) suggest a single nucleotide polymorphism (SNP) when in fact it is presence/absence polymorphism due to the deletion in Cadenza and the non genome specificity of the markers as illustrated with the marker *XBS00010669* (fig. 4.5).

The results reveal the need for markers to be genome specific when designed for use in polyploid wheat. The KASPar markers (Allen *et al*., 2011) on the 1DL *Eps* region illustrate what happens when markers are not genome specific. When these markers were used to define the 1DL deletion allelic polymorphism between Spark and Rialto was observed (data not shown) when in fact Spark does not have the D genome sequence in that region. With the availability of the draft Chinese Spring 454 sequence data, and the flow sorted chromosome arm sequences (http://wheat-urgi.versailles.inra.fr/Seq-Repository), it is now possible to make gene assemblies of the three homologues and verify the genome specificity of these markers (procedure described in chapter 3).

Allen *et al*., (2011) showed the chromosome location of the KASPAr on 1DL and this thesis suggests that the clustering of markers on 1DL (Fig. 4.4) is due to the 1DL deletion. These markers (Allen *et al*., 2011) will only show polymorphism when one of two varieties being compared has the 1DL deletion. The non specific KASPar markers work well when mapping Charger X Badger DH as well as the Spark X Rialto map because Spark and Badger both have the Cadenza deletion. Without the deletion, the markers are unlikely to show any porlymorphism as evidenced by the Rialto X Savannah map which has none of the 20 polymorphisms in the cluster of markers which lie in the 1DL deletion (Fig. 4.4).

While *B. distachyon* has 12 genes between *Bradi2g14130* and *Bradi2g13790* (Table 4.1) nine of these eight genes do not match any of the wheat group 1 chromosomes (Table 4.1). Two of the genes *TaBradi2g14120* and *TaBradi2g14110* match both group1 and 3 (Table 4.1). The gene *TaBradi2g14090* matches group 1 only but the 1DL specific primers designed for this gene did not give clean PCR amplicons for both Spark and Rialto (data not shown). The distal end of the deletion was defined and probably ends at the gene *TaBradi2g14130* (Fig.4.2, K) and the next two genes on the distal side of *TaBradi2g14130* that is *TaBradi2g13790* and *TaBradi2g13750* are both intact for Spark (Fig. 4.2) showing that the deletion does not extend beyond these genes.

Furthermore, there are three predicted genes between *Bradi2g13750* and *Bradi2g13790* and these are *Bradi2g13760*, *Bradi2g13770* and *Bradi2g13780.* Apart from Bradi2g13770 for which the sequence could not be retrieved from the Brachypodium database, the other two do not match any of the group 1 genes (data not shown). Based on this data and the colinearity of this region with the wheat group 1 chromosomes, it can be inferred that the next three genes after *TaBradi2g14130* are *TaBradi2g14090*, *TaBradi2g13790* and *TaBradi2g13750* (Table 4.2 and 4.3). Sequencing the Spark gene *TaBradi2g14090* will be vital to show if the deletion does not extend beyond *TaBradi2g14130*.

However, the possibility of the presence of other wheat specific genes on group1 chromosomes between *TaBradi2g13750* and *TaBradi2g13790* cannot be ruled out until this wheat region is fully annotated. Work done recently on *T. monococcum* using the same syntenous region showed that two genes *Poz* and *Ap2-like* are present on *A. tauschii* but absent from rice and Brachypodium, while *MOT1*, *FtsH4 and Rbp1* were present on both Brachypodium and wheat but absent from rice (Faricelli *et al.*, 2010). None the less, even if other genes were to be present between *TaBradi2g13750* and *TaBradi2g13790,* the results from this study shows that the deletion does not extend beyond *TaBradi2g13790*. It is also noted that the results suggest a “surgical” deletion but this may not be the case given the complex nature of DNA repair mechanisms. Further work needs to be done for example a PCR across the deletion with the aim of joining the two ends of the deletion. Such information will give insight into the nature of the deletion and to find a possible mechanism of how the deletion mutation came about.

The proximal end of the deletion shows that it extends to include the gene *TaBradi2g14730* but does not go beyond *TaBradi2g14790* (Fig. 4.2, I). There are five genes between *Bradi2g14730* and *Bradi2g14790*. Of these five genes, three genes, *Bradi2g14780*, *Bradi2g14760* and *Bradi2g14750* do not match any of the group1 chromosomes (data not shown). The gene *Bradi2g14770* partially matches the gene on the short arms of group1 chromosomes as well as group 3 chromosomes (Table 3.1). The gene *Bradi2g14770* was therefore not considered for defining the 1DL deletion which is on the long arm of 1DL. *Bradi2g14740* matches genes on both group1 and group 3 chromosomes and hence was not used for defining the 1DL deletion. Based on the Brachypodium synteny, there is one gene between *TaBradi2g14730* and *TaBradi2g14790* that is *TaBradi2g14740* (Table 4.1).

However, as discussed for the distal end of the deletion, the presence of wheat specific genes between *TaBradi2g14730* and *TaBradi2g14790* cannot be ruled out. The results do show that the deletion does not extend beyond *TaBradi2g14790* (Table 4.1, Fig. 4.1 G and Fig. 4.3). The results also show that *TaBradi2g14790* is a codominant marker which is just outside the deletion and this marker will be important for the identification of recombinants on 1DL.

The polymorphic markers from *TaBradi2g14790* (Fig. 4.1, G) are due to an insertion in Spark which introduces a premature stop codon in the gene that resembles *RNA polymerase sigma factor rpoD-like*. The three PCR markers from *TaBradi2g14790* were outside the deletion and were used to genotype Spark X Rialto NILs as well the SSD populations and this is discussed in detail in the next chapter. The gene *TaBradi2g19670* (*TaFT3*) is a homologue of *HvFT3* a gene that has been shown to affect short day flowering in barley (Faure *et al*., 2007). A silent mutation on *TaBradi2g19670* was used to design a KASPar marker and it segregates between Spark and Rialto. This marker was used to score Spark X Rialto NILs as well as SSD and DH populations. The gene *TaFT3* is discussed in detail in a separate chapter.

5 Chapter 5

5.1 High resolution genetic mapping of the 1DL *Eps* QTL

The 1DL *Eps* QTL was identified in an earlier study (Griffiths *et al.*, 2009) using **m**ulti **e**nvironment **t**rait **a**nalysis (META) of doubled haploid populations in field based experiments in the UK, France and Germany. In this study the same doubled haploid populations were grown in controlled environments, so that photoperiod and vernalization conditions could be defined, and QTL analysis was carried out. In addition to that, four independent single seed decent (SSD) populations (F5) derived from a cross between Spark and Rialto that segregated for the 1DL QTL were phenotyped and genotyped. The doubled haploid and SSD populations as well as the near isogenic lines (NILs) described in chapter 2 were all genotyped using the markers described in chapter 3 and 4.

5.2 Methodology

5.2.1 Doubled haploid populations and NILs

Ninety-six lines each from four independent doubled haploid (DH) populations of crosses between Spark X Rialto, Charger X Badger, Avalon X Cadenza and Malacca X Hereward, were grown. The growth conditions were as decribed for the NILs in chapter 2: the plants were vernalized for 8 weeks under short days (10hrs light) at 6-10 ^{o}C using natural vernalization in an unheated glasshouse. The plants were then grown under short days (SD, 10 hrs light), long days (LD, 16 hrs light) and very long days (VLD, 20hrs light), at 13-18 ^{o}C. Additional lighting was provided using 4 hours and 8 hours artificial white light (tungsten bulbs) to aid the LD and VLD respectively. All the plants were grown in triplicate using block randomization. Scoring of ear emergence was the same as descibed in chapter 2 for the NILs. The heading date scores were then used to carry out QTL confidence interval mapping (CIM) analysis using R and genstat. The NILs that are genotyped in this chapter are the same NILs that were validated in the field and controlled environment for ear emergence in chapter 2.

5.2.2 SSD populations

The SSD populations were derived from a cross between Spark and Rialto. The same Spark X Rialto doubled haploid lines SR9 and SR23 used to develop the NILs (chapter 2) were used to develop the SSD populations. The only difference is that after screening the bagged and selfed homozygotes from Backcross 2 for the NILs, the heterorozygotes at the same markers used for the NILs were selected to form the recombinant populations.

A total of 265 Backcross 2 F3 (BC_2F_3) individuals derived from four maintained independent populations (59, 70, 64 and 72 individuals respectively) were grown using single seed descent (SSD), up to BC_2F_5. The lines were kept pure and the four populations independently maintained because cross pollination was avoided by bagging the heads before anthesis. Four plants were grown for each SSD line in 1 litre pots and were vernalized under short days (10hrs light) for eight weeks at 6-10^{o}C in a controlled room and then grown at 16-18hrs light with 4 hrs supplementary light using halogen lamps. The plants were scored for ear emergence as described for the NILs in chapter 2.

5.2.3 Genotyping

The NILs, SSD and DH populations were genotyped using the markers *TaBradi2g14210* *TaBradi2g14290* (*TaELF3*), *TaBradi2g14340* (*TaMOT1*) and *TaBradi2g14730* as well as *TaBradi2g14790* and *TaBradi2g19670* (*TaFT3*) described in chapter 3 and 4. Histograms were then used to compare the genotype and the phenotype of the NILs, SSD and doubled haploid populations.

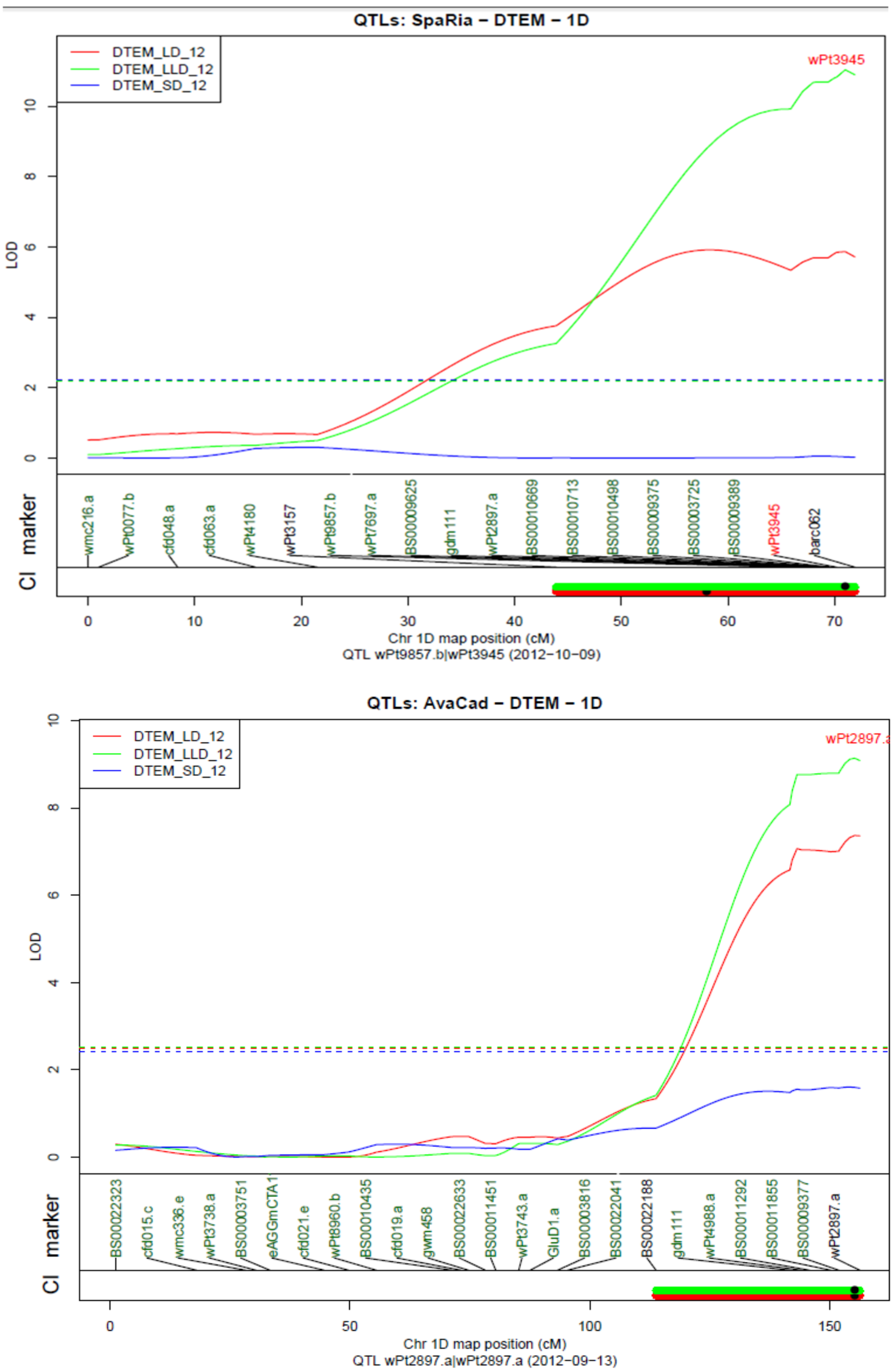
5.3 Chapter 5 Results

The Spark X Rialto and Avalon X Cadenza DH populations had the same 1DL heading date QTLs that were revealed in the field by META QTL (Fig 5.1, A and B). Histograms were made from the heading date data for both Spark X Rialto and Avalon X Cadenza DH populations and these were scored using the 1DL deletion markers (Fig.5.2, A and B). The NILs were also genotyped using the 1DL markers as well as the marker *TaBrad2g14790* (Fig. 5.3). SSD populations were also phenotyped for heading date and genotyped (Fig. 5.4). These results will now be discussed in this chapter.

5.3.1 Double haploid populations

These 1DL QTLs were both detected in long days but not in short days (Fig 5.1). Both the Spark X Rialto and Avalon X Cadenza QTLs have LOD peaks coincident with loci detected by markers that have been shown to be inside the 1DL deletion described in chapters 3 and 4. For example the LOD peak for the Spark X Rialto QTL (Fig. 5.1) is *Xbarc62* (3'UTR of *TaELF3*) which was shown to be deleted (Fig. 3.13). The Avalon X Cadenza QTL peaks on *XwPt-2897*and the marker BS00009377 (*TaBradi2g14730*) which was shown to be within the deletion (chapter 4, Fig. 4.2, I).

The detection of the Spark X Rialto and Avalon X Cadenza QTL in the controlled environment was additional validation of these QTLs given that these had been detected when the plants were grown in natural field conditions. The two doubled haploid populations (Fig. 5.1) also show that the QTL is detectable in long days (16hours and 20hours light) but not in short days (10 hours light)



A

B

Fig. 5.1 Chromosomal location of the 1DL heading QTL for Spark X Rialto (A) and Avalon X Cadenza (B) doubled haploid (DH) population vernalized at 7-10°C for 8 weeks and grown in short days (SD) 10 hrs light, long days (LD) 16 hrs light and very long days (LLD) 20 hrs light. Key: SpaRia = Spark X Rialto DH, AvaCad = Avalon X Cadenza DH, DTEM = **d**ays **t**o **e**ar **e**mergence.

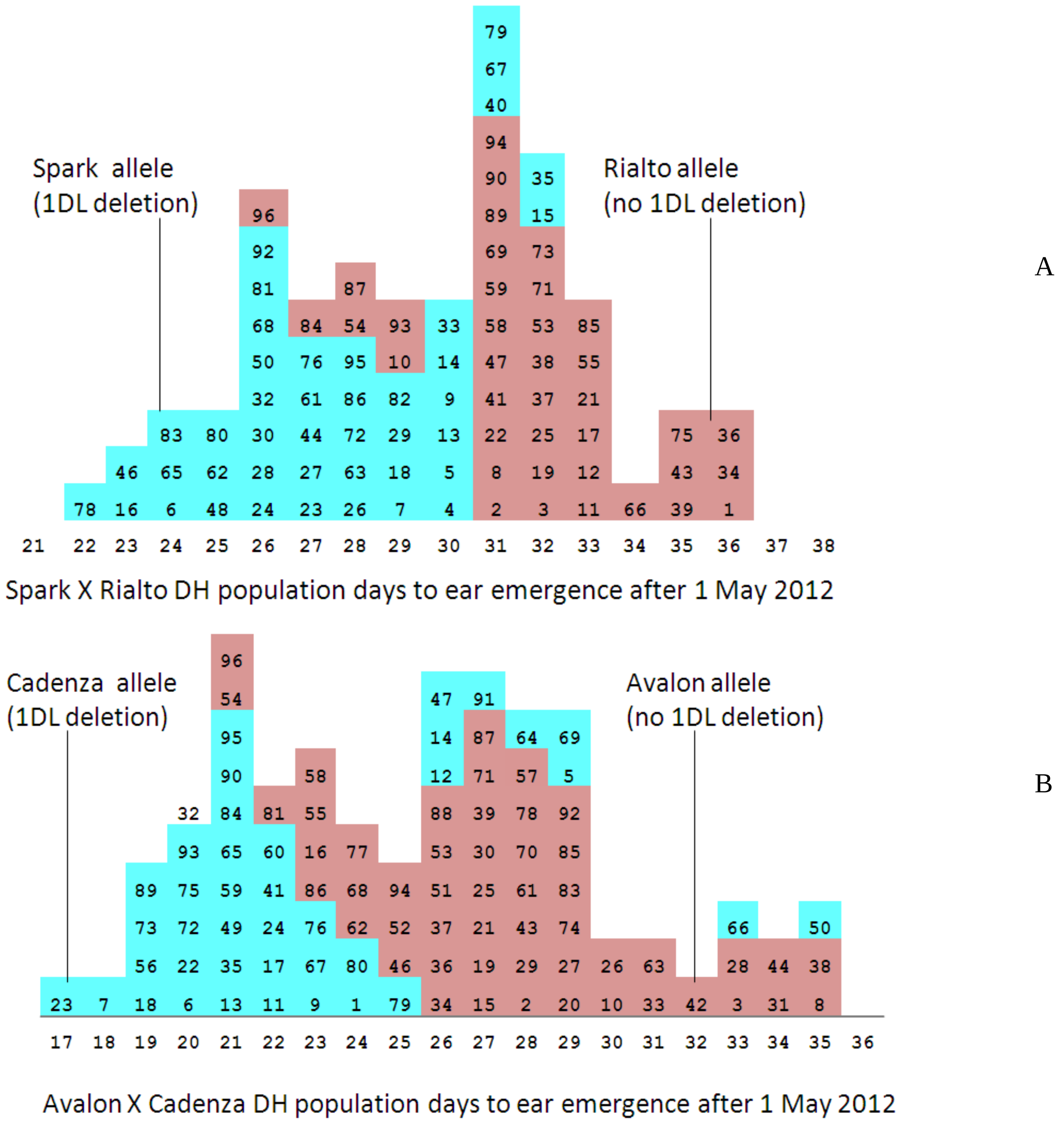


Fig. 5.2 Days to ear emergence of Spark X Rialto (A) and Avalon X Cadenza (B) DH populations grown in Long days (16hrs light). The coloured numbers represent the presence of the 1DL deletion (sky blue) in the lines carrying the Spark (A) and Cadenza (B) alleles, and the presence of the wild type chromosomal segment (brown) in the lines carrying the Rialto (A) and Avalon (B) alleles. The unshaded numbers at the bottom of the histograms are the days to heading after 1 May 2012. There was no genotype data for line 32. The deletion is correlated with the early flowering phenotype

5.3.2 Near isogenic lines

The four independent NIL pairs (light green A1-B5), dark blue (A6-B9), orange (A10-B14) and light blue (A15-B18) are the same NILs that were validated in chapter 2. Fig.5.3 A is the same heading date data that was used for field validation of the NILs in chapter 2 (Fig. 2.2) and is included here to show the association of the heading date and the genotypes at markers *TaBradi2g14790* (B), *TaBradi2g14290* (C), *TaBradi2g14340* (D) and *TaBradi2g14210* (E). All the NILs carrying the 1DL deletion (Spark allele) are early flowering (Fig. 5.3).

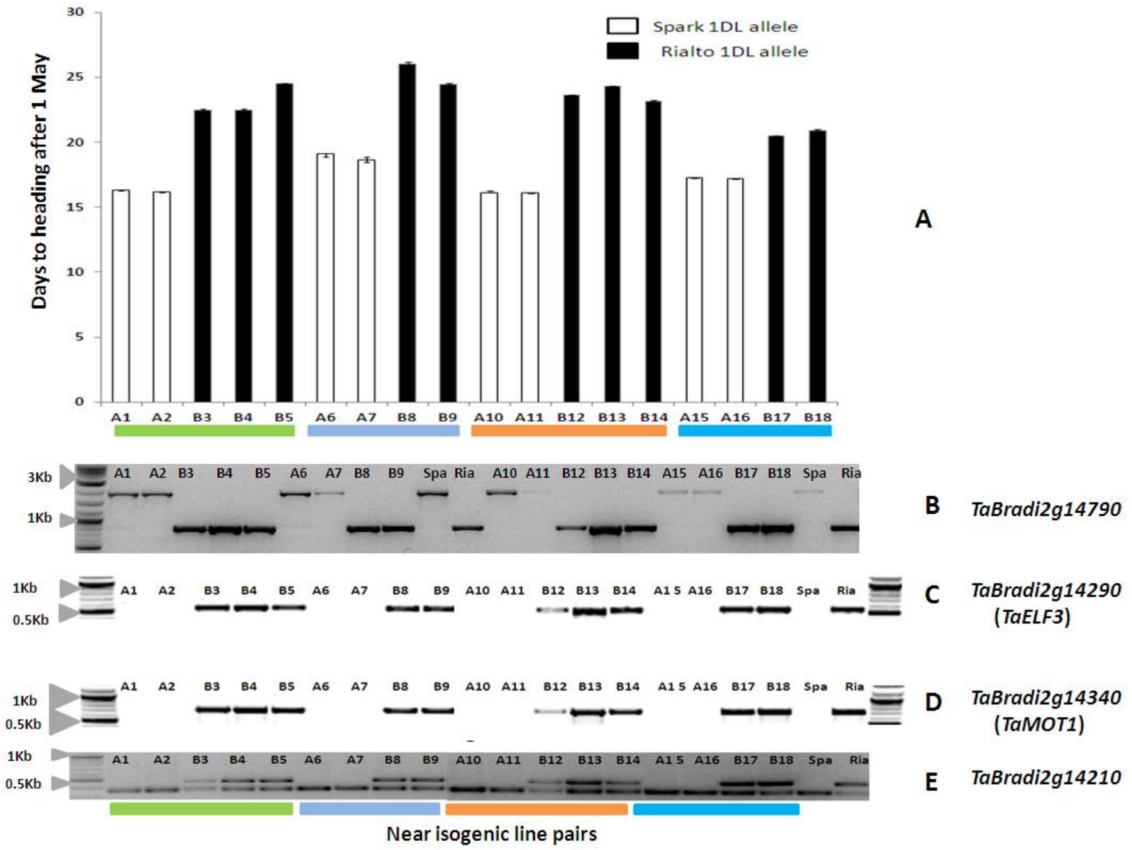


Fig. 5.3 Leading tiller days to ear emergence (50% ear out of flag leaf) of field grown (UK) Spark X Rialto NILs (A) and the genotypes of the NILs with markers *TaBradi2g14790* (B), *TaBradi2g14290* (C), *TaBradi2g14340* (D) and *TaBradi2g14210* (E). The smaller band produced by *TaBradi2g14210* DDF3R4 was sequenced and does not match any of the ABD *TaBradi2g14210* sequences. The expected amplicon size for *TaBradi2g14210* (Fig.5.3, E) was the larger size amplicon which is absent from Spark and that is consistent with Spark having the 1DL deletion.

5.3.3 Single seed descent populations (SSD)

The distribution of heading date classes in four SSD populations is shown in Fig. 5.4. The mean of four plants for each line was used to calculate the heading date for each of the 265 lines. The numbers at the bottom of each histogram (Fig. 5.4) are the days to ear emergence after 21 December 2012. The numbers highlighted in sky blue indicate the Spark 1DL deletion and those highlighted in brown indicate the wild type chromosomal segment present in Rialto (Fig. 5.4). Population E22 (D) has flowering shifted 5 days later relative to the other three populations (A, B, and C) due to a possible background effect but the ear emergence segregation due to the 1DL deletion remains consistent for the four populations.

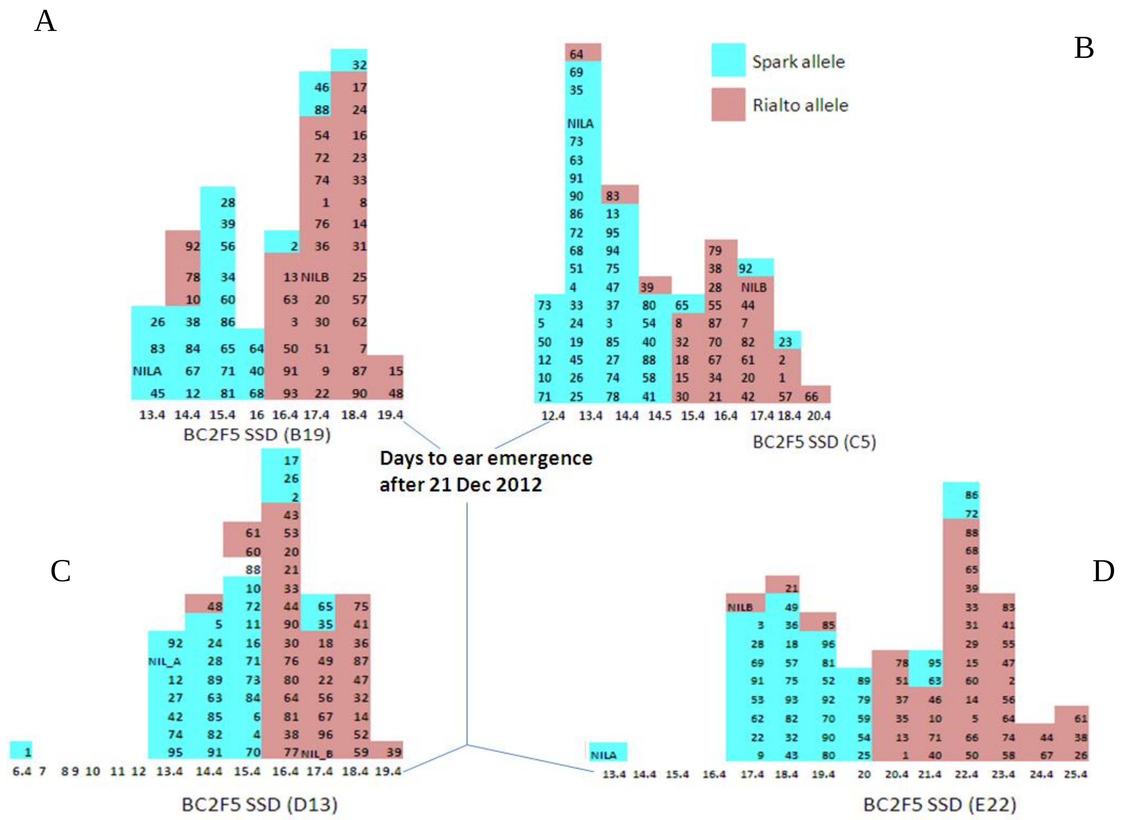


Fig. 5.4 Days to ear emergence of four independent Spark X Rialto Backcross 2 (BC_2) single seed descent (SSD) populations (A, B, C and D) scored at F5 (BC_2F_5). Two near isogenic lines NILA (NILA10) and NILB (NILB12) carrying the Spark and Rialto alleles respectively, were used as controls and grown together with SSD populations. The highlighted numbers are the individual BC_2F_5 lines of each population and the numbers below each population are the mean (average of 4 plants) days to ear emergence after 21 December 2012.

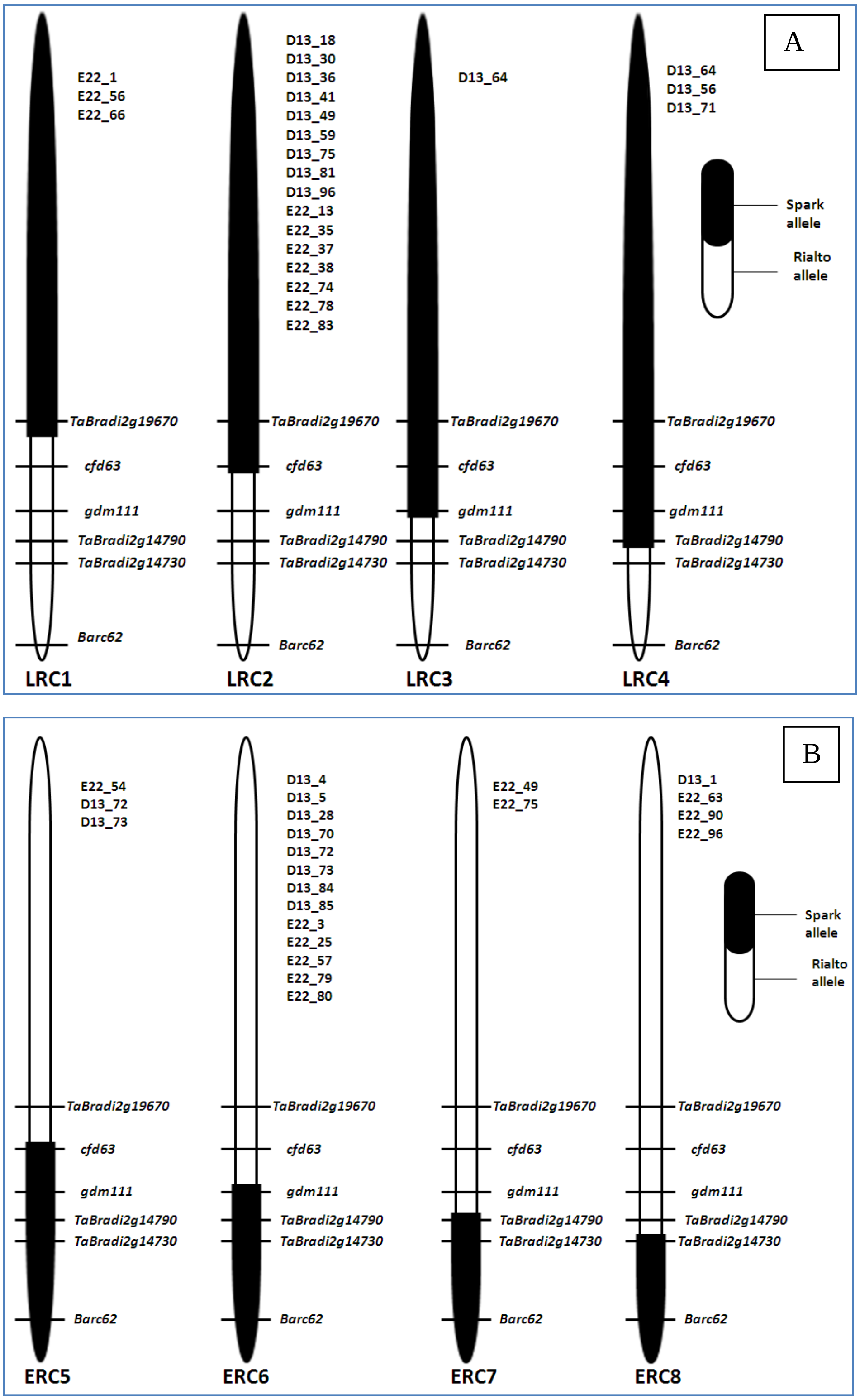


Fig. 5.5 The recombinants at the 1DL QTL interval that segregate for late flowering (A) and early flowering (B) in the BC_2F_5 SSD lines of a cross between Spark and Rialto. LRC denotes the **l**ate flowering **r**ecombinant **c**lass and ERC denotes **e**arly flowering **r**ecombinant **c**lass for the eight groups of recombinants.

5.4 Description of results

There is a bimodal distribution of lines carrying the deletion and those with an intact portion of the chromosome for three of the four SSD populations (Fig. 5.4). For population C the distribution becomes bimodal when the deletion is used to score the population (Fig. 5.4). Most lines with the deletion have an early flowering phenotype and this is consistent with the segregation of the NILs (Fig. 5.3) and the doubled haploid populations (Fig. 5.2). For population B19 (Fig. 5.4, A), lines 10, 78 and 92 are early flowering although they do not have the deletion. On the other hand, lines 2, 32, 46 appear in the late flowering group but there is only one day difference in flowering suggesting that these lines could just be at the end of an overlapping normal distribution. However lines 2, 46 and 88 for the same population are only one day late (Fig. 5.4 A).

The same result is observed for population C5 (Fig. 5.4, B) in which lines 39, 65 83 appear to be at the end of an overlapping normal distribution but line 64 is in the early heading group despite not having the deletion and lines 23 and 92 have the deletion but are late flowering (Fig. 5.4, B). The same is observed for population D13 (Fig. 5.4, C), in which lines 2, 17, 26 and lines 60 and 61 are at the overlapping end of a normal distribution but line 48 is early flowering but does not have the deletion and lines, 35 and 65 are late flowering despite having the deletion (Fig. 5.4, C). Lines 63, 85, and 95 for population E22 are at the end of an overlapping normal distribution but line 21 is early heading but does not have the deletion while lines 72 and 95 have the deletion but are late flowering (Fig. 5.4, D). These lines that have an unexpected phenotype are hereafter referred to as outliers.

If the deletion of the 1DL region causes the early heading date effect of Spark and Cadenza, then co-segregation of the deletion and earliness would be expected. There are a number of possible interpretations of the observed behaviour of the SSD lines (outliers) that do not show this relationship (Fig. 5.4). One possibility is that the gene responsible is outside the deletion but closely linked to the deletion hence the lines B19 (10, 38, 92 and 2, 32, 46 and 88), C5 (39, 64 and 83 23, 65 and 92), D13 (48, 60, 61, 2, 17, 26, 35, 65) and E22 (21, 85, 63, 72, 86 and 95) would be recombinants (Fig. 5.4). However, when the SSD populations were scored with the markers inside the deletion and 6 markers outside the deletion, there was no observed recombination to suggest a gene on the proximal side of the deletion (Fig.5.5). Line

D65 has a Spark 1DL chromosome arm, (data not shown) hence line D65 is an outlier that is not due to recombination between the deletion and another gene outside the deletion.

Another and most likely possibility is that there is another gene(s) in the background on a different chromosome that results in the outliers. The shifting of population E22 which flowers five days later than the other populations as well as the very early flowering observed for line 1 for population D13 (Fig. 5.4, C) are both possible evidence supporting the background gene hypothesis.

The DH populations also show outliers as observed for the SSD populations. The Spark X Rialto DH population line 93 has a Rialto 1DL chromosome arm with no Spark portion (data not shown) but it is early flowering (Fig. 5.2, A). Lines 67 and 79 have Spark 1DL chromosome arms (data not shown) but both of them are borderline late flowering (Fig. 5.2, A). The Avalon X Cadenza, lines 16, 46, 62, 68, 77 and 86 all have Avalon 1DL chromosome arms (data not shown) but they are all early flowering (expected to be late flowering) (Fig. 5.4, B) while lines 12, 14, 47, 64 and 66 all have Cadenza 1DL chromosome arms (data not shown) but they are all late flowering (expected to be early flowering) (Fig. 5.4, B). The results suggest that the outliers could be due to a gene(s) in the background that is/are more dominant than the 1DL effect.

Taken together, these results suggest that the flowering segregation of these DH lines is not due to recombination between the deletion and a closely linked QTL, but maybe due to another gene in the background. The absence of recombinants for the outliers observed in the SSD populations (Fig. 5.5) between the 1DL genotype and the flowering phenotype, further supports the possibility of a background gene effect.

The five day relative delay in flowering observed in BC_2F_5 SSD (E22) (Fig. 5.4 D) was observed even at BC_2F_4, and is likely due to another gene in the background. However it is interesting to note that the gene responsible does not affect the segregation due to the 1DL QTL (Fig. 5.4 D) but just delays the flowering of the whole population by five days relative to the other populations (Fig. 5.4, D). Identifying such a gene or genes would be vital in providing breeders with more options for fine tuning heading date in wheat.

The marker *Xbarc62* used for Spark X Rialto DH population was shown to be inside the deletion and is downstream of the *TaELF3* stop codon. The marker BS00009377 (*Bradi2g14730*) for Avalon X Cadenza DH (Fig. 5.1 B) was also shown to be inside the 1DL deletion (Fig. 4.2). The marker wpt2897 (Fig. 5.6) which is the peak of the Avalon X Cadenza DH 1DL QTL (Fig.5.1, B) was mapped to be above the *Xbarc62* marker (Fig. 5.6) in a different population from the one that was used in this study (Crowley, 2010) as shown in Fig. 5.6.

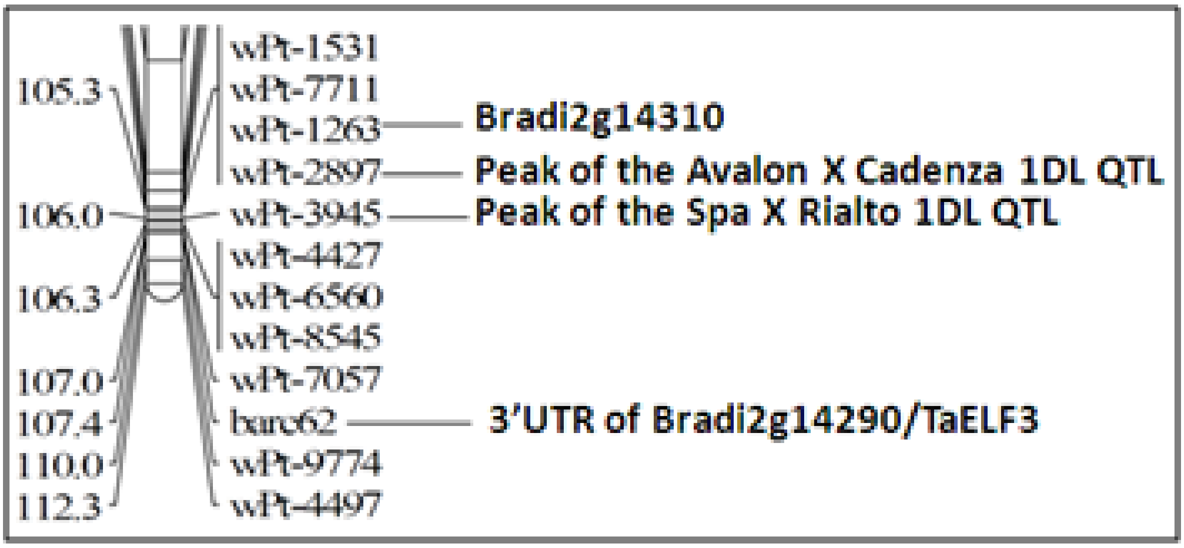


Fig. 5.6 Position of the DArT markers *XwPt-2897* and *XwPt-3945* (A) relative to deleted genes *Bradi2g14310* and *Bradi2g14290*/barc62 on a map of chromosome 1DL in wheat (adapted and annotated from Crowley, 2010).

Both DArT markets *XwPT-2897* and *XwPt-3945* are within the 1DL deletion given that they are flanked by barc62 and *Bradi2g14310* (Fig. 5.6) and it has been shown that barc62 the 3'UTR of *TaELF3* and *TaBradi2g14310* are inside the 1DL deletion. Whether KASPar, DArT or SSR markers, are used, the peak of the QTL is always coincident with the deletion for Avalon X Cadenza and Spark X Rialto DH populations suggesting genes within this deletion are likely candidates for the heading date effect.

5.5 Chapter 5 Discussion

The common feature for the different *Eps* definitions is that authors agree that *Eps* genes control flowering when both vernalization and photoperiod requirements have been satisfied (Shitsukawa *et al*., 2007; van Beem *et al*., 2005; Appendino *et al.,* 2003; Bullrich *et al.,* 2002; Appendino *et al.,* 2003; Lewis *et al.,* 2008). It was shown (chapter 2) using NILs that the 1DL NILs have an *Eps* effect. The NILs have a five day difference in flowering time with those NILs carrying the Spark allele flowering earlier than those carrying the Rialto allele when fully vernalized and grown in 10hrs, 16hrs and 20hrs light periods (chapter 2 Fig. 2.4) which is consistent with *Eps* effect.

However, the 1DL QTL is only detectable in long and very long days (16hrs light and 20 hrs light respectively) while it is undetectable in short days for both DH populations. When plants are exposed to 10hrs light, photoperiod requirement is limiting which causes other short day QTLs to exert their effect, like the 1BL QTL which has a very dominant effect in short days and segregates in Spark X Rialto DH (discussed in chapter 6). For the NILs, the *Eps* effect is detectable even in short days because of common background probably because it reduces or eliminates background photoperiod genes contrary to the case with the DH populations.

The results also show that the segregation in flowering (days to ear emergence) is associated with the deletion of several genes on 1DL. The results therefore suggest that the 1DL deletion could contain one or more genes that are responsible for the 1DL *Eps* QTL. Further evidence is from the Avalon X Cadenza DH population which behaves like Rialto and Spark in that Cadenza has the Spark deletion and Avalon has an intact chromosome. The segregation of the Avalon X Cadenza DH population is similar to the Spark X Rialto population with those lines carrying the Cadenza deletion flowering earlier than those with an intact 1DL (Fig. 5.2).

Evidence against the causative role of the 1DL deletion for earliness is that Charger X Badger DH population does not have the 1DL QTL (data not shown), even though Badger and Charger segregate for the 1DL deletion. It is possible that Charger may have an independent loss of function mutation for the gene in the 1DL deletion which would account for why Charger X Badger does not segregate for the QTL. Sequencing Charger for all the possible candidate genes may help in identifying the gene responsible provided the candidate gene is in the deletion and has a loss of function mutation. However, if it is a regulator of the gene in the deletion which has a mutation in Charger, then sequencing candidates in the deletion may not reveal the candidate. A combination of sequencing candidate genes for Charger as well as gene expression analysis for the candidate genes may help in identifying the candidate. Another possibility is that there could be epistatic interaction between the 1DL QTL and another locus or a linked effect with an allele of the opposite effect in the same phase.

The four SSD populations were independently made but like the NILs and DH populations they all suggest that the 1DL deletion underlies the *Eps* effect (Fig. 5.2, Fig. 5.3 and Fig. 5.4). The deletion contains *TaELF3* a circadian clock gene whose homologues are known to cause flowering variation in *Arabidopsis thaliana* (Dixon *et al*., 2011), *Oryza sativa* (Matsubara *et al*., 2012), *Hordeum vulgare* (Faure *et al*., 2012), *Zea mays* (Bate and Aukerman, 2007), the legumes lentil and pea (Weller *et al*., 2012). In all these species, it has been shown that mutations at genes homologous to *TaELF3*, have an effect on flowering time. The heading date QTL on 1DL is at the same location as the eam8/Mat-a heading QTL in barley (Faure *et al*., 2012; Zakhabekova *et al*., 2012) and there is conserved gene order between the cluster of genes containing *TaELF*3 in Brachypodium, wheat and barley (Higgins *et al*., 2010).

It is only in *Oryza sativa* that mutations at *Hd17* (homologue of *Arabidopsis thaliana ELF3*) have been shown to affect flowering but not through arrhythmia of the clock genes (Mathubara *et al*., 2012) while circadian clock arrhythmia has been shown to result from mutation at the *ELF3* homologues for Arabidopsis, and legumes (Dixon *et al*., 2011; Weller *et al*., 2012). In barley *eam8* mutants, there is no circadian clock arrythmia but rather the circadian clock is impaired (Faure *et al*., 2012).

The other reason why *1DL* deletion is suggested as likely containing a candidate of the *Eps* gene is that independent studies have had flowering time QTLs linked and with QTL peaks at the marker *Xbarc62* (Lin *et al*., 2008; Griffiths *et al*., 2009) and it was shown that the *Xbarc62* marker is the 3'UTR of *TaELF3* only 255 bases from the *TaELF3* stop codon (Fig. 3.13) and that it is deleted in Spark (Fig.3.12). For the Spark X Rialto DH QTL, the peak of the QTL coincides with the deletion (Fig. 5.1 A). It is suggested that the gene responsible for a QTL should coincide with the peak of the QTL (Price, 2006) a situation which is apparent with the 1DL deletion for two independent double haploid populations (Fig. 5.1A and B). It is unlikely due to chance that two independent double haploid populations have QTL peaks at exactly the same location.

The other two genes in the deletion that are possible candidates are *MOLYBDENUM TRANSPORTER 1* (*MOT1*) and *FILAMENTATION TEMPERATURE SENSITIVE H4* (*FtsH4*) which have been suggested to be likely candidates for *Eps* in *Triticum monococcum* (Faricelli *et. al*., 2010). *MOT1* and *FtsH4* are considered as candidates because the 1DL deletion spans the entire *Triticum monococcum Eps* region as shown in chapter 3. If the deletion is the one responsible for the *Eps* effect, it suggests that the gene is a supressor of flowering and *TaELF3* one of the candidates is a well known supressor of flowering (Higgins *et al*., 2010). Expression patterns of the three homologues would reveal why the 1DL QTL has such an effect.

6 **Chapter 6**

6.1 **Identifying new photoperiod response genes in bread wheat (*Triticum aestivum*)**

6.2 **Introduction**

The major photoperiod gene in wheat is *PHOTOPERIOD-1* (*Ppd-1*) which was shown to be a pseudo response regulator (PRR) first in barley (Turner *et al*., 2005) and then its homologues were then identified in wheat (Wilhelm *et al*., 2009; Beales *et al*., 2007). However, there is still genetic variation for photoperiod response in bread wheat that cannot be accounted for by *Ppd-1* (Kumar *et al*., 2012). In barley, another gene *Ppd-2* was shown to influence flowering and its effect was more under short day conditions and this gene was designated *HvFT3* (Faure *et al*., 2007 Kikuchi *et al*., 2009). The aim in this study was to define the genetic basis of differences in photoperiod response not accounted for by *Ppd-1*.

6.3 Background and methodology

Following the observation that Rialto was less sensitive to short days and flowers about fifteen days earlier than Spark (Zikhali *et al*., 2014), this effect was mapped using 96 doubled haploid lines of a cross between Spark and Rialto. Three more doubled haploid populations (Avalon X Cadenza, Charger X Badger and Malacca X Hereward) were also grown together with the Spark X Rialto population and again 96 lines were used for each of the three populations. The Malacca X Hereward population was not grown in short days due to space limitation. These doubled haploid populations are those described in Chapter 5 and were grown at the same time under the same conditions as for the NILs described in Chapter 2. In this Chapter, the focus is on the QTL that was observed on 1BL.

Avalon X Cadenza and Charger X Badger were included because the parental lines of these populations showed similar behaviour to that of Spark and Rialto under short days in an earlier experiment when plants were vernalized for 4 weeks. The Malacca X Hereward population was included as a control because work done by Diaz *et al*., (2012) showed that there was a vernalization QTL on chromosome 5A when the plants are inadequately vernalized (4 weeks) related to copy number variation of *Vrn-A1*. Hence the Malacca X Hereward population was used as a control to determine if the plants had been adequately vernalized (eight weeks at 6-10 ^{o}C). The UK wheat varieties Claire and Savannah were also included in the study. In addition, 25 winter wheat varieties from Sweden (Meridian, Terra, Holme, Eroica, Folke, Kranich, Walde, Starke II, Helge, Hildur, Virgo, Jarl, Sleijpner, Eroica II, Kosack, Stava, Virtus, Odin, Starke, Svale, Solid, Eroica, Banco, Skandia IIIB and William) were also grown under the same conditions as the UK varieties and the DH lines. The Swedish varieties, which are part of the Gediflux collection (http://www.wgin.org.uk/) were included because work done earlier at the John Innes Centre, UK, at Church farm had showed that these genotypes were relatively late flowering in the UK.

Furthermore, 5 spring wheat varieties from Kazakhstan (Tsuleinaya Yubeleinaya, Pamyat Azieva, K2 Rannespelgya and Shortandinskaya 95) were also grown under the same conditions. Three wheat varieties from the United States of America (USA) Blackhull, Early Blackhull and Extra Early Blackhull were also grown. The plants were grown in triplicate for each line with complete block randomization together with the doubled haploid populations.

Photoperiod response QTL were identified on 1BL in the region of *TaFT3* the homologue of the Brachypodium gene *Bradi2g19670* which is similar to *HvFT3* (Faure *et al*., 2007), therefore genome specific primers were designed for each of the three *TaFT3* homologues. The Ta*FT3* gene was identified as a possible candidate for the short day heading date QTL on 1BL because its homologue is known to influence flowering under short day conditions in barley (Faure *et al*., 2007) and it also coincided with the peak of the QTL for the Spark X Rialto and Charger X Badger QTL. The primers were designed as described in Chapters 3 and 4. Five overlaping primer pairs which spanned the entire *TaFT3-A1* gene were designed and six overlaping primers pairs were designed for each of the *TaFT3-B1* and *TaFT3_D* genes. Three non genome specific primers were designed to amplify from all the three genomes and these were used to sequence the *A. tauschii* and *T. urartu* genomes because when the gene was assembled from the "Chinese Spring" 454 sequence database, the chromosome arm sequences (http://www.wheatgenome.org/) were not yet available. However, when the chromosome arm sequence database was available, the three homologues of *TaFT3* were confirmed and had all been correctly assigned to the A, B and D genomes. These primers were used to amplify PCR fragments of the wheat varieties from UK, Sweden, Kazakhstan and USA described earlier.

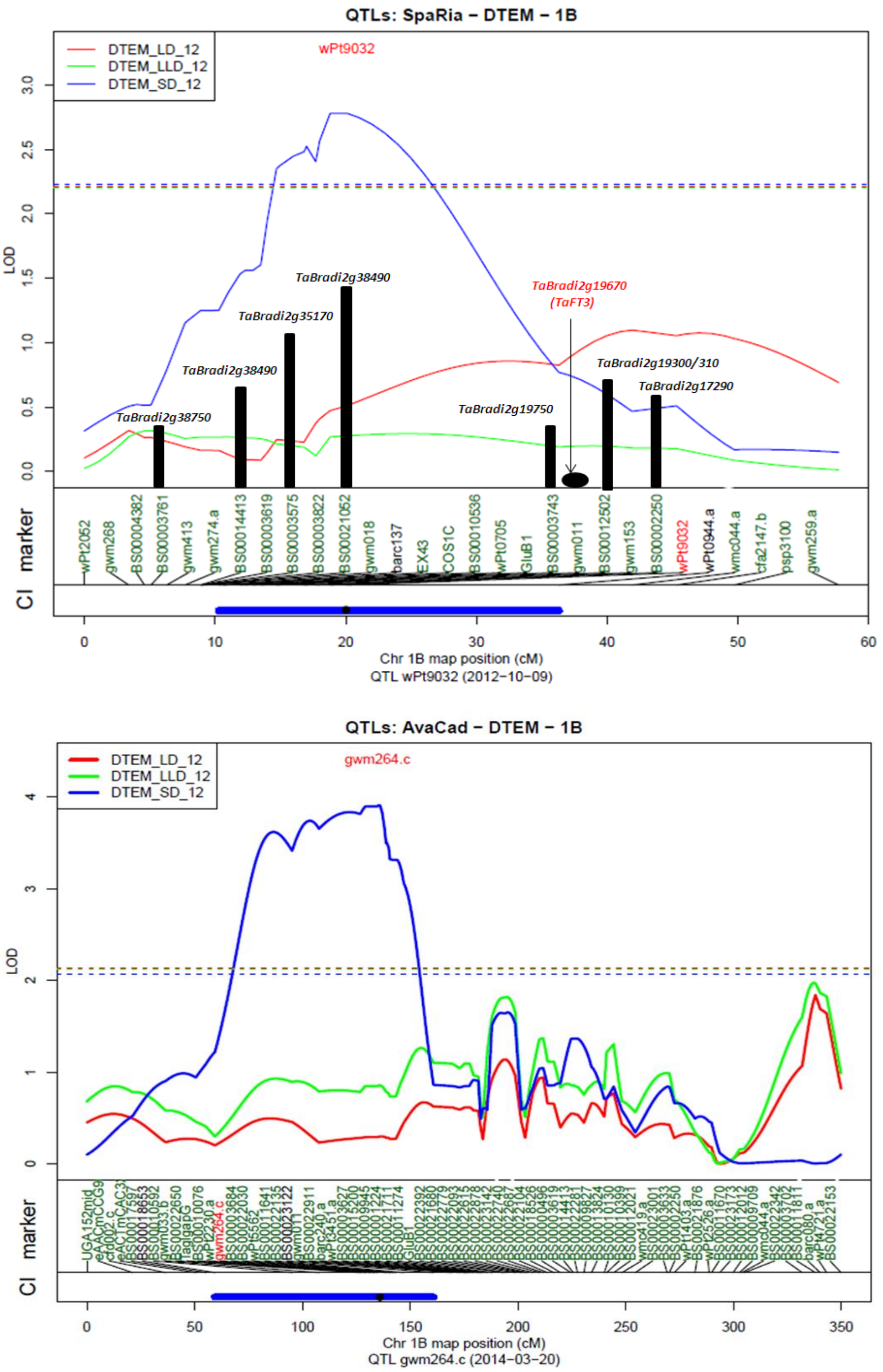
Three KBiosicences allele specific PCR (KASPar) markers were designed one for each of the three *TaFT3* homoeologues. The KASPar markers were designed to be specific to each of the genomes at the same time distinguishing for the genome copy polymorphism. For example the *TaFT3-B1* KASPar marker had two primers that were specific to the B genome (selectively amplified from the B genome copy but not the A and D genome copies) at the same time each distinguished for the B copy polymorphism between Spark and Rialto.

6.4 Chapter 6 Results

No significant QTL were detected for Malacca X Hereward on all the chromosomes including the *Vrn-A1* copy number variation QTL on the long arm of chromosome 5A which was detected when the population was inadequately vernalized (Diaz *et al*., 2012). Even the parental lines Malacca and Hereward flowered at the same time when they were vernalized for 8 weeks (Chapter 2, Fig. 2.5; Zikhali *et al*., 2014) while there is more than 30 days difference when inadequately vernalized (Diaz et al., 2012). These result show that the plants used in this study were adequately vernalized.

A significant QTL was observed on the long arm of chromosome 1B (1BL) for Spark X Rialto, Avalon X Cadenza and Charger X Badger. The QTL was short day specific for Spark X Rialto and Avalon X Cadenza DH populations (Fig. 6.1). The Charger X Badger QTL was unique in that it was detectable on all the three photoperiod regimes tested (Fig. 6.2). Of the three short day QTLs, Spark had the lowest LOD score (between 2.5 and 3.0) while Avalon X Cadenza had the intermediate LOD score (about 4.0) and Charger X Badger had the highest LOD score (above 4.5) (Fig. 6.1 and Fig. 6.2).

The sequences from which the KASPar markers were designed were used to homology search the Brachypodium sequence database using the **B**asic **L**ocal **A**llignment **S**earch **T**ool (BLAST) alogorithym (Altschul *et al*., 1990) in order to predict the most likely gene order represented by the KASPar markers. Since the wheat group1 chromosomes are syntenous with the Brachypodium chromosome 2, the KASPar markers which matched the Brachypodium genes on chromosome 2 were used to compare the positions of the three QTLs. The 1BL QTL from the three populations will be descibed here.



A

B

Fig.6.1 Days to ear emergence QTL of Spark X Rialto (A) and Avalon X Cadenza (B) DH populations vernalized at 7-10°C for 8 weeks and then grown in short days (SD) 10 hrs light, long days (LD) 16 hrs light and very long days (LLD) 20 hrs light. Both Spark X Rialto and Avalon X Cadenza (X) have a short day specific effect on 1BL. The gene *TaFT3* (*TaBradi2g19670*) is between the markers *XTaBradi2g19750* and *XTaBradi2g19300/19310* for Spark X Rialto DH which coincides with the peak of the QTL although it appears from fig6.1 A that it is outside the peak. A close examination shows that marker *XwPT9032* is at the peak of the QTL as are the markers Xbarc137 to *XBS00002250*. The vertical black bars are used to show the gene scored by the KASPar markers (BS00003743 = *TaBradi2g19750*).

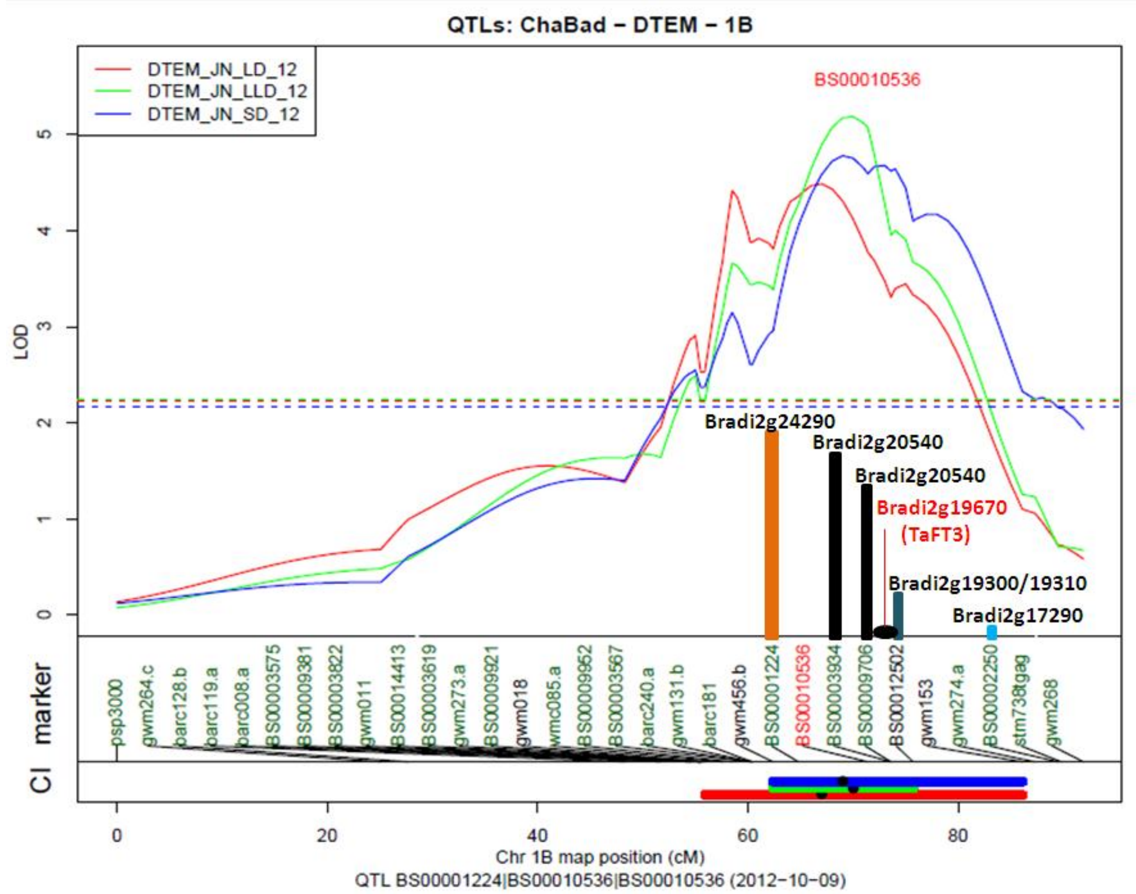


Fig. 6.2 Heading date QTL of Charger X Badger DH population vernalized at 7-10°C for 8 weeks and then grown in short days (SD) 10 hrs light, long days (LD) 16 hrs light and very long days (LLD) 20 hrs light. Unlike Spark X Rialto and Avalon X Cadenza (Fig. 6.1), the QTL was detected in all the tested photoperiod treatments for Charger X Badger (Fig. 6.2).

The distal Avalon X Cadenza QTL (Y) with *Bradi2g16340* flanking marker (Fig. 6.1, B) is interesting given that it was detectable under long days (16 hrs light) and very long days (20 hrs light) but not in short days (10 hrs light), an observation which was consistent with the 1DL QTL (Chapter 5 Fig. 5.1). However, the distal 1BL QTL is below the significance threshold (Fig. 6.1, B).

Charger X Badger is the only population that has the 1BL QTL detectable in the three photoperiod treatments (SD, LD, LLD) (Fig. 6.2) while Spark X Rialto and Avalon X Cadenza have the QTL as short day specific (Fig. 6.1 A, B).

Having detected the 1BL QTLs for Spark X Rialto, Charger X Bader (Fig. 6.1 A) and Avalon X Cadenza (Fig. 6.1 B (X)) DH populations, it was realized that the QTLs were similar and at the same chromosomal locus. The sequences used to design the KASPar markers (Allen *et al*., 2011) obtained from the cereals database were used to homology search the Brachypodium database to determine the gene order represented by the KASPar markers. For example marker Bradi2g24290 lies under the peak of the QTL for Avalon X Cadenza and Charger X Badger populations (Fig. 6.1, B and Fig. 6.2). The co-linearity of the wheat group 1 chromosome with the *Brachypodium distachyon* chromosome 2 and the barley chromosome 1 genes was used to identify a possible candidate for the common 1BL QTL.

For Avalon X Cadenza, it is evident from Fig. 6.1 (B) that some markers are interchanged for example *Bradi2g37480*, *Bradi2g38650*, *Bradi2g25040*, *Bradi2g24290*, *Bradi2g21330* and *Bradi2g28460* occur in that order along the chromosome. The curve of the QTL shows that the markers which are in the right order are *Bradi2g25040*, *Bradi2g24290*, *Bradi2g21330* and the curve is smooth in that region [Fig. 6.1 B (X)].

However, the Spark X Rialto and particularly the Charger X Badger QTL show the conserved gene order between the Brachypodium genes and the wheat genes. Faure *et al*., (2007) reported that the barley homologue of Arabidopsis *Flowering Time 3* (*FT3*), *HvFT3* accelerates flowering in short days in barley (Faure *et al*., 2007). The *HvFT3* sequence was used to identify the Brachypodium orthologue *Bradi2g19670* gene. For both Spark X Rialto and Charger X Badger DH populations, the gene *TaBradi2g19670* (*TaFT3*) coincides with the peak of the QTL (Fig. 6.1, A and Fig. 6.2). The marker order is mixed up for Avalon X Cadenza DH map hence the position of the QTL peak is not clear (Fig. 6.1, B).

The Barley *HvFT3* (DQ411319.1) sequence was used to conduct a homology search of the "Chinese Spring" unassembled 454 reads database using BLASTn. The three wheat homoeologues of the gene were then assembled and the genes were designated *TaFT3*. The *Aegilops tauschii* sequence database was used to assign the D genome. Resequencing *Aegilops tauschii* using non genome specific primers confirmed the D genome sequence from the assembly. The *Triticum urartu* sequence obtained using non genome specific primers was used to determine the A genome and the remaining sequence was assigned to the B genome. When the flow sorted chromosome arm sequence data (http://www.wheatgenome.org/) became publicly available, the database was searched with the *HvFT3* sequence. There was 100% identity for the A, B and D genomes that had been assembled using the "Chinese Spring" unassembled 454 reads and diploid wheat sequences.

Overlapping genome selective primers (favouring the amplification of one of the three genomes at a time) for the three genomes, were designed and used to amplify full length sequences of the three *TaFT3* genes. The primers were used to amplify PCR fragments from wheat varieties from UK, USA, Sweden and Khazakhstan as well as *A. tauschii* and *T. urartu*. The most interesting result was that the *TaFT3* B gene was deleted (Fig. 6.3, and Fig. 6.7) from a number of varieties and this was associated with late flowering in short days (Fig. 6.4 and Fig. 6.6). Although the variety Charger flowers earlier than Badger in both short and long days (Fig. 6.6) it is evident that the deleted Charger *TaFT3-B1* copy delays flowering in the Charger X Badger DH population (Fig. 6.4, A). The early flowering of Charger in short days, despite losing the *TaFT3-B1* copy (Fig. 6.3 and Fig. 6.6), could be due to another gene in the background.

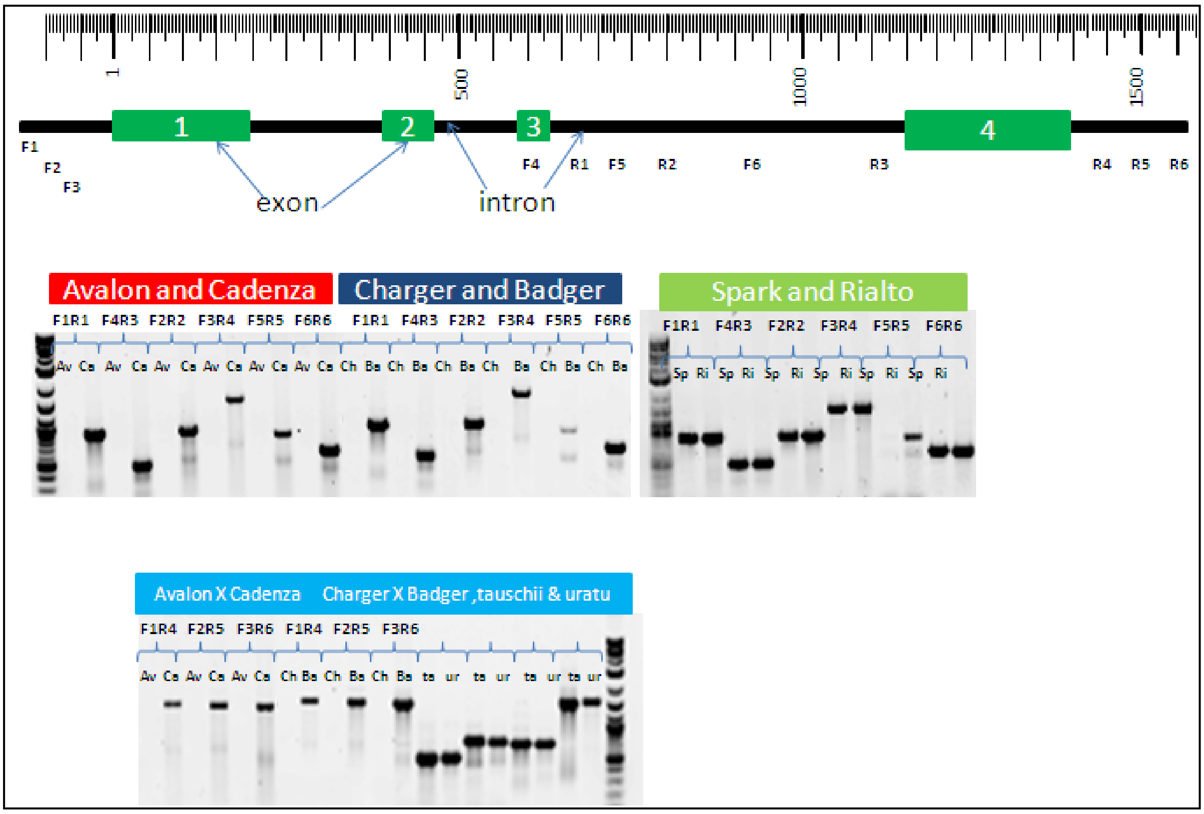


Fig. 6.3 *TaFT3* B gene is deleted in Avalon (Av) and Charger (Ch) but is intact in Cadenza (Ca). Spark (Sp) and Rialto (Ri) both have the full length gene. The absence of a fragment for Rialto F5R5 is just a failed PCR given that F4R3 and F6R6 give fragment sizes which are the same as those for Spark, Avalon, Cadenza Charger and Badger. For *A. tauschii* (ta) and *T. urartu* (ur) (Fig. 6.3), the non genome specific primers (Table 6.1) were used to produce the PCR amplicons for *A. tauschii* (ta) and *T. urartu* (ur).

The primers BF1R1 and F6R6 (Fig. 6.3) were used to amplify PCR fragments for Charger X Badger and Avalon X Cadenza DH populations and showed that there is segregation of the two alleles in both DH populations where the lines that have the gene are relatively early flowering while those that have the gene deleted are late flowering with a few outliers suggesting segregation of other QTLs in the background (Fig. 6.4).

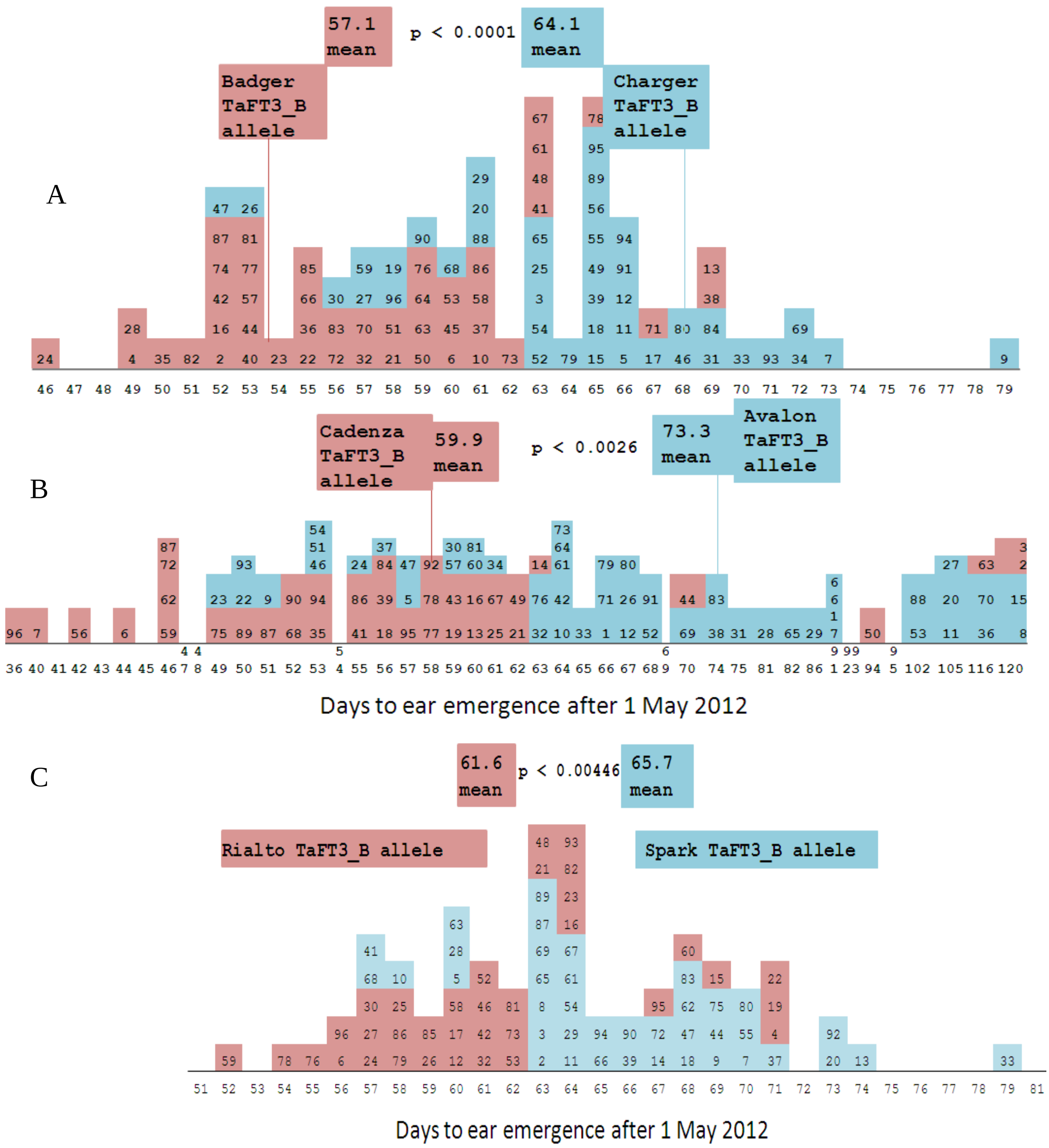


Fig. 6.4 Days to ear emergence of Charger X Badger (A) and Avalon X Cadenza (B) DH populations grown in short days and then scored for the presence (brown highlighted numbers) or absence due to deletion (sky blue highlighted numbers) of the *TaFT3-B1* gene. The Spark X Rialto DH population (C) was scored using the KASPar marker *TaFT3_1B* Kasp1 (Table 6.2). The KASPar marker scores the single nucleotide polymorphism that changes a conserved glycine (Rialto wild type) to serine (Spark, mutant) shown on Fig. 6.5).

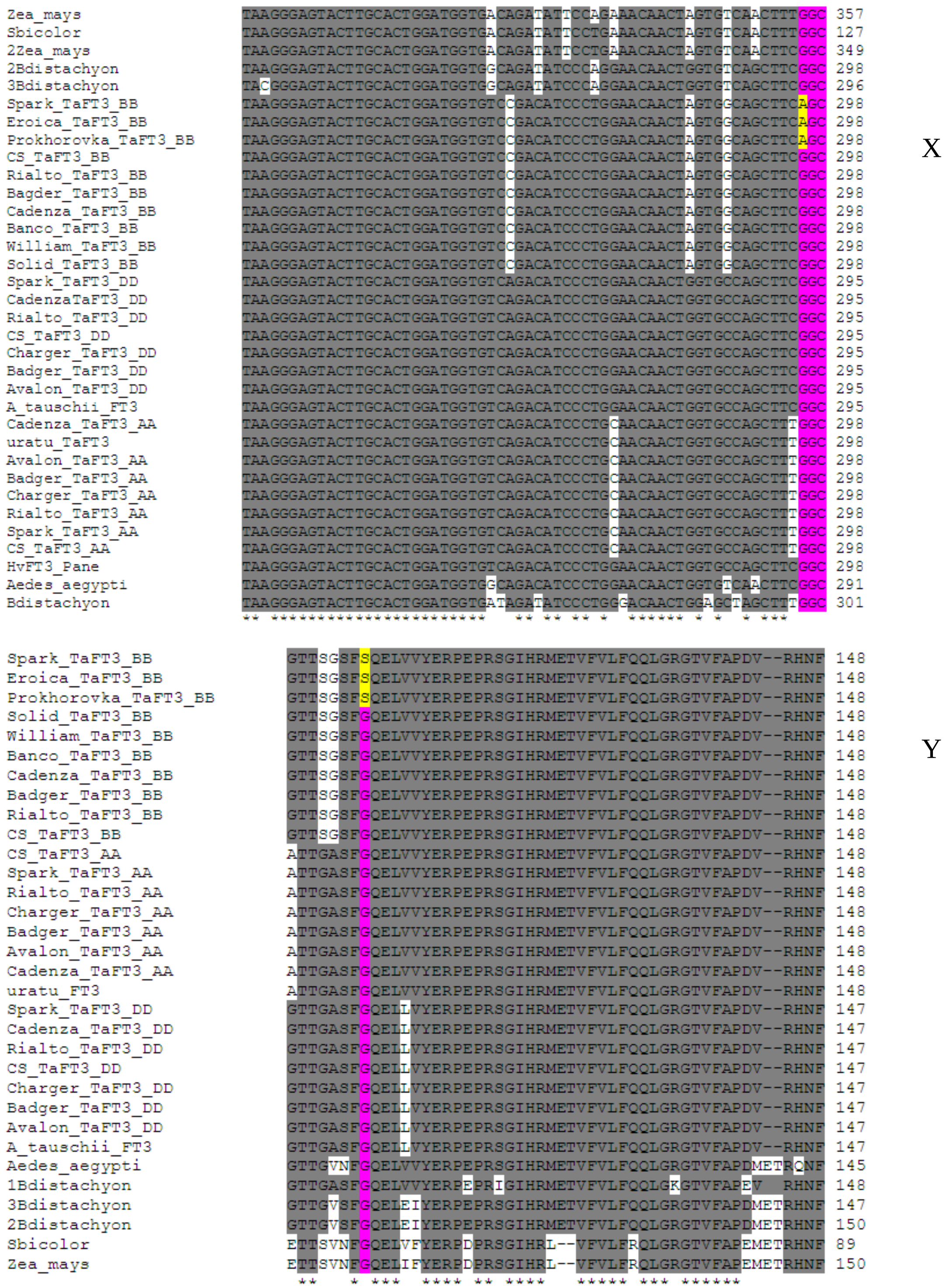


Fig. 6.5 The point mutation G/A (X) changes a highly conserved amino acid glycine (G) to serine (S) (Y) in Spark, Eroica and Prokhorovka in the *TaFT3-B1* gene. The mutation occurs at the exon3/intron3 junction (appendix 6.3 and 6.4). The mRNA sequences were used for alignment. The glycine amino acid is conserved across all the three homologues and different species including *Zea mays Sorghum bicolor, Brachypodium distachyon, Aedis aegypti.*

The mutation on the conserved glycine (fig. 6.5) which is in the phosphatidylethanolamine-binding protein (PEPB) domain was also shown to be conserved in all the five *Hordeum valgare FT* genes (*HvFT1, HvFT2, HvFT3, HvFT4,* and *HvFT5*), fourteen *Oryza sativa FT* genes and the *Arabidopsis thaliana FT gene* (Faure *et al*., 2007). The glycine is not only conserved at amino acid level but the bases GGC are also conserved (Fig. 6.5).

Twenty Swedish varieties have the *TaFT3-B1* gene deleted as demonstrated by failure to amplify using primers BF1R1 and BF6R6, but William, Banco and Solid produce an amplicon using these primers (Fig. 6.7). Interestingly Prokhorovka (Kazakhstan) and Eroica (Sweden) share the Spark (UK) single nucleotide polymorphism that changes a conserved amino acid which is likely to affect function for *TaFT3-B1* (Fig. 6.5). The Khazakhstan varieties lack the *TaFT3-B1* gene (Fig. 6.7). The *TaFT3-A1*, *TaFT3-B1*, and *TaFT3*_D sequences for UK, Sweden, Khazakhstan varieties are shown in Appendix 6.4.

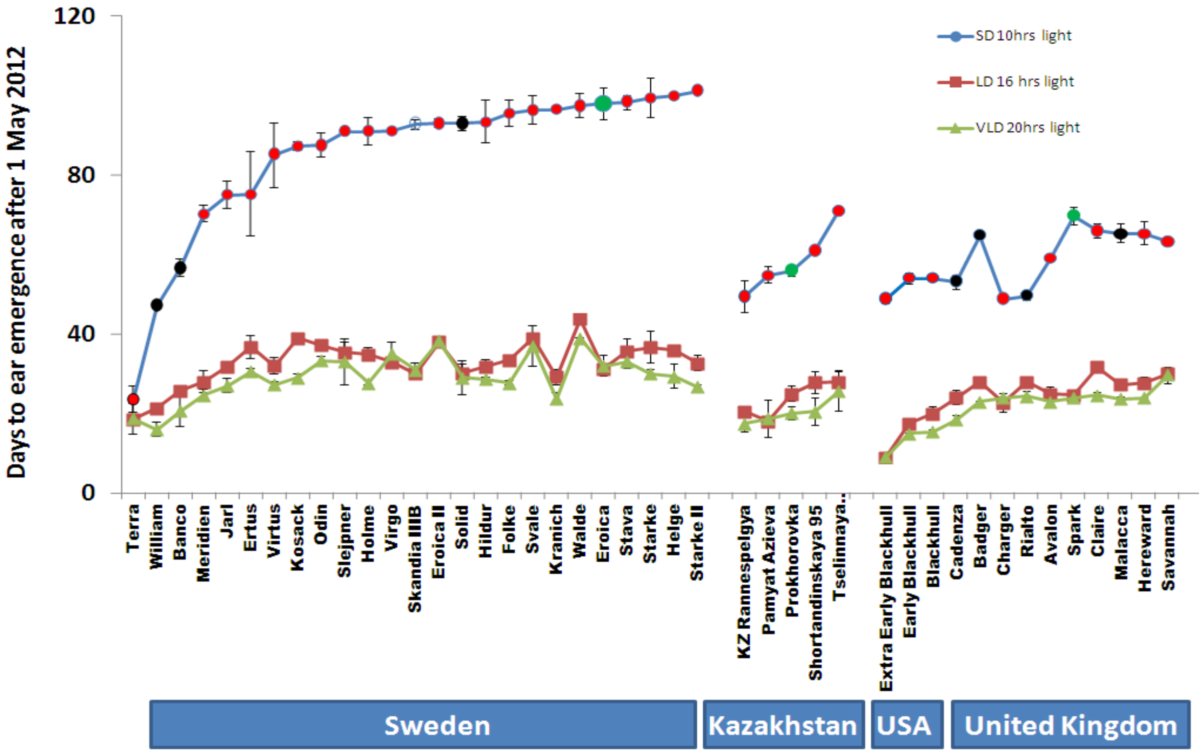


Fig. 6.6 Days to ear emergence of forty-three wheat varieties from Kazakhstan, Sweden, USA and United Kingdom vernalized at 5°C for 8 weeks and then grown in short days (10 hrs light), long days (16 hrs light) and very long days (20hrs light). Red circles indicate that *TaFT3-B1* is deleted, while the black circles show that *TaFT3-B1* is intact (Fig. 6.6). The green circles (Fig. 6.6) indicate lines with the same *TaFT3-B1* mutation that is likely to affect function. Terra is photoperiod insensitive given that its heading date is almost the same in the three photoperiod regimes (Fig. 6.6). Rialto which does not have mutations at all the *TaFT3* homologues flowers about 15 days earlier than Spark, Claire, Hereward and Savannah which all have *TaFT3-B1* mutations. At the same time, These UK *TaFT3-B1* mutants flower more than 30 days earlier than the average of the Swedish late flowering lines (Fig. 6.6). The Swedish varieties William and Banco which both have the *TaFT3-B1* gene flower at about the same time with the UK varieties that have the *TaFT3-B1* gene (Fig. 6.6) while Solid a Swedish variety is very late flowering despite having the *TaFT3-B1* gene. The lateness of Solid requires further analysis for example sequencing more of the 5'UTR of *TaFT3-B1* and the *Ppd-1* gene to determine if any of the A, B and D genome copies could account for the lateness. Skandia IIIB was not genotyped hence the colourless circle (Fig. 6.6).

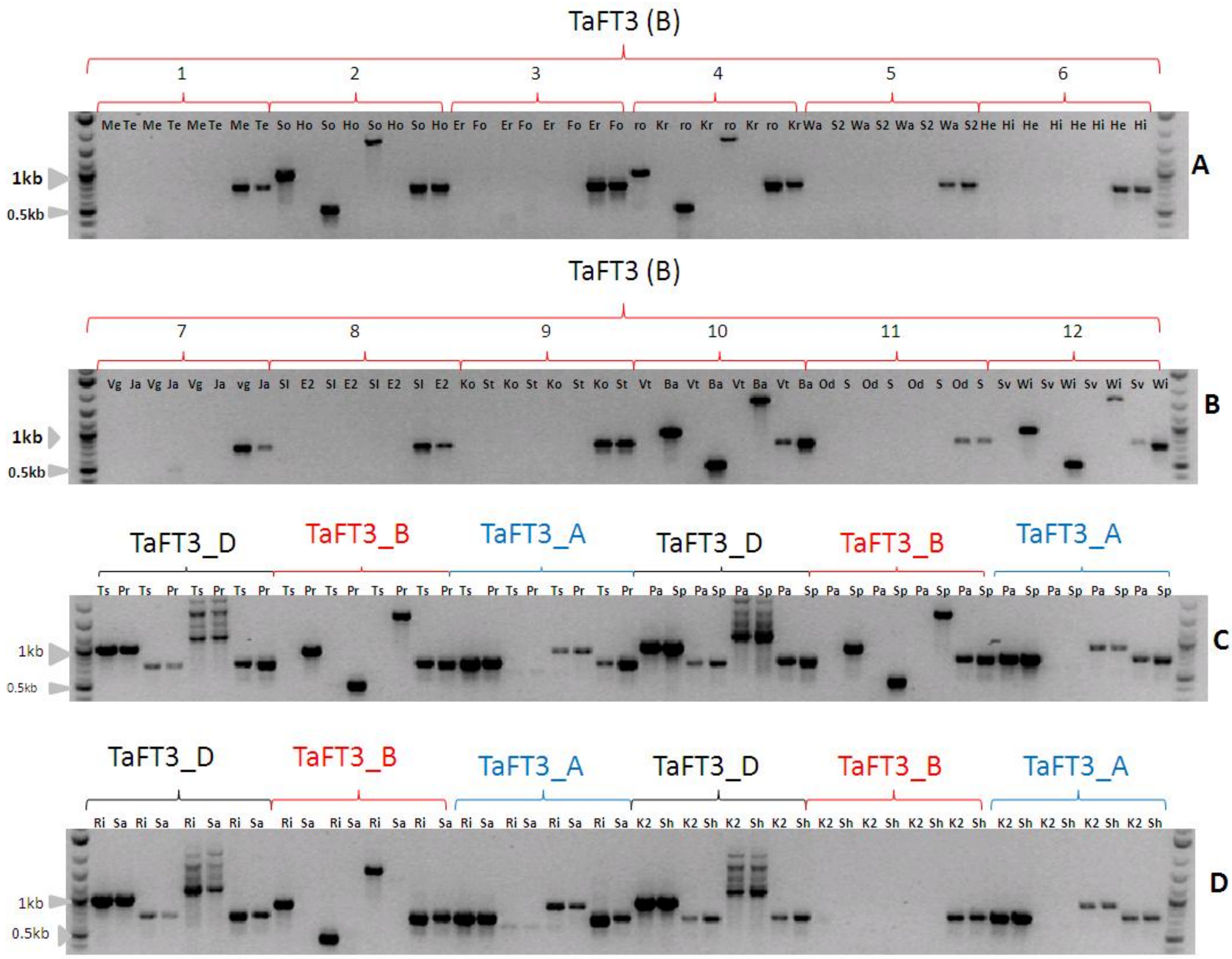


Fig. 6.7 Deletion of the *TaFT3-B1* gene from some Swedish (A and B) wheat varieties Meridian (Me), Terra (Te), Holme (Ho), Eroica II (Er), Folke (Fo), Kranich (Kr), Walde (Wa), Starke II (S2), Helge (He), Hildur (Hi), Virgo (Vg), Jarl (Ja), Sleijpner (Sl), Eroica II (E2), Kosack (Ko), Stava (St), Virtus (Vt), Odin (Od), Starke (S) and Svale (Sv). The *TaFT3-B* gene is not deleted from Solid (So), Eroica (ro), Banco (Ba) and William (Wi) but Eroica has a mutation similar to Spark which causes a change from glycine to serine in a very conserved region (Fig. 6.5). Spark (Sp), Rialto (Ri) and Savannah (Sa) were used as controls for the intact gene (Spark and Rialto) and the deletion (Savannah). The *TaFT3-B* gene is also deleted from Kazakhstan (C and D) wheat varieties Tsuleinaya Yubeleinaya (Ts), Pamyat Azieva (Pa), K2 Rannespelgya (K2) and Shortandinskaya 95 (Sh). Prokhorovka (Pr) does not have the *TaFT3-B* deletion but it has the same mutation as Spark which causes a change from Glycine to serine (Fig. 6.5).

The primers AF1R1, AF4R2, AF5R5, BF1R1, BF4R3, BF3R6, DF2R2, DF5R5, BF1R6 (Table 6.1) were used to amplify the A, B and D genome copies of the *TaFT3* gene with the fourth primer pair being none genome specific primer F3R3 (Fig. 6.7). The numbers 1-12 (Fig. 6.7, A and B) show two varieties each that were sequenced for example 1 shows Meridian (Me) and Terra (Te) that were sequenced for the *TaFT3-B1* using primers from left to right BF1R1, BF4R3, BF3R6 and the non-genome specific F3R3. Only the non-genome specific primer amplified from Meridian and Terra suggesting that the failure to amplify with the *TaFT3-B1* specific primers was due to absence of the *TaFT3-B1* copy from these two Swedish varieties (Fig. 6.7, A1). The same pattern observed for Meridian and Terra was observed for all the varieties which lack the *TaFT3-B1* gene (Fig. 6.7).

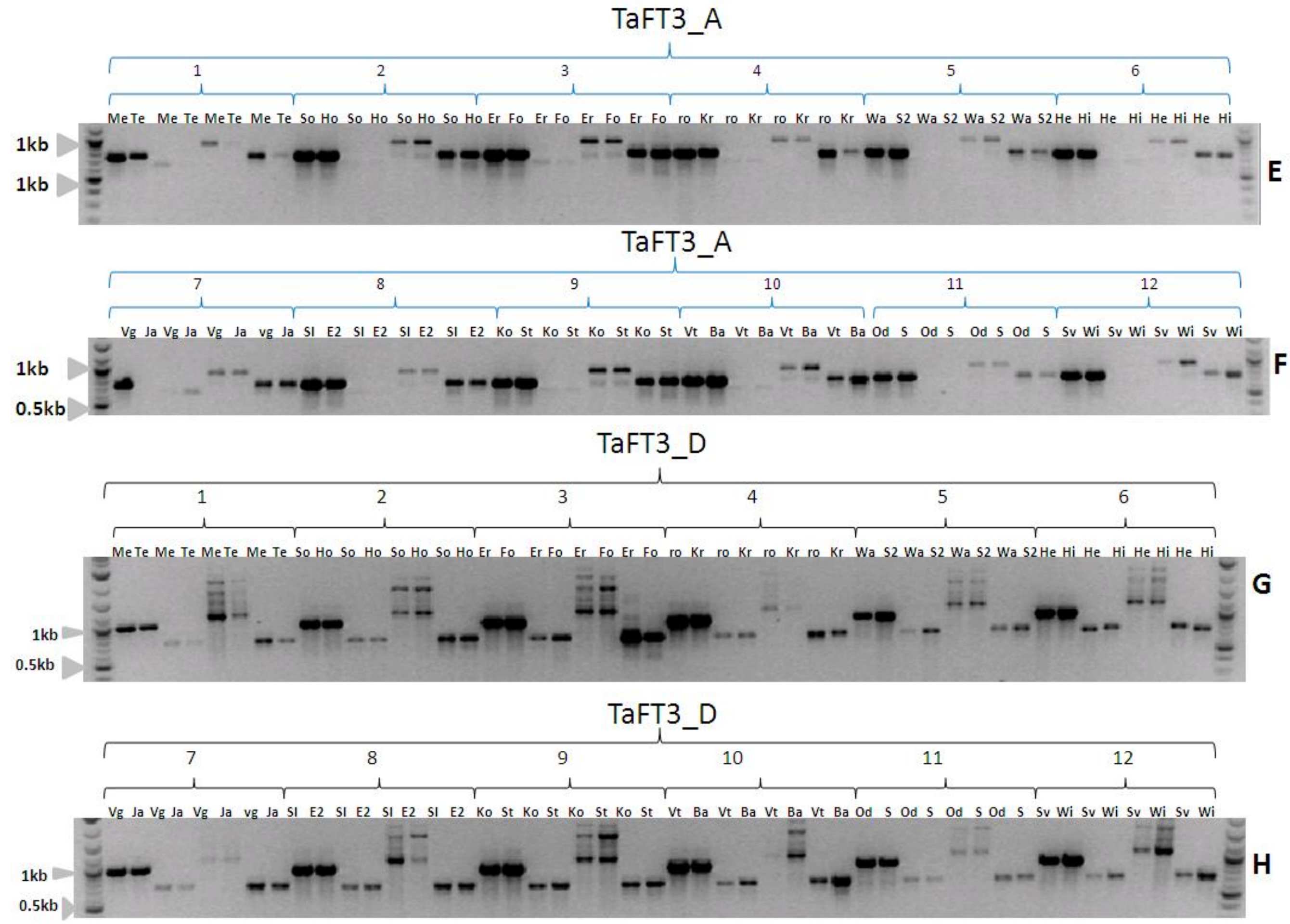


Fig. 6.8 Agarose gel electrophoresis separated PCR fragments from the A (E, F) and D (G, H) genomes of the *TaFT3* gene. Numbers 1-12 were used for the same purpose as described in Fig. 6.7.

The A and D genome copies are not deleted from the Swedish and Kazakhstan varieties (Fig. 6.7 and Fig. 6.8) a pattern which is similar to that observed for the UK varieties (Fig. 6.3). For the A copy, Fig. 6.8 (F, G) suggest that the primer AF4R2 does not amplify for all the varieties. This is likely due to a specific PCR problem given that the primer does not amplify for Spark and Rialto as well but the same primer had amplified for the two varieties in an earlier experiment (data not shown). Based on the PCR fragment sizes, the A and D copies of the *TaFT3* gene seem to be present for the Swedish and Kazakhstan varieties and the functionality of these copies will need to be verified with sequencing.

```
                          start!          ! Conserved Alanine (A)
Spark_TaFT3-A1                     MSAADPLVVAHVLQDVLDPF 20
CS_TaFT3-A1                        MSAADPLVVAHVLQDVLDPF 20
Rialto_TaFT3-A1                    MSAADPLVVAHVLQDVLDPF 20
Charger_TaFT3-A1                   MSAADPLVVAHVLQDVLDPF 20
Badger_TaFT3-A1                    MSAADPLVVAHVLQDVLDPF 20
Avalon_TaFT3-A1                    MSAADPLVVAHVLQDVLDPF 20
urartu_TuFT3                       MSAADPLVVAHVLQDVLDPF 20
Cadenza_TaFT3-A1                   MSAADPLVVAHVLQDVLDPF 20
Solid_TaFT3-B1                     MSAADPLVVAHVLQDVLDPF 20
William_TaFT3-B1                   MSAADPLVVAHVLQDVLDPF 20
Banco_TaFT3-B1                     MSAADPLVVAHVLQDVLDPF 20
Cadenza_TaFT3-B1                   MSAADPLVVAHVLQDVLDPF 20
Bagder_TaFT3-B1                    MSAADPLVVAHVLQDVLDPF 20
Rialto_TaFT3-B1                    MSAADPLVVAHVLQDVLDPF 20
CS_TaFT3-B1                        MSAADPLVVAHVLQDVLDPF 20
Prohorovka_TaFT3-B                 MSAADPLVVAHVLQDVLDPF 20
Eroica_TaFT3-B1                    MSAADPLVVAHVLQDVLDPF 20
Spark_TaFT3-B1                     MSAADPLVVAHVLQDVLDPF 20
Spark_TaFT3_D                      MSAADPLVV-HVIQDVLDPF 19
CadenzaTaFT3_D                     MSAADPLVV-HVIQDVLDPF 19
Rialto_TaFT3_D                     MSAADPLVV-HVIQDVLDPF 19
CS_TaFT3_D                         MSAADPLVV-HVIQDVLDPF 19
Charger_TaFT3_D                    MSAADPLVV-HVIQDVLDPF 19
Badger_TaFT3_D                     MSAADPLVV-HVIQDVLDPF 19
Avalon_TaFT3_D                     MSAADPLVV-HVIQDVLDPF 19
A_tauschii                         MSAADPLVV-HVIQDVLDPF 19
HvFT3_Pane                         MSAADPLVVAHVMQDVLDPF 20
2Bdistachyon                       MSAVDPLVVAHVIQDVLDPF 20
3Bdistachyon                       MSAVDPLVVAHVIQDVLDPF 20
1Zea mays                          MSATDHLVMARVIQDVLDPF 20
2Zea mays                          MSATDHLVMARVIQDVLDPF 20
3Zea mays                          MSATDPLVMARVLQDVLDTF 20
Aedes_aegypti                        AADPMVVAHVI        20
```

Fig. 6.9 Deletion (-) of the conserved amino acid alanine (A) in the D genome copy of the *TaFT3* gene that is likely to affect function.

The D copy of *TaFT3* (*TaFT3-D1*) lacks a conserved amion acid alanine (Fig. 6.9). This amino acid is also absent from *Aegilops tauschii* the putative donor of the D genome of wheat suggesting that the mutation is ancient. Given that this mutation occurs in a conserved amino acid, it is possible that the *TaFT3-D1* copy may have reduced function but additional experiments are required to prove this. The *TaFT3* gene sequences generated by this thesis were annotated and deposited onto the GenBank database and the accession numbers are listed in appendix 6.5

Sixty-eight promoter polymorphisms, identical for the A and D genomes, but unique for the B genome, were detected in the region from -1380 bases to -6 bases upstream of the *TaFT3-B1* start codon (appendix 6.3). The polymorphisms included 59 single nucleotide polymorphisms, 1 single base pair deletion, 3 double base deletions, 1 triple base deletion, 1 six base deletion, 1 eight base deletion, and 1 nineteen base deletion were detected and are shown and numbered 1-68 in appendix 6.3. The single nucleotide polymorphism which is -26 bases from the start codon labelled number 67 (appendix 6.3) changes the TATAWA (W can be A or T) box variant TATTAA to TGTTAA may affect expression since it occurs at the TATA box expected area (Bernard *et al*., 2010). The *TaFT3-B1* copy has TATTAA while both the A and D genomes copies of *TaFT3* have the TGTTAA (appendix 6.3).

Table 6.1 The primers used to amplify the *TaFT3* gene copies from the A, B and D genomes.

marker/gene name	Primer sequence 5'-3'	Tm$^{\alpha}$	% GC$^{\beta}$	SecStr$^{\gamma}$	Dimer$^{\delta}$
TaFT3-A1_F1	ACAATACAAGTAGTTCGTGCAAGTAGG	64.11	40.74	vweak	no
TaFT3-A1_F2	GCTAGGCACAATAACAGACAAAGG	64.58	45.83	no	no
TaFT3-A1_F3	GACAAAGGCTAAGGCTGTTAAC	60.67	45.45	vweak	no
TaFT3-A1_F4	TCCTATTTAAGTTGCCCTGATTAC	61.03	37.5	no	no
TaFT3-A1_F5	CAAATGACTCCATACAAGTTAATTCT	60.19	30.77	vweak	no
TaFT3-A1_R1	AAAGCTGGCACCAGTTGTTG	65.11	50	weak	no
TaFT3-A1_R2	CCCTAATATTAATTAGTTTAGAGTTTCAAA	59.38	23.33	weak	no
TaFT3-A1_R3	ATTATTTGTGATGCAACACTACG	60.33	34.78	weak	no
TaFT3-A1_R4	AGATGATACAGGGTATTCTATATGCTA	59	33.33	weak	no
TaFT3-A1_R5	TTCCCACAAGAATACTCTCCG	62.86	47.62	vweak	no
TaFT3-B1_F1	GTTACGTGTATACAGGTGACACAG	59.92	45.83	mod	no
TaFT3-B1_F2	GACACAGTTTGTTTCAGGTCTC	60.21	45.45	weak	no
TaFT3-B1_F3	GCAGACAAGGACAAAGGCTA	61.94	50	no	no
TaFT3-B1_F4	CGACATCCCTGGAACAACTAGTGG	69.4	54.17	no	no
TaFT3-B1_F5	AAGCTAATTCCAATATAGTCCATCA	60.57	32	vweak	no
TaFT3-B1_F6	GAAGAGTTTTATGGTACACTCCCTAT	60.51	38.46	mod	no
TaFT3-B1_R1	ATGACCTGATTTATGCATCTG	58.99	38.1	vweak	no
TaFT3-B1_R2	CAAATGTCATTTTACCCTGTTTAGAT	61.88	30.77	no	no
TaFT3-B1_R3	TTAGTCATTTATCTGCGATGTG	59.23	36.36	vweak	no
TaFT3-B1_R4	TTCTATATACTGCACATTATTTGTGGTA	60.42	28.57	mod	no
TaFT3-B1_R5	GATTGAGATATATTCCATCAAGCTT	60.21	32	weak	no
TaFT3-B1_R6	CAGGTGATTAACTAATGATTGAGATATATT	60.56	26.67	no	no
TaFT3_D_F1	GAGTATACAGGTGACGCACG	60.78	55	weak	no
TaFT3_D_F2	GTAGTTCGTGCAAGTAGTTCCTG	61.62	47.83	no	no
TaFT3_D_F3	AGTTCCTGCATAGACACAACTG	60.78	45.45	weak	no
TaFT3_D_F4	CATGAAACTTTAGATGTATGTTCCATAC	61.46	32.14	weak	no
TaFT3_D_F5	TCGTTAACACCAAGACATCTTG	61.51	40.91	mod	no
TaFT3_D_F6	AGTATGTTTTGCAAATGAAATGG	61.45	30.43	no	no
TaFT3_D_R1	TGTTATTCTTTGTCATGGTTCAAGATG	65.57	33.33	weak	no
TaFT3_DD_R2	ACAGTGGCCTTGTCTTAATGTT	61.34	40.91	vweak	no
TaFT3_DD_R3	TGGTTCTGGCCTTTCATAAACTAA	64.31	37.5	vweak	no
TaFT3_DD_R4	ATGGTCAGTACTCTGTACTATCTAGTCC	59.95	42.86	mod	no
TaFT3_DD_R5	AGTACCGCATACAATGGTCAG	61.38	47.62	weak	no
TaFT3_DD_R6	CATATAATGCTGCATATTTAGGTGAC	61.25	34.62	vweak	no
TaHvFT3_ngs_F1	AATAAGACAACCCTCATCGC	60.5	45	no	no
TaHvFT3_ngs_R1	CTCCCTTAGTGATGGGTGAC	60.95	55	mod	no
TaHvFT3_ngs_F2	CCCTGGTAAGCTTCTAACTCTAGT	59.88	45.83	vweak	no
TaHvFT3_ngs_R2	CAAAACCAGTATAAGATTGAATGATATT	60.26	25	no	no
TaHvFT3_ngs_F3	CATGTTAAGTTCTTTCCCTCAAA	60.86	34.78	no	no
TaHvFT3_ngs_R3	CTACTCCCCTTGAGAACTTTCTG	62	47.83	weak	no

$^{\alpha}$ = melting temperature, $^{\beta}$= guanine: cytosine content, $^{\gamma}$ = secondary structure, δ= primer dimer, *= non genome specific primer, $^{\psi}$= very weak (secondary stricture), $^{\mu}$ = D genome specific primer. F and R = forward and reverse primers

Table 6.2 KASPar primers designed for *TaFT3* A, B and D gene copies.

marker/gene name	Primer sequence 5'-3'	Tm$^{\alpha}$	%GC $^{\beta}$	SecStr$^{\gamma}$	Dimer$^{\delta}$
TaFT3 1A Kasp1_F	gaaggtgaccaagttcatgctGCTAATTCGATTC CAAACC**A**	61.37	40	no	no
TaFT3 1A Kasp1_V	gaaggtcggagtcaacggattGCTAATTCGATTC CAAACC**C**	62.08	45	no	no
TaFT3 1A Kasp1_C	GAGATATATCGTAATCAGGGCAAC	61.38	41.67	vweak	no
TaFT3 1B Kasp1_F	gaaggtgaccaagttcatgctAACAACTAGTGGC AGCTTC**A**	60.07	45	no	no
TaFT3 1B Kasp1_V	gaaggtcggagtcaacggattACAACTAGTGGC AGCTTC**G**	60.64	52.63	no	no
TaFT3 1B Kasp1_C	CATGACCTGATTTATGCATCTG	61.85	40.91	$^{\psi}$ vweak	no
TaFT3 1D Kasp1_F	gaaggtgaccaagttcatgctAGGCGGAAGAAG GTTTAG**A**	60.35	47.37	no	no
TaFT3 1D Kasp1_V	gaaggtcggagtcaacggattGGCGGAAGAAGG TTTAG**G**	61.14	55.56	no	no
TaFT3 1D Kasp1_C	ATGGTCAGTACTCTGTACTATCTAGT CC	59.95	42.86	vweak	no

$^{\alpha}$ = melting temperature, $^{\beta}$= guanine: cytosine content, $^{\gamma}$ = secondary structure, δ= primer dimer, $^{\psi}$= very weak (secondary stricture), F = fam and V = vic fluorescent tails, *TaFT3-A1* = A genome copy, *TaFT3-1B* = B genome copy, *TaFT3-D1* = D genome copy, C = common primer. The red and green highlight (Table 6.2) denotes the fam and vic fluorescent tails.

The KASPar marker for *TaFT3-A1* (Table 6.2**)** is a single nucleotide polymorphism in intron 2 (appendix 6.4) and the varieties Spark and Charger have the DNA base **A** (mutant**)** and are distinguishable from wild type *T. urartu*, Rialto, Avalon, Cadenza, Badger and "Chinese Spring" which have the DNA base **C**. The KASPar marker *TaFT3-B1* (Table 6.2) is a single nucleotide polymorphism at the last base of exon3 (appendix 6.3 and 6.4) and the varieties Spark, Eroica and Prokhorovka have the DNA base **A** (mutant) and are distinguishable from the wild type which have the DNA base (**G**). The KASPar marker *TaFT3-D1* (Table 6.2) is a single nucleotide polymorphism in exon4 (appendix 6.3 and 6.4) but it is a silent mutation and the varieties Spark, Claire and Paragon have the mutant DNA base **A** and are distinguishable from the wild type which have the DNA base (**G**). The marker *TaFT3-D1* was used to eliminate *TaFT3-D1* as a possible for the 1DL *Eps* effect (Zikhali *et al*., 2014). The *TaFT3-B1* KASPar marker was used to screen wheat varieties with the glycine to serine amino acid mutation as well as to score the Spark X Rialto DH population. The *TaFT3-A1* KASPar marker was not used in this study but will be useful when updating the genetic map of the Spark X Rialto DH population.

6.5 **The 5A short day QTL**

The Spark X Rialto DH population also revealed a short day QTL that is linked to the *XBarc151* marker on chromosome 5A when the plants were vernalized for 4 weeks (Fig. 6.10). The QTL explained 33.68% of this differerence in flowering time. The *XBarc 151* marker is known to be linked with flowering time genes like *Vrn-A1* and *PHYC* (Xue *et al*., 2008; Distelfeld and Dubcovsky 2010).

Work done recently showed that under long days, copy number variation at *Vrn-A1* and *Ppd-B1* is associated with altered flowering time in wheat (Diaz *et al*., 2012). A single nucleotide polymorphism (SNP) in exon 7 of the *Vrn-A1* gene (Diaz *et al*., 2012) clearly distinguished Spark from Rialto and this marker was used to score the Spark X Rialto DH lines segregating for the 5A QTL. The *PHYC* was also assembled from the Chinese Spring 454 sequence two of the three homoeologues matched the two sequences produced by Devos *et al.,* (2005) showing that the method of assembly used in this thesis is reliable. Spark, Rialto, Badger, Charger, Cadenza, Avalon, Savannah, Malacca and Hereward were resequenced using genome specific primers that amplified from the A genome. KASPar markers were designed and used to score the Spark X Rialto DH population segregating for the 5A QTL in addition to the *Vrn-A1* marker.

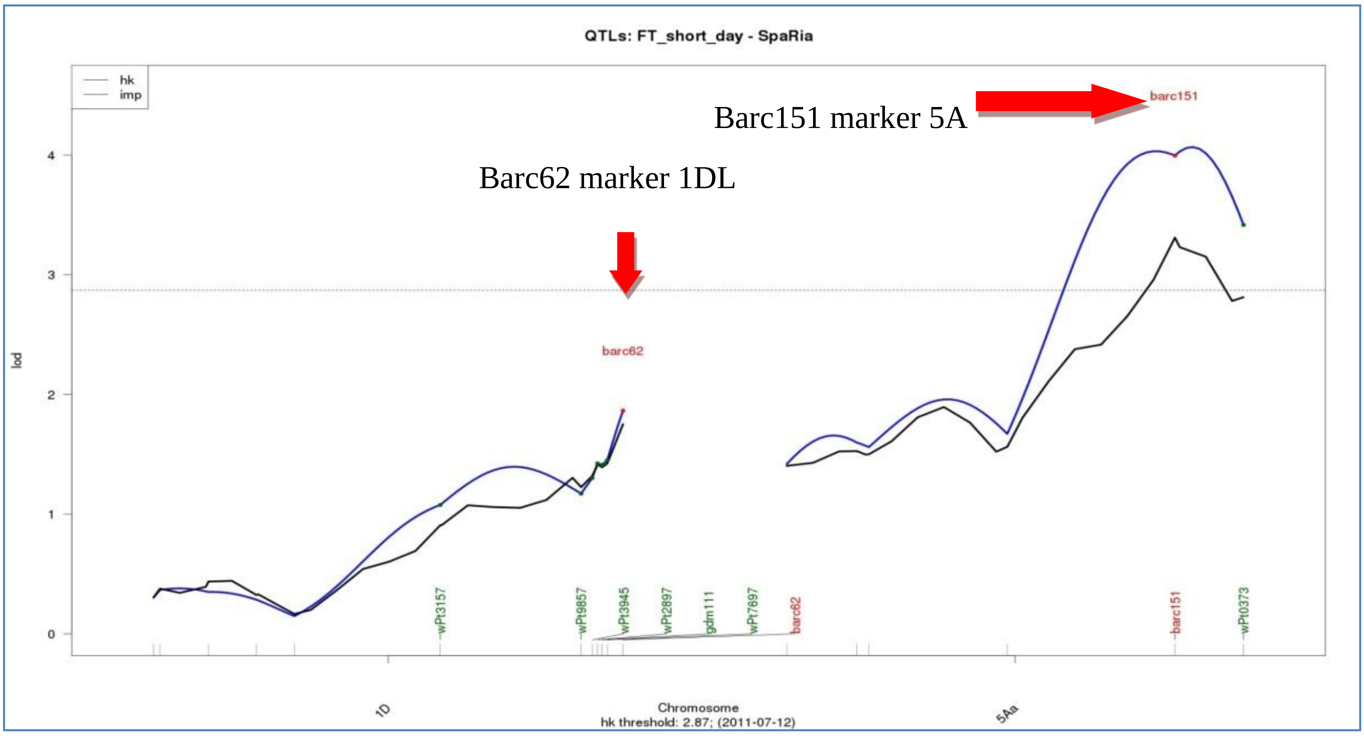


Fig. 6.10 QTL plot using the programme R of mean days to ear emergence in Spark X Rialto DH lines grown under short days.

There was no clear association between the phenotype of the DH lines and the genotype scores for all the three markers (Fig.6.11). Less than 96 lines were scored as some lines died and hence the population might have been too small to reveal a clear segregation of the lines. Given that there was a clear association between *Vrn-A1* copy number and flowering time when Malacca and Hereward were grown under long days (Diaz *et al*., 2012), the results may suggest that *Vrn-A1* may not be a suitable candidate for the 5A short day QTL (Fig. 6.10 and Fig. 6.11 B).

The use of NILs may be more suitable to determine the possible candidate given that the Spark X Rialto DH population also segregates for the 1DL *Eps* QTL and the 1BL QTL (both shown in this study) which may be introducing background noise.

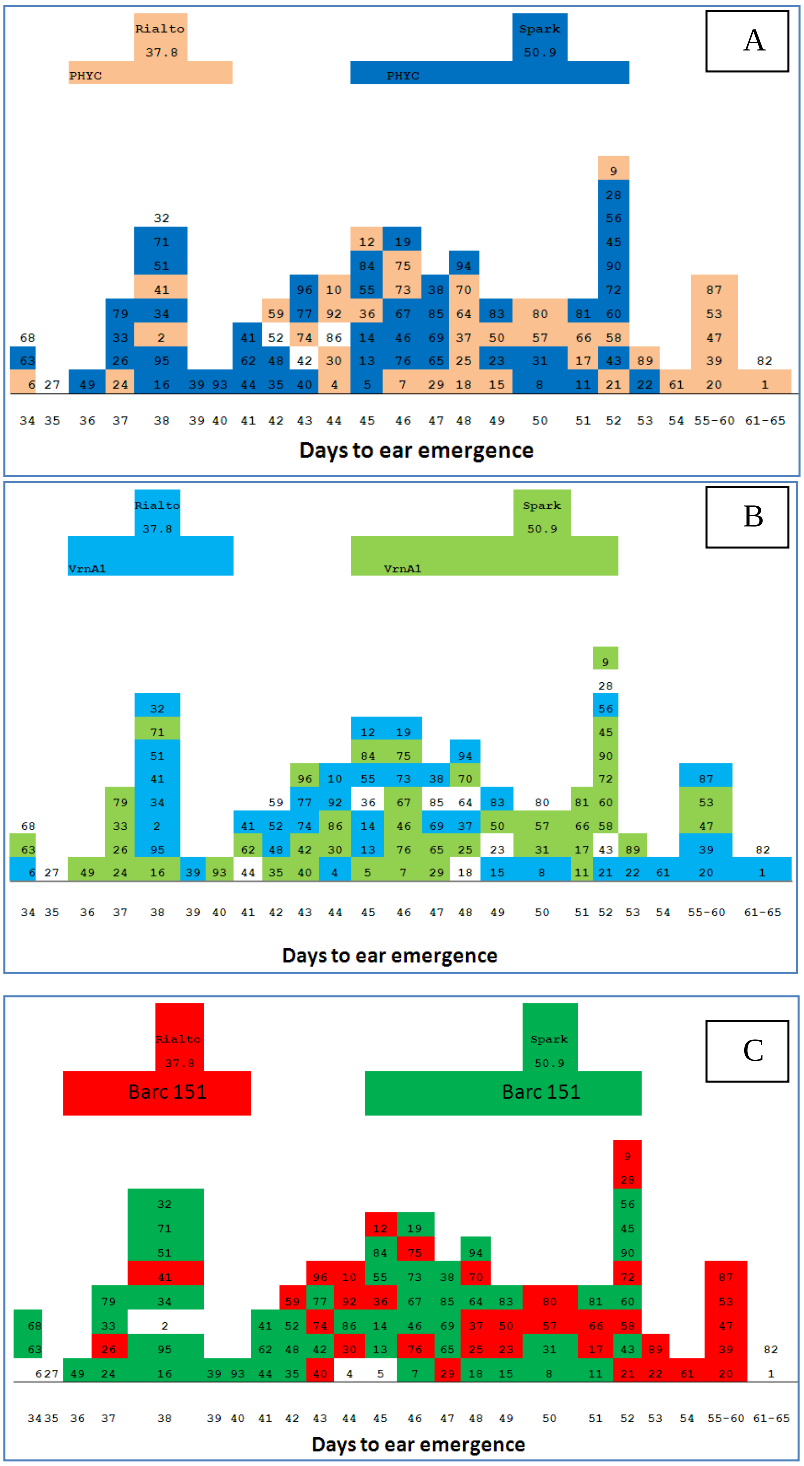


Fig. 6.11 Scoring of the Spark X Rialto DH lines grown under short days with markers *PHYC* (A), *Vrn-A1* (B) and *Xbarc 151* (C) on chromosome 5A. The mean heading dates for parental lines Spark and Rialto are also incuded. The colour indicate the genotype of each DH for each marker

6.6 **Chapter 6 Discussion**

The results suggest that *TaFT3* might contribute towards early flowering in short days (Fig. 6.1, Fig. 6.2, and Fig. 6.6) in wheat given that the 1BL QTL is short day specific for Spark X Rialto and Avalon X Cadenza DH populations. The results are consistent with studies done in barley, a plant with photoperiod pathways which are very similar to wheat, which showed that *HvFT3* is expressed in short days (Laurie *et al*., 1995; Faure *et al*., 2007). In this study, varieties with loss of function mutation at *TaFT3-B1* are late flowering relative to those with the intact gene (Fig. 6.6). In the Igri X Triumph and Septoe X Morex populations, there is a strong short day QTL and late flowering is associated with the Igri or Septoe alleles which are a partial deletion of *HvFT3* (Kikuchi *et al*., 2009; Faure *et al*., 2007).

The association of late flowering with the partial deletion of the Igri *HvFT3* parallels the results from the current study in wheat where deletions of *TaFT3-B* result in late flowering (Fig. 6.3, Fig. 6.4, Fig. 6.6 - Fig. 6.8) suggesting that the gene has the same function in both species. Another study showed that over-expression of *HvFT3* results in early flowering (Kikuchi *et al*., 2009). Taken together, the results from studies in barley and this study suggest that *FT3* like other FT family genes acts by promoting flowering.

Another very interesting result is that Spark X Rialto and Avalon X Cadenza DH populations have the short day specific 1BL QTL while the QTL at the same locus for Charger X Badger is observed in short days as well as long days (Fig. 6.1 and 6.2). One possibility is that Badger may have a promoter mutation that causes the Badger *TaFT3-B1* gene to be mis-regulated resulting in expression even in long days. This possibility was checked by sequencing 1380 *TaFT3-B1* gene bases upstream of the start codon and there was not a single polymorphism between the Badger gene and other varieties in this region (appendix 6.3). While the results show no polymorphism in the promoter region likely to cause mis-regulation of the *TaFT3-B1* gene, the possibility of a promoter mutation cannot be ruled out as this maybe further upstream than the 1380 bases sequenced in this study.

Another possibility is that there is a mutation in a gene(s) that regulate *TaFT3* in long days for either Charger or Badger. A recent study in barley showed that *VRNH2* is a repressor of *HvFT3* under long days (Casao *et al*., 2011a). It is also interesting to note that while the Spark X Rialto and Avalon X Cadenza DH populations have the 1DL *Eps* QTL Charger X

Badger does not have the 1DL *Eps* QTL although Badger has the 1DL deletion and Charger has an intact 1DL *Eps* region (Chapter 3).

In the southern part of Sweden, the growing season is from beginning of October to end of July or latest 1st week of August while for mid Sweden it is from September 15 to beginning of August. Growing season in the north of Kazakhstan (the major wheat growing region) is from mid-May to the end of August. The loss of *TaFT3* genes in wheat grown in Kazakhstan is unlikely to be a significant problem given that Kazakhastan varieties are spring wheat and the growing season coincides with long days.

However, *TaFT3* loss of function mutations may adapt Swedish varieties to the long winter season by ensuring delayed flowering until the onset of long days. Given the 20 weeks of winter in Sweden from November to March, The vernalization requirement is satisfied within 8 weeks (by December) in Sweden but the loss of function at the *TaFT3-B* may ensure delayed flowering until the onset of long days after winter which ensures avoidance of frost damage.

It would be very interesting to determine when *TaFT3* exerts its effect during the growth of wheat. For barley, it was shown that *HvFT3* expression is detected in the first week and increases between week 3 and week four in short days and between week 2 and week 3 in long days (Faure *et al*., 2007) which coincides with the vegetative to floral switch. Similarly, Kikuchi *et al*., (2009) reported that in cultivar Morex, *HvFT3* is expressed under short and long days in the first week although expression under short days was much higher. Casao *et al*., (2011a) also detected *HvFT3* in the first week of growth under short days but also under long days when *VRN2* was absent. It will also be interesting to determine if *TaFT3* responds to vernalization particularly its interaction with *TaVRN2*.

It is also noted that the *TaFT3-B1* mutation is a deletion for Avalon, Charger and the Swedish and Kazakhstan varieties and the Blackhulls and this may well extend to other neighbouring genes. Sequencing the *TaFT3* gene neighbours will show the extent of the deletion. None the less, given that the mutation which gives a similar phenotype in Spark is not a deletion, but a single nucleotide polymorphism which changes a conserved amino acid, there is reason to propose *TaFT3* as the candidate gene responsible for 1BL QTL in short days in wheat. The development of 1BL NILs and 1BL recombinants of a cross between Spark and Rialto can be used to check this.

The proposed mutation that causes the heading date QTL described here is a recessive mutation. One would expect the A and D copies to compensate for the loss of function or reduced function caused by mutations at the B genome copy. However, it is evident from the results that the loss of function mutations caused by the deletion of the *TaFT3-B1* copy result in significant heading date effects for the varieties used in this study (Fig. 6.6). One explanation could be that the three copies contribute equally in a dose dependent manner such that the loss of function mutation at one of the homologues results in significant heading date changes. A recent report in barley showed that increasing the copy number of *HvFT1* a relative of *FT3* accelerated flowering (Nitcher *et al*., 2013)

A recent study in wheat showed that there is genome predominance in gene expression of the three wheat homoeologues (Shaw *et al.*, 2012). The study by Shaw *et al.*, (2012) used genome specific primers and showed one or two genomes were dominant in gene expression. More interestingly, Shaw *et al.*, (2012) showed that the B genome was the only genome expressed for all the genes used in their study and it was the main contributor to the expression of *Ppd-1, TaGI, TaCDF1, TaCO2* and *TaFT1* a close relative of *TaFT3*. The results from this current study could explain why the B genome maybe expressed more than the A and D genome copies. The deletion of a conserved amino acid alanine from the D copy (Fig. 6.9) may affect the function of the D copy but there was no 1DL QTL in the populations used in this study probably because all varieties used in this study have the amino acid deletion on the D copy and hence there will be no segregation for the amino acid deletion in the DH populations used in this thesis.

Furthermore, the three base deletion from the A copy -8 to -6 bases from the start codon as well as deletion of four bases -55 to -52 from the start codon (appendix 6.3) in the promoter may affect the expression of the A copy. In addition to that the single nucleotide base change from A to G -26 bases from the start codon changes a TATA box variant TATTAA to TGTTAA (appendix 6.3). The TATA box containing genes in *Arabidopsis thaliana* have been shown to be associated with highly expressed genes (Bernard *et al.*, 2010).

The results in this study show that the *TaFT3-B1* gene has the TATA box variant TATTAA while the A and D *TaFT3* copies have the TGTTAA at the TATA box expected position (appendix 6.3). In addition there are sixty seven promoter polymorphisms which are identical for A and D copies but unique for the B copy of the *TaFT3* gene (appendix 6.3). These differences may to an extent explain why the *TaFT3-B1* mutants (deletion of the whole gene or the glycine to serine amino acid change) causes significant delay in heading date effects but gene expression assays are needed for the three *TaFT3* homoeologues to verify the hypothesis.

TaFT3 behaves differently from the group 2 photoperiod genes *Ppd-D1a*, *Ppd-A1a, Ppd-B1* (Beales *et al*., 2007; Wilhelm *et al*., 2009; Diaz *et al.*, 2012). Photoperiod insensitivity has been shown to be due to promoter deletions upstream of the start codon for the *Ppd-D1a, Ppd-A1a* with about 850 common bases deleted (Beales *et al*., 2007; Wilhelm *et al*., 2009). Day neutrality is also conferred by copy number variation at the *Ppd-B1* gene (Diaz *et al* 2012). The common feature of the group 2 photoperiod genes is that they confer photoperiod insensitivity but *TaFT3* on group 1 genes only causes early flowering particularly in short days with loss of function mutations causing delayed heading date.

The 1BL QTL seems to have effect on flowering earlier than the long day photoperiod genes (Fig. 6.6). There is a difference of about 20 days between the earliest flowering and the latest flowering (Terra and Walde) in long days but this difference is stretched to about 80 days in short days (Fig. 6.6). There is a difference of about seven days between Banco and StarkeII in long days but the difference increases to 44 days between the two under short days (Fig. 6.6).

In barley, *HvFT3* has been reported to be expressed more between week three and four in short days and the increased expression coincides with the vegetative to floral transition (Faure *et al*., 2007). It is possible that *TaFT3* is expressed early (short days) in wheat development before the more dominant long day induced photoperiod genes like *Ppd-1*. A recent report of a study in barley indicates that *PPDH2* adapts southern European germplasm by promoting early flowering of non vernalized plants in short days (Casao *et al*., 2011b). The results of this study on *TaFT3* provide additional control for wheat breeders in addition to the well known group two photoperiod genes when breeding for specific environments.

7 Chapter 7

7.1 General discussion

The *Eps* effects are clearly important adaptive traits but they have not been well studied in the past. For example it was reported almost half a century ago that earliness *per se* genes caused some photoperiod sensitive varieties to flower earlier than photoperiod insensitive varieties (Martinic 1975). One reason why *Eps* genes have not been well studied is that they were often been mapped in crosses segregating for *Ppd and Vrn*. Worland *et al*., (1994) underscored the need to develop genetic stocks that could be used to reveal the importance of *Eps* in wheat adaptability. This thesis shows using Doubled haploid (DH), developing SSD populations, and use of near isogenic lines (NILs) that *Eps* genes can be isolated as Mendelian factors and fine mapped. This means *Eps* genes can be defined and positional cloned in the same way as the *Ppd* (Turner *et al*., 2005) and *Vrn* (Yan *et al*., 2003) genes were.

Most of the work done to try and clone the *Eps* genes in wheat used the ancient diploid species *T. monococcum* (Bullrich *et al.,* 2002; Appendino *et al.,* 2003; Lewis *et al.,* 2008). This thesis used elite 21st century winter wheat like Spark and Rialto which have undergone selection for more than half a century. It is easier and quicker to manipulate *Eps* effects which are already in the elite adapted varieties than obtaining the variation from an ancient species and this thesis shows that it is possible to fine map these effects directly in hexaploid wheat.

Earliness *per se* (*Eps*) effects are clearly important given that in *T. monococcum,* the *Eps-*A^m*1* locus was reported to determine the number of spikelets as well as the number of grains per spike in addition to affecting heading time (Lewis *et al*., 2008). Grain quality can also be improved by manipulating *Eps* loci given that Hendle *et al*., (2008) showed that *Eps* together with the major genes that control vernalization and photoperiod flowering influence grain protein content. This study aimed to increase our understanding of *Eps* in bread wheat and to eventually clone the *Eps* gene(s) on chromosome 1DL of bread wheat. The study also aimed to increase our understanding of photoperiod response in bread wheat particularly under short days.

7.2 **The 1DL QTL**

The results (Fig. 2.2-Fig.2.3) suggest that the 1DL heading date QTL is an *Eps* effect and this was validated in both the field and controlled environment conditions (Zikhali *et a*l., 2014). Results obtained from the Spark X Rialto doubled haploid (DH), Spark X Rialto single seed descent (SSD) and Spark X Rialto near isogenic lines (NILs) as well as the Avalon X Cadenza DH population suggest that the deletion on 1DL encompassing several genes might be responsible for the heading date *Eps* QTL.

The term earliness *per se* (*Eps*) also referred to as ear emergence *per se,* earliness in narrow sense, intrinsic earliness, and at times is called basic development rate (Lewis *et al.,* 2008; Shitsukawa *et al*., 2007; Cockram *et al.,* 2007; Laurie *et al*., 2004) is not adequately defined. Some definitions of *Eps* suggest that this is flowering variation that is independent of both vernalization and photoperiod genes (Bullrich *et al.,* 2002; Worland *et al*., 1994). Similarly others define *Eps* as all other genes controlling flowering time but not involved in either vernalization or photoperiod requirements (Lewis *et al.,* 2008). Some definitions ascribe *Eps* to those genes that cause flowering variation when both vernalization and photoperiod requirements are met (Shitsukawa *et al*., 2007; van Beem *et al*., 2005; Appendino *et al.,* 2003). A recent report ascribed flowering variation that could not be accounted for by *Vrn-1* and *Ppd-D1* alleles to *Eps* in spring wheat (Kumar *et al*., 2012).

One of the reasons why the *Eps* is not well defined in wheat is that no *Eps* gene has been cloned as yet hence the role of individual *Eps* genes is yet to be fully defined. One of the reasons why it has taken a long time to clone *Eps* genes is that they have small effects and are usually mapped in crosses segregating for *Ppd* or *Vrn* effects. Photoperiod response genes have been cloned in cereals firstly in barley and the major gene is *PHOTOPERIOD 1* (*PPD1*) a pseudo response regulator (Turner *et al*., 2005) and its homologues in wheat are largely due to allelic variation at the *PPD1* genes (Wilhelm *et al*., 2009; Beales *et al*., 2007). For vernalization, the *VRN* genes 1, 2 and 3 have been shown to be responsible for the vernalization response (Beales *et al*., 2007; Trevaskis *et al*., 2007; Distelfeld *et al*., 2009a/b).

Recently, Diaz *et al*., (2012) reported that copy number variation (CNV) affecting *Photoperiod-B1* (*Ppd-B1*) and *Vernalization-A1* (*Vrn-A1*) affects flowering where increased *Ppd-B1* copies resulted in early flowering day neutral phenotype while increased *Vrn-A1* copies increased the vernalization requirement. The *Vrn-A1* CNV was shown using three varieties Claire, Malacca and Hereward which required short, intermediate and long (about 8 weeks of cold exposure) vernalization respectively. If the *VRN1* gene had not been cloned, the late flowering of Hereward when vernalized for six weeks may have been wrongly classed as *Eps* given that Claire and Malacca are fully vernalized after six weeks of vernalization (Diaz *et al*., 2012).

Suggesting that *Eps* genes work independently of both vernalization and photoperiod genes might not be accurate given the inter-dependence and inter-connections of the flowering time genes. Furthermore, not all the genes that are involved in flowering time have been identified to date. It may not be accurate to define *Eps* genes as those genes that work independently of both vernalization and photoperiod genes because new vernalization and photoperiod genes may be identified later and these may be shown to interact with the yet to be cloned *Eps* gene(s). The results from this study are consistent with the suggestion that *Eps* effects cause heading date variation when both vernalization and photoperiod requirements are satisfied (Shitsukawa *et al*., 2007) without necessarily being independent of the two environmental cues. Both the Spark X Rialto and Avalon X Cadenza DH populations have the 1DL QTL under long days when the plants are fully vernalized but the QTL is not observable when the fully vernalized plants are grown under short day conditions (Fig. 5.1).

The disappearance of the 1DL QTL under short day conditions for both DH populations may be interpreted to mean that the 1DL QTL is not an *Eps* effect if one takes the definition that suggests that *Eps* is independent of photoperiod (Bullrich *et al.,* 2002). However, results from the NILs suggest the 1DL effect is an *Eps* effect given that all the NILs carrying the Spark deletion are consistently early flowering under all the three photoperiod regimes of short days, long days and very long days (Fig. 2.2-Fig.2.3; Zikhali *et al*., 2014).

Furthermore, the results show that Rialto has a separate short day effect (Fig. 2.5) which was mapped to chromosome 1B and is closely linked to the *TaFT3* gene (Fig. 6.1 and Fig.6.2). The results also show another short day effect on chromosome 5A that is linked to the *Xbarc151* marker (Fig. 6.10). The NILs have a common Rialto background while the DH populations have a lot of background differences (1B, 5A QTLs and copy number variation at *Vrn-A1*) and this may explain why the 1DL QTL is observable under both short and long day conditions for the NILs but not observable under short days for the doubled haploid populations. It might also be due to reduced heritability under short days hence the effect may be there but hard to detect.

The disappearance of the 1DL QTL in short days observed in the DH populations may be due to epistatic interactions between the 1DL QTL and other flowering time genes in the background. In this study, the QTL on chromosome 1BL causes a difference of about two weeks in heading date between Spark (late) and Rialto (early) when grown under short day conditions. Given that the 1DL *Eps* QTL causes differences in heading date of a few days (3-5 days), the 1DL *Eps* QTL is likely to be masked by the more dominant photoperiod effect on 1B when the photoperiod is limiting.

The QTLs on the distal end of group 1 chromosomes have been speculated to be orthologues of the *Triticum monococcum* $Eps\text{-}A^{m}1$ (Lin *et al*., 2008; Griffiths *et al*., 2009) reported to be on the distal region of *Triticum monococcum* chromosome $1A^{m}L$ (Faricelli *et al*., 2010; Valarik *et al.,* 2006; Bullrich *et al.,* 2002). The results from this study provide possible evidence that $Eps\text{-}A^{m}1$ and the 1DL *Eps* QTL might be orthologues given that both occur at the same locus although it is yet to be proven that the same gene is responsible for the heading date *Eps* effect in both species. However, even though this study has shown that the entire $Eps\text{-}A^{m}1$ locus is deleted on the 1DL locus, the possibility of different genes being responsible for the *Eps* in both species cannot be ruled out until the individual genes are cloned in both species.

7.2.1 Prioritization of candidates for the *Eps* gene in the 1DL deletion

The results from this study suggest that 1DL *Eps* heading date effect is likely due to a deletion that includes several genes. Theoretically, all the genes in the deletion are potential candidates for the *Eps* effect and the possibility of more than one gene being responsible is not ruled out. Deletion mutations of large portions of chromosomes (Shitsikawa *et al*., 2007; Distelfeld and Dubcovsky 2010), or single genes (Faure *et al*., 2012) or portions of genes (Yan *et al*., 2003; Fu *et al*., 2005; Wilhelm *et al*., 2009) have been shown to cause variation in flowering time. While the genotypes of DH, and NILs as well as SSD populations and recombinants of the SSD population and comparative genomics with Brachypodium and *T. monococcum* all suggest that the *Eps* effect is due to the 1DL deletion, the possibility of the presence of a wheat specific gene just outside the 1DL deletion cannot be ruled out until the complete physical map of 1DL is constructed. Considering that the deletion encompasses several genes, it is also possible that other genes in the deletion that affect development may be the cause of the observed *Eps*.

However, among the deleted genes there are some candidates which stand out like *MOLYBDENUM TRANSPORTER 1* (*MOT1*) and *FILAMENTATION TEMPERATURE SENSITIVE H* (*FtsH4*) the suggested candidates for the *Eps-*A^m*1* (Faricelli *et al*., 2010). Results from this study suggest that the *Eps-*A^m*1* is at the same locus as the *Triticum aestivum* 1DL *Eps* locus given that both candidates suggested for the *Eps-*A^m*1* are in the 1DL deletion that this study showed to be tightly linked with the heading date *Eps* QTL.

MOT1 was suggested because it has the SNF2_N and HELICc domains of the SNF2 family of transcription factors (Faricelli *et al*., 2010). In addition to that two SNF2 members *PHOTOPERIOD INDEPENDENT EARLY FLOWERING* gene 1 (*PIE1*) and the gene *BRM* were shown to be involved in flowering time regulation and vegetative and reproductive growth respectively in *Arabidopsis thaliana* (Faricelli *et al*., 2010). In the study by Faricelli *et al*., (2010), it was reported that the gene *MOT1* was expressed in both the vegetative shoot apical meristem and the developing spike; the expected tissues for *Eps-*A^m*1* expression. Two amino acid substitutions were identified between lines DV92 and G3116 but both mutations were outside the conserved SNF_2 and HELICc domains hence Faricelli *et al*., (2010) acknowledged the complication of predicting the effect of the mutation in protein function. In addition to that real time PCR showed no significant differences in the transcript levels from the lines segregating for the *Eps-*A^m*1* (Faricelli *et al*., 2010).

The other gene that was suggested as a candidate for *Eps-*A^m*1* is *FtsH4* but this gene showed no amino acid substitution in the predicted *FtsH4* protein sequences of the lines segregating for the *Eps-*A^m*1*. Again there were no significant heading date differences between NILs segregating for *Eps-*A^m*1* (Faricelli *et al*., 2010). It should also be pointed out here that a study in *Arabidopsis thaliana* also showed that *FtsH4* loss did not affect growth under adequate photoperiod but only affected late rosette development under limiting photoperiod when the plants were grown in short days (Gibala *et al*., 2009). This was different from the effect caused by the 1DL *Eps* where the effect was stronger under long days but not detectable under short days for both the Spark X Rialto and Avalon X Cadenza DH populations. Of the two candidates, *MOT1* was considered the more likely candidate despite the aforementioned shortcomings because one of the amino acid changes in *MOT1* caused a negative BLOSUM62 score even though this change was outside the conserved region (Faricelli *et al*., 2010).

In this study, another gene which was designated *Triticum aestivum Early flowering 3* (*TaELF3*) is also suggested as a possible candidate in addition to *MOT1* and *FtsH4* because it is also among the deleted genes and has been shown to affect flowering in a number of species. There is only one gene between the distal *Eps-A^m1* marker *Adk1* (*Bradi2g14210*) (Faricelli *et al*., 2010) and *TaELF3* (*Bradi2g14290*) in the Brachypodium collinear region. Despite this close proximity of *TaELF3* to the distal marker of the *Eps-A^m1*, this gene is not discussed in the study by Faricelli *et al*., (2010).

The gene *TaELF3* is a circadian clock gene whose homologues are known to cause flowering variation in *Arabidopsis thaliana* (Dixon *et al*., 2011), *Oryza sativa* (Matsubara *et al*., 2012), *Hordeum valgare* (Faure *et al*., 2012; Zakhrabekova *et al*., 2012), *Zea mays* (Bate and Aukerman, 2011), the legumes lentil and pea (Weller *et al*., 2012). The heading date QTL on 1DL is at the same location as the eam8/Mat-a heading QTL in barley (Faure *et al*., 2012; Zakhabekova *et al*., 2012) and there is conserved gene order between the cluster of genes containing *TaELF*3 in Brachypodium, wheat and barley (Higgins *et al*., 2010).

A recent patent in maize (Bate and Aukerman 2011) suggests that over expressing the *Zea mays Early Flowering 3* (*ZmELF3*) gene enabled the plants to be grown in high density because over- expressing *ZmELF3* suppressed the shade avoidance response by enabling plants to tolerate limited light. The suppression of the shade avoidance response enabled higher densities of plants to be grown per unit area resulting in increased yield. The functioning of the *ZmELF3* in delaying flowering when the plants are stressed by limited light is consistent with observations in our study where loss of *TaELF3* by deletion of the gene results in early flowering relative to the plants with an intact gene which are later flowering.

Given that one of the genes in the 1DL deletion and a possible candidate for the 1DL *Eps* effect is the circadian clock gene *TaELF3* which is involved in a pathway that includes both the photoperiod and vernalization pathways (Higgins *et al*., 2010), this further shows that defining *Eps* as independent of both vernalization and photoperiod genes might not be accurate.

7.3 The 1B QTL

The 1BL QTL had a LOD score of 3.9 and accounted for 18 % of the variation with an additive effect of eight days in short days for the Avalon X Cadenza DH population but it clearly does not completely account for why the Swedish material which also have loss of function mutation at *TaFT3-B* are later flowering than the UK and Khazakhstan/Russian varieties (Fig.6.6). There is not a big difference in flowering time between the Swedish and UK/Khazakhstan varieties when the plants are grown under long days in a controlled environment (Fig.6.6). However, in an earlier analysis when the plants were grown in the field at Church farm, Norwich Norfolk United Kingdom there was a significant difference in flowering time between the Swedish and UK material in the field.

One possible explanation for this difference is that for the controlled environment, the plants were vernalized for 8 weeks and then allowed to grow at fixed day length conditions (10hrs, 16hrs and 20hrs light). However, in the field, day length increases gradually from short days during winter and spring to long days in summer. The plants grown in the field, start with a lengthy short day period between September and April in the UK.

In a study done in barley, it was shown that *HvFT3* which is syntenic with the *TaFT3* gene is expressed earlier during the development with peak expression coinciding with the vegetative to floral transition between week three and four from sowing (Faure *et al*., 2007). Taken together, with results from this study, it is tempting to speculate that the loss of function mutation at *TaFT3* delays flowering in short days as observed in barley (Faure *et al*., 2007).
However, given that the Swedish varieties are very late in both the field and short day conditions, it is likely that another gene or genes in addition to *TaFT3* cause the Swedish lines to be late flowering and warrants further investigation. Considering that Terra appears photoperiod insensitive and flowers almost at the same time under the three photoperiod regimes (Fig. 6.6), it is vital to investigate the genetic basis of this difference so as to clone the gene(s) responsible which will give breeders more control in manipulating flowering time. A likely target would be *Ppd-1* which has been shown to have mutations that cause

photoperiod insensitivity in wheat (Diaz *et al*., 2012; Wilhelm *et al*., 2009; Beales *et al*., 2007).

Two mutant alleles of the *TaFT3-B* gene have been shown in this study. One of the alleles is the deletion of the gene and the other is a point mutation which changes a very well conserved amino acid. It is proposed in this study that the *TaFT3* gene is likely the *Ppd-2* gene which modulates flowering time under short days. More germplasm screens may show other alleles of this gene which could give breeders more control in breeding varieties adapted to short day photoperiods in addition to the well studied *Ppd-1*. In barley it has been shown that *PPDH2* adapts non vernalized plants to early flowering in short days (Casao *et al*., 2011b) and this study suggests that similar or other benefits could be obtained from *TaFT3* for wheat.

7.4 The 5A short day QTL

This study also identified a QTL on chromosome 5A that is linked to the *Xbarc151* marker. KASPar markers were developed for the *PHYTOCHROME C* (*PHYC*) gene that distinguished Spark and Rialto. The *Vrn-A1* KASPar marker developed by Diaz *et al*., (2012) was also used to score the Spark X Rialto DH population that was segregating for the 5A short day QTL. Both *Vrn-A1* and *PHYC* were selected because they are both linked to the *Xbarc151* marker (Xue *et al*., 2008; Distelfeld and Dubcovsky 2010).

An earlier study had indentified copy number variation (CNV) at *Vrn-A1* as the cause of variation in flowering time among winter wheat varieties (Diaz *et al*., 2012). It was identified in this study that Spark has one copy of the gene and that Rialto has two *Vrn-A1* copies (data not shown). No clear association was observed between the *Vrn-A1* marker and the heading phenotype in the doubled haploid population suggesting that CNV might not be the cause of the short day QTL identified from the Spark X Rialto DH population. However, the possibility of background noise affecting the association is not ruled out.

The other gene that was considered as candidate for the 5A short day QTL was *PHYC*. A recent study that characterised the *maintained vegetative phase* (*mvp*) mutants that do not flower (Shimada *et al*., 2009) showed that in addition to the deletion of *Vrn-a1*, other genes including *PHYC* were also deleted (Distelfeld and Dubcovsky 2010). It was hypothesised that

VRN1 was responsible for the non-flowering phenotype and that *PHYC* deletion was responsible for down regulating *VRN2* and *FT1* (Distelfeld and Dubcovsky 2010).

In the current study, when the Spark X Rialto DH population that was segregating for the short day QTL on 5A was scored using the KASPar makers that distinguished Spark from Rialto for *PHYC*, no clear association was observed between the phenotype and the KASPar scores (Fig. 6.11). However, given that only 96 lines were used, this may have been too small to reveal the variation. Furthermore, the population was also segregating for the 1B short day QTL as well as the 1DL *Eps* QTL which may have introduced background noise. Making near isogenic lines in a common background as well as a large F2 population to identify recombinants may help in fine mapping the gene.

7.5 Possible use of information and data generated from this study

The results show the importance of genome specific primers in revealing vital information like the 1BL and 1DL deletion in polyploid wheat. DNA primers which lack genome specificity can lead to inaccurate conclusions. This was the case for the KASPar markers by Allen *et al*., (2011) that suggested allelic polymorphism in Avalon and Cadenza when in fact Cadenza lacks the portion of the chromosome on 1DL. However, it should be pointed out that Allen *et al*., (2011) produced very good KASPar markers which can be used to score the 1DL deletion in studies that include material that is known to be segregating for the deletion.
The thesis also sequenced several genes many of them covering the complete coding sequence for group1 and group 5 chromosomes. Most of the genes have been annotated and their homologues in brachypodium have been identified and linked to markers on genetic maps. These sequences will be vital when the scaffolds are being joined for constructing the yet to be made physical maps of group1 and group 5 chromosomes. To date, only the chromosome 3B physical map has been constructed to an advanced stage.

Furthermore, eight KASPar markers for the genes *TaELF3-D*, *TaFT3-A*, *TaFT3-B*, and *TaFT3-D* were designed and can be used in marker assisted selection (MAS). The *TaFT3* genes sequenced in this study were deposited onto the GenBank database (accession numbers listed in appendix 6.5) and will be useful for further studies. Sequences for *TaELF3*, *PHYC* and all the genes sequenced on 1DL will also be deposited onto the GenBank database when fully annotated. Several PCR based genome specific primers were designed and PCR based makers were developed which can be used for fine mapping other traits close to the 1DL locus. The marker design protocol developed and described in this study like *de novo* assembly of homologous genes can be extended with a few modifications to other polyploids like the complex sugarcane polyploid to sequence gene rich regions.

The alleles identified in this study, the 1DL deletion of several genes and the 1BL deletion of *TaFT3-B* and single nucleotide polymorphism at *TaFT3-B* can be used in marker assisted selection. Although this study has not identified the gene underlying the 1DL QTL, there are adequate markers developed in this study which can be used in MAS to select for the deletion which this study has shown to be tightly linked with the *Eps* QTL. The 5A QTL needs further investigation but data generated from this study lays the foundation for further studies.

In a nutshell, this study validated the 1DL *Eps* QTL as an *Eps* effect. The study also identified the presence of a deletion on chromosome 1DL in some varieties and that the deletion was linked with the early flowering phenotype. Among the deleted gene, *FtsH4*, *MOT1* both identified by Faricelli *et al*., (2010) were considered as possible candidates. In this study, the gene *TaELF3* is also suggested as a possible candidate given that it is among the deleted genes and is a well-known and well-studied circadian clock gene identified in *Arabidopsis thaliana* (Yoshida *et al*., 2009) and its homologues in maize, rice, barley and legumes have all been shown to be involved in the circadian clock and mutations at this gene affect flowering. This study also identified new flowering time loci on chromosome 1B and chromosome 5A. The chromosome 1B QTL might be due to *TaFT3* (*Ppd-2*). Three alleles for *TaFT3* were identified and these can be used in marker assisted selection. The 5A QTL still needs to be further investigated although this study suggests that it is unlikely to be *Vrn-A1*. The other candidate that was considered was *PHYC* and the data from this study is not conclusive to determine whether *PHYC* is the candidate for the QTL that was identified on chromosome 5A linked to the *Xbarc151* marker. The identification of the QTL on 5A and the development of markers for genes around the *Xbarc151* done in this study serves as the foundation for further studies to fine map the gene responsible.

7.6 Future work

7.6.1 Can the mechanism of 1DL *Eps* be understood before cloning the gene?

One question that can be asked based on the results this thesis has generated is if the physiological effects of the 1DL *Eps* can be understood before the gene is cloned. Dissecting NIL apices during floral initiation through to terminal spikelet production and stem extension would show how development is different. One important question is what phase of development is altered by early alleles at this locus? It is possible that vegetative to floral transition is brought forward, but equally, discrete phenological phases like double ridge to terminal spikelet could be compressed. This has important implications for the potential effects and breeding uses of these alleles particularly yield increase (Slafer *et al*., 1994).
Measurements will include culm dissection to show which phenological stages are shortened or prolonged and measurement of yield components. A new set of NILs for these alleles in the background of the variety Paragon are being developed. These will be inter-crossed with other Paragon NILs developed for genes such as *Ppd-1*. This will show how different flowering time genes interact in wheat and explain why some allelic combinations are found in commercial varieties, while others are not.

7.7 How can work on the 1DL deletion be taken further?

7.7.1 1. Use of Paragon gamma deletion lines

The 1DL deletion includes several genes which are all potential candidates. There is need to define the part of the deletion that is responsible for the heading date effect. One strategy is the use of overlapping deletions in Paragon gamma ray lines and determine which part of the deletion gives the heading date effect. This strategy was used successfully to define *Ph1* (Griffiths *et al*., 2006). The drawback of gamma deletions is that they are sometimes too big and may include more than one gene affecting flowering time as was the case with the maintained vegetative phase mutants (*mvp*) (Shitsukawa *et al*., 2007; Distelfeld and Dubcovsky, 2010).

7.7.2 2. Targeting Induced Local Lesions In Genomes (TILLING)

Another strategy that can be used is TILLING. TILLING mutants are produced by single nucleotide polymorphisms which induce deleterious mutations like introducing premature stop codons, misplicing due to mutations at the splice junctions as well as amino acid changes in conserved domains. TILLING has been successfully used to determine the role of the *VRN1* gene in wheat (Chen and Dubcovsky 2012). Tilling mutant populations developed by Uauy *et al*., (2009) for tetraploids can be used to determine the role of any of the prioritised candidates by comparing the phenotype of single and double (null) mutants. There is also a population of hexaploid wheat TILLING mutants which can also be screened for single, double and triple mutants of any of the candidate genes in the deletion.

7.7.3 3. The transgenic approach

In rice, TDNA insertion was used to knockout the *OsELF3* gene the homologue of Arabidopsis *ELF3* and the mutants were very late flowering (Fu *et al*., 2009). The same approach with some modifications can also be used in hexaploid wheat to knockout the candidate genes and then comparing the phenotype of the knockouts with the wild-type. For example will a knockout of the Rialto genes in the equivalent region with the Spark deletion result in an early phenotype?

7.8 Temperature time course experiment

This thesis suggests that the *T. monococcum* $Eps\text{-}A^{m}1$ (Bullrich *et al.,* 2002; Appendino *et al.,* 2003; Lewis *et al.,* 2008) is at the same locus as the 1DL *Eps* QTL. However, it was not determined if the 1DL QTL is also thermosensitive. Growing NILs under different temperatures (5, 10, 15, 20 and 25 degrees Celsius) may reveal if the 1DL *Eps* gene responds to ambient temperature as an environmental cue. Crevillen & Dean **(**2010) showed in their model of flowering time that *Arabidopsis thaliana* also responds to ambient temperature as an environmental cue in addition to vernalization and photoperiod.

References

Allen, MA., Barker, GLA., Berry, ST., Coghill, JA., Gwilliam, R., Kirby, S., Robinson, P., Brenchley, RC., D'Amore, R., McKenzie, N., Waite, D., Hall, A., Bevan, M., Hall, N., Edwards KJ., 2011. Transcript-specific, single nucleotide polymorphism discovery and linkage analysis in hexaploid bread wheat (*Triticum aestivum* L.). *Plant Biotechnology Journal* doi:10.1111/j.1467-7652.2011.00628X.

Altschul, SF., Gish, W., Miller, W., Myers, EW., Lipman, DJ.1990. Basic Local Alignment Search Tool. *Journal of Molecular Biology* **215**, 403-410.

Appendino, ML., Bartoloni, N., Slafer, GA. 2003. Vernalization response and earliness *per se* in cultivars representing different eras of wheat breeding in Agentina. *Euphytica* **130**, 61-69.

Appendino, ML., Slafer, GA. 2003. Earliness *per se* and its dependence upon temperature in diploid wheat lines differing in the major gene *Eps*-A^m1 alleles. *Journal of Agricultural Science* **141**, 149-154.

Atsmon D, Bush MG, Evans LT. 1986. Stunting in gigas wheat as influenced by temperature and daylength. *Australian Journal of Plant Physiology* **13**, 381–389

Bate, NJ., Aurkerman, MJ. 2011. Composition and methods for increasing plant tolerance to high population density. United States Patent. Patent number 7,868,224 B2. Date of Patent January 11 2011.

Beales, J., Turner, A., Griffiths, S., Snape, JW., Laurie, DA. (2007) A *Pseudo-Response Regulator* is misexpressed in the photoperiod insensitive *Ppd-D1a* mutant of wheat (*Triticum aestivum* L.). *Theoretical and Applied Genetics* **115**, 721–733.

Bernard, V., Brunaud, V., Lecharny, A. 2010. TC-motifs at the TATA-box expected position in plant genes: a novel class of motifs involved in the transcription regulation. *BMC Genomics* **11**, 166.

Borlaug N E 1973 Building a protein revolution on grain legumes. *In* Nutritional Improvement of Food Legumes by Breeding, pp 7–11. Protein Advisory Group Symposium, Rome 3–5 July 1972, UN, New York

Bradley, D., Carpenter, R., Copsey, L., Vincent, C., Rothstein, S., Coen, E. 1996. Control of Inflorescence architecture in *Antirrhinum*. *Nature* **379**, 791-797

Brenchley, R., Spannagl, M., Pfeifer, M., Barker, GLA., D/'Amore, R., Allen, AM., McKenzie, N., Kramer, M., Kerhornou, A., Bolser, D., Kay, S., Waite, D., Trick, M., Bancroft, I., Gu, Y., Huo, N., Luo, M., Sehgal, S., Gill, B., Kianian, S., Anderson, O., Kersey, P., Dvorak, J., McCombie, WR., Hall, A., Mayer, KFX., Edwards, KJ., Bevan, MW., Hall, N.,2012. Analysis of the bread wheat genome using whole-genome shotgun sequencing *Nature* **491**, 705–710

Brinkman, R. 1980. Saline and sodic soils. In: Land reclamation and water management, p. 62-68. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.

Bullrich, L., Appendino, ML., Tranquilli, G., Lewis, S., Dubcovsky, J. 2002. Mapping a thermo-sensitive earliness *per se* gene on Triticum monococcum chromosome $1A^{m}$. *Theoretical and Applied Genetics* **105**, 585-593.

Casao, CM., Igartua, E., Karsai, I., Lasa, JM., Gracia, PM., Casas, AM. 2011a. Expression analysis of vernalization and day-length response genes in barley (Hordeum vulgare L.) indicates that *VRNH2* is a repressor of *PPDH2* (*HvFT3*) under long days. *Journal of Experimental Botany* **6**, 1939-1949.

Casao, MC., Karsai, I., Igartua, E., Gracia, MP., Veisz, O., Casas, AM. 2011b. Adaptation of barley to mild winters: a role for *PPD-H2*. BMC Plant Biol 11:164

Cauvain, SP., Cauvain PC. 2003 *Bread Making*. CRC Press. p. 540. ISBN 1-85573-553-9.
Chen, A., Dubcovsky, J. 2012. Wheat TILLING Mutants Show That the Vernalization Gene VRN1 Down-Regulates the Flowering Repressor VRN2 in Leaves but Is Not Essential for Flowering. *PLoS Genetics* 8(12), e1003134. doi:10.1371/journal.pgen.10031 34

Chen, A., Dubcovsky, J. 2012. Wheat TILLING Mutants Show That the Vernalization Gene *VRN1* Down-Regulates the Flowering Repressor *VRN2* in Leaves but Is Not Essential for Flowering. *PLoS Genet*ics **8(12):** e1003134. doi:10.1371/journal.pgen.1003134

Cockram J., Jones H., Leigh FJ., O'sullivan D., Powell W., Laurie DA., Greenland, AJ. 2007. Control of flowering time in temperate cereals: genes, domestication, and sustainable productivity. *Journal of Experimental Botany* **58**, 1231-1244.

Coff, C., Barling, D., Korthals, M., Nielsen T. 2008. Ethical Traceability and Communicating Food. Springer Netherlands.

Comadran, J., Kilian, B., Russel, J., Ramsay, L., Stein, N., Ganal, M., Shaw, P., Bayer, M., Thomas, W., Marshall, D., Hedley, P., Tondelli, A., Pechioni, N., Francia, E., Korzun, V., Walther, A., Waugh, R. 2012. Natural variation in a homologue of *Antirrhinum CENRORADIALIS* contributed to spring growth harbit and environmental adaptation in cultivated barley. *Nature Genetics* 44, 1388-1392.

Crevillen P., Dean C. 2010. Regulation of the floral repressor gene FLC: the complexity of transcription in a chromatin context. *Current Opinion in Plant Biology* 14, 38–44.

Crowley, Nicholas A., "Quantitative trait loci for agronomic and end-use quality performance and the effect of soilborne wheat mosaic virus in a hard winter wheat population in Nebraska" (2010). *Theses, Dissertations, and Student Research in Agronomy and Horticulture.* Paper 8. http://digitalcommons.unl.edu/agronhortdiss/8

Devos, KM., Beales,J., Ogihara,Y., and Doust,AN. 2005. Comparative sequence analysis of the phytochrome C gene and its upstream region in allohexaploid wheat reveals new data on the evolution of its three constituent genomes. *Plant Mol. Biol.* 58(5), 625-641.

Dı´az, A., Zikhali, M., Turner, A.S., Isaac, P. and Laurie, D.A. (2012) Copy number variation affecting the Photoperiod-B1 and Vernalization-A1 genes is associated with altered flowering time in wheat (Triticum aestivum). *PLoS One*, **7(3)**, e33234. doi:10.1371/journal.pone. 0033234.

Distelfeld, A., Dubcovsky, J., 2010. Characterization of the maintained vegetative phase deletions from diploid wheat and their effect on VRN2 and FT transcript levels. *Molecular Genetics and Genomics* **283**, **223-232.**

Distelfeld, A., Tranquilli G., Li, C., Yan, L., Dubcovsky, J. 2009a. Genetic and Molecular variation of the *VRN2* loci in tetraploid wheat. *Plant Physiology* **149**, 245-257.

Distelfeld A, Li C, Dubcovsky J (2009b) Regulation of Flowering in temperate cereals. *Current Opinion in Plant Biology* **12**,178–184.

Dixon, J., Braun, HJ., Kosina, P., Crouch, J. 2009 *Wheat Facts and Futures 2009*. CIMMYT, Mexico, D.F.

Dixon, LE., Knox, K., Kozma-Bognar, L., Southern, MM., Pokhildo, A., Millar, A., 2011. Temporal repression of core circadian genes is mediated through *EARLY FLOWERING 3* in Arabidopsis. *Current Biology* **21**, 120-125.

Dubcovsky, J., Loukoianov, A., Fu, D., Valarik, M., Sanchez, A., Yan, L. 2006. Effect of photoperiod on the regulation of wheat vernalization genes *VRN1* and *VRN2*. Plant Molecular Biology **60**, 469–480.

Duggan, BL., Richards, RA., Tsuyuzaki, H. 2002. Environmental effects on stunting and the expression of a tiller inhibition (tin) gene in wheat. *Functional Plant Biology* **29**, 45–53.

Evans LT. 1975. Crops and world food supply, crop evolution and the origins of crop physiology. In Crop physiology (Ed LT Evans). Cambridge University Press, Cambridge University Press, Cambridge, UK .

FAOSTAT http://faostat3.fao.org (2012).

Faricelli, ME., Valarik, M., Dubcovsky, J. 2010. Control of flowering time and spike development in cereals: the earliness *per se Eps-1* region in wheat, rice, and Brachypodium. *Functional and Integrative Genomics* **10**, 293-306.

Faure, S., Higgins, J., Turner A., Laurie DA. 2007. The *FLOWERING LOCUS T*-like gene family in barley (*Hordeum vulgare*). *Genetics* 176**:** 599–609.

Faure, S., Turner, AS., Gruszka, D., Christodoulou, V., Davis, SJ., von Korff, M., Lairie, DA. 2012. Mutation at the circadian clock gene *Early maturity 8* adapts domesticated barley (*Hordeum vulgare*) to short growing seasons. *PNAS* **109(21),** 8328–8333

Francis, SA. 2009. British Field Crops, a pocket guide to identification, history, and uses of arable crops in Great Britain. Moreton Hall Press, England.

Fu, C., Yang, O., Chen, W., Ma, Y., Hu, J., Li, S. 2009. *OsEF3*, a homologous gene of *Arabidopsis ELF3* has pleiotropic effects in rice. *Plant Biology* **11**, 751-757.

Fu, D., Szucs, P., Yan, L., Helguera, M., Skinner, JS., von Zitzewitz, J., Hayes, PM., Dubcovsky, J. 2005. Large deletions within the first intron in VRN-1 are associated with spring growth habit in barley and wheat. *Molecular Genetics and Genomics* 273, 54-65.

Gawroński, P., Ariyadasa, R., Himmelbach, A., Poursarebani, N., Kilian, B., Stein, N., Steuernagel, B., Hensel, G., Kumlehn, J., Sehgal, SK., Gill, BS., Gould, P., Hall, A., Schnurbusch, T. 2014. A distorted circadian clock causes early flowering and temperature-dependent variation in spike development in the *Eps-3A^{m}* mutant of einkorn wheat. Genetics 10.1534/genetics.113.158444

Gawrosnski, P., Schnurbusch, T. 2012. High-density mapping of the earliness per se-3A^{m} (Eps-3A^{m}) locus in diploid einkorn wheat and its relation to the syntenic regions in rice and Brachypodium distachyon L. *Molecular Breeding* **30**, 1097-1108

Gibala, M., Kicia, M., Sakamoto, W., Gola, EM., Kubrakiewicz, J., Smakowska, E., Janska, H. 2009. The lack of mitochondrial *AtFtsH4* protease alters Arabidopsis leaf morphology at the late stage of rosette development under short-day photoperiod. *The Plant Journal* **59 (5)**, 685-99.

Gill, BS., Appels, R., Botha-Oberholster, AM., Buell, CR., Bennetzen, JL., Chalhoub, B., Chumley, F., Dvorák, J., Iwanaga, M., Keller, B., Li, W., McCombie, WR., Ogihara, Y., Quetier, F., Sasaki, T. 2004. A Workshop Report on Wheat Genome Sequencing: International Genome Research on Wheat Consortium Genetics, **168,** 1087 - 1096.

Greenup A., Peacock WJ., Dennis ES., Trevaskis B. 2009. The molecular biology of seasonal flowering in *Arabidopsis* and cereals. *Annals of Botany* **103(8),** 1165-1172.

Griffiths, S., Simmonds, J., Leverington, M., Wang, Y., Fish, L., Sayers, L., Alibert, L., Orford, S., Wingen, L., Herry, L., Faure, S., Laurie, D., Bilham, L., Snape, J. 2009. Meta-QTL analysis of the genetic control of ear emergence in elite European winter wheat germplasm. *Theoretical and Apllied Genetics* **119 (3)**, 383-395.

Griffiths, S., Sharp, R., Foote, TN., Bertin, I., Wanous, M., Reader, S., Colas, I., Moore, G. 2006. Molecular characterization of *Ph1* as a major chromosome pairing locus in polyploid wheat. *Nature* 439, 749-752.

Gupta, PK., Mir, RR., Mohan, A., Kumar, J. (2008) Wheat Genomics: Present Status and Future Prospects. *International Journal of Plant Genomics* doi:10.1155/2008/896451

Hedden, P. 2003. The genes of the Green Revolution. *Trends in Genetics* **19**, 5–9.

Herndl, M., White, J.W., Hunt, L.A., Graeff, S., Claupein, W. 2008. Field-based evaluation of vernalization requirement, photoperiod response and earliness per se in bread wheat (*Triticum aestivum* L). *Field Crops Research* **105**, 193-201.

Herndl, M., White, J.W., Hunt, L.A., Graeff, S., Claupein, W. (2008) Field-based evaluation of vernalization requirement, photoperiod response and earliness per se in bread wheat (*Triticum aestivum* L). *Field Crops Research* **105**, 193-201.

Higgins, JA., Bailey, PC., Laurie, DA. 2010. Comparative Genomics of Flowering Time Pathways Using *Brachypodium distachyon* as a Model for the Temperate Grasses. *PLoS ONE* **5(4)**: e10065. doi:10.1371/journal.pone.0010065

Jizeng, J.,Shancen, Z., Xiuying, K.,Yingrui L., Guangyao, Z., Weiming, H., Rudi, A., Matthias, P.,Yong, T., Xueyong, Z., Ruilian, J., Chi, Z., Youzhi, M., Lifeng, G., Chuan, G., Manuel, S., Klaus, FXM., Dong, L., Shengkai, P., Fengya, Z., Qun H., Xianchun, X., Jianwen, L., Qinsi, L., Jie C. 2013. *Aegilops tauschii* draft genome sequence reveals a gene repertoire for wheat adaptation. *Nature* **496**, 91-95.

Khan, MS., 2007. Engineering photorespiration in chloroplasts: a novel strategy for increasing biomass production. *Trends in Biotechnology* **10**, 437-440.

Kikuchi, R., Kawahigashi, H., Ando, T., Tonooka, T., Handa, H., 2009. Molecular and functional characterization of PEBP genes in barley reveal the diversification of their roles in flowering. *Plant Physiology* **149**, 1341-1353.

Kim, WY., Hicks, KA., Somers, DE. 2005. Independent roles of *EARLY FLOWERING 3* and *ZEITLUPE* in the control of circadian timing, hypocotyls length, and flowering time. *Plant Physiology* **139**, 1557-1569.

Kitagawa, S., Shimada, S., Murai, K., 2012. Effect of *Ppd-1* on the expression of flowering-time genes in vegetative and reproductive growth stages of wheat. *Genes and Genetic Systems* 87, 161-168.

Kubaláková, M. *et al*., 2005, Chromosome sorting in tetraploid wheat and its potential for genome analysis, *Genetics* **170**, 823–9.

Kumar, S., Sharma, V., Chaudhary, S., Tyagi, A., Mishra, P., Priyadarshini, A., Singh, A. 2012. Genetics of flowering time in bread wheat *Triticum aestivum*: complementary interaction between vernalization-insensitive and photoperiod-insensitive mutations imparts very early flowering habit to spring wheat. *Journal of Genetics* **91**, 33–47.

Langridge, P. 2012. Genomics: Decoding our daily bread. *Nature* 491, 678–680.

Laurie, DA, Griffiths, S., Dunford, RP., Christodoulou, V., Taylor, SA., Cockram, J., Beales, J., Turner, A. 2004. Comparative genetic approaches to the identification of flowering time genes in temperate cereals. *Field Crops Research* **90**, 87–99.

Laurie, DA. 1997. Comparative genetics of flowering time. *Plant Molecular Biology* **35**, 167-177

Laurie, DA., Pratchett, N., Bezant, JH., Snape, JW. 1995. RFLP mapping of five major genes and eight quantitative trait loci controlling flowering time in a winter×spring barley *Hordeum vulgare* L. cross. *Genome* **38**, 575–585.

Lewis, S., Faricelli ME., Appendino, ML., Valarik, M., Dubcovsky, J. 2008. The chromosome region including the earliness *per se* locus *Eps-Am1* affects the duration of early developmental phases and spikelet number in diploid wheat. *Journal of Experimental Botany* **59 (13)**, 3593-3607.

Li, G., Yu, M., Fang, T., e Cao, S., Carver, BF., Yan, L.(2013) Vernalization requirement duration in winter wheat is controlled by TaVRN-A1 at the protein level. *The Plant Journal* **76**, 742–753.

Lin, F., Xue, SL., Tian, DG., Li, CJ., Cao, Y., Zhang, ZZ., Zhang, CQ., Ma, Q. 2008. Mapping chromosomal regions affecting flowering time in a spring wheat RIL population. *Euphytica* 164, 769-777.

Ling, HQ., Zhao, S., Liu, D.,Wang, J., Sun, H.,Zhang, C.,Fan, H., Li, D., Dong, L., Tao, Y., Gao, C., Wu, H., Li, Y., Cui, Y., Guo, X., Zheng, S., Wang, B., Yu, K., Liang, Q., Yang, W.,Lou, X.,Chen, J.,Feng, M., Jian, J., Zhang, X., Luo, G., Jiang, Y., Liu, J., Wang, Z., Sha, Y., Zhang, B.,Wu, H.,Tang, D., Shen, Q., Xue, P., Zou, S., Wang, X., Liu, X., Wang, F., Yang, Y.,An, X., Dong, Z., Zhang, K., Zhang, X., Luo, MC., Dvorak, J., Tong, Y., Wang, J., Yang, H., Li, Z., Wang, D., Zhang, A., Wang, J., 2013. , Draft genome of the wheat A-genome progenitor *Triticum urartu*. Nature **496**, 87–90.

Lopes, M., Reynolds, MP., Manes, Y., Singh, RP., Crossa, J., Braun, HJ. 2012. Genetic yield gains and changes in associated traits of CIMMYT spring bread wheat in a 'Historic' set representing 30 years of breeding. *Crop Science* **52,** 1123–1131.

McIntosh, RA., Yamazaki, Y., Devos, KM., Dubcovsky, J., Rogers, WJ., *et al*. 2003. Catalogue of Gene Symbols for Wheat.
Available: http://wheat.pw.usda.gov/ggpages/wgc/2003/. Accessed 2011 May 25.

Martinić, Z., 1975. Life cycle of common wheat varieties in natural environments as related to their response to shortened photoperiod. *Z. Pflanzenzüchtung* **75**, 237–251.

Massoud, F I 1974 Salinity and alkalinity as soil degradation hazards. Rept. FAO/UNEP Expert Committee on Soil Degradation. FAO (Rome).

Matsubara, K., Tanaka, EO., Hori, K., Ebana, K., Ando, T., Yano, M. 2012. Natural variation in *Hd17*, a homolog of *Arabidopsis ELF3* that is involved in rice photoperiod flowering. *Plant Cell Physiology* 53(4), 709-716.

Miura, H., Nakagawa, M., Worland, AJ., 1999. Control of ear emergence time by chromosome 3A of wheat. *Plant Breeding* **118**, 85-87.

Mueller-Cajar, O., Stotz, M., Bracher, A. 2013. Maintaining photosynthetic CO2 fixation via protein remodelling: the Rubisco activases. *Photosynth Research* Mar 31

Nass, LL., Pereira AA., Ellis D. 2007. Biofuels in Brazil: An Overview. *Crop Science* **47** 2228-2237.

Nitcher R., Disterfield, A., Tan, C., Yan., L., Dubcovsky, J., 2013. Increased copy number at the HvFT1 locus is associated with accelerated flowering time in barley. *Molecular Genetics and Genomics* **288 (5-6)**, 261–275.

Parry, MAJ., Andralojc, PJ., Scales, JC., Salvucci, ME., Carmo-Silva, AE., Alonso, H., Whitney, SM. 2013. Rubisco activity and regulation as targets for crop improvement. *Journal of Experimental Botany* **64 (3)**, 717-730.

Peng, J. H., Zadeh H., Lazo, G. R., Gustafson, J. P., Chao, S., Anderson, O. D Echalier, L. L. Q.,BGill, . B. S., Dilbirligi, M., Sandhu, D., Gill, K. S., Greene, R. A., Sorrells, M. E.,Akhunov, E. D., Dvorˇa´k, J., Linkiewicz, A. M., Dubcovsky, J., Hossain, K. G., Kalavacharla, V., Kianian, S. F., Mahmoud, A. A. Miftahudin, Conley, E. J.,Anderson, J. A., Pathan, M. S., Nguyen, H. T., McGuire, P. E.,Qualset C. O., Lapitan N. L. V. 2004. Chromosome bin map of expressed sequence tags in homologous group 1 of hexaploid wheat and homeology with rice and Arabidopsis. *Genetics* **168,** 609-623.

Price, AH. 2006. Believe it or not, QTLs are accurate! *Trends in Plant Science* 11, 213-216.

Rebetzke, GJ., Appels, R., Morrison, AD., Richards, RA., McDonald, G., Ellis, M.H., Spielmeyer, W., Bonnett, DG., 2001. Quantitative trait loci on chromosome 4B for coleoptile length and early vigour in wheat (*Triticum aestivum* L.). *Australian Journal of Agricultural Research*, **52**, 1221-1234.

Rebetzke, GJ.; Ellis, MH., Bonnett, DG., Condon, AG., Falk, DE., Richards, RA. 2011. The *Rht13* dwarfing gene reduces peduncle length and plant height to increase grain number and yield of wheat. *Field Crops Research* **124(3)**, 323-331.

Reynolds, M., Foulkes, J., Furbank, R., Griffiths, S., King, J., Murchie, E., Parry, M., Slafer, G. 2012. Achieving yield gains in wheat. *Plant, Cell and Environment* **35**, 1799–1823.

Richards, RA. (1988) A tiller inhibitor gene in wheat and its effect on plant-growth. *Australian Journal of Agricultural Research* **39**, 749–757.

Rosegrant, MW., Agcaoili, M. 2010. *Global Food Demand, Supply, and Price Prospects to 2010*. International Food Policy Research Institute, Washington, DC, USA.

Rousset, M., Bonnin, I., Remoue´, C., Falque, M., Rhone´, B., Veyrieras, J., Madur, D., Murigneux, A., Balfourier, F., Le Gouis, J., Santoni, S., Goldringer, I. 2011. Deciphering the genetics of flowering time by an association study on candidate genes in bread wheat (Triticum aestivum L.). *Theoretical and Applied Genetics* **123**, 907-926.

Sharpley AN. *et al.* 1994. Managing agricultural phosphorus for protection of surface waters: issues and options. *J. Environ. Qual.* **23**, 437–451.

Shaw LM, Turner AS, Laurie DA. 2012. The impact of photoperiod insensitive *Ppd-1a* mutations on the photoperiod pathway across the three genomes of hexaploid wheat (*Triticum aestivum*) *Plant Journal* **71**, 71–84.

Shimada, S., Ogawa, T., Kitagawa, S., Suzuki, T., Ikari, C., Shitsukawa, N., Abe, T., Kawahigashi, H., Kikuchi, R., Handa, H., Murai, K. 2009. A genetic network of flowering time genes in wheat leaves, in which an *APETALA1*/*FRUITFULL*-like gene, *VRN1*, is upstream of *FLOWERING LOCUS T*. *Plant Journal* 5**8**, 668–681

Shitsukawa, N., Ikari, C., Shimada, S., Kitagawa, S., Sakamoto, K., Saito, H., Ryuto, H., Fukunishi, N., Abe, T., Takumi, S., Nasuda, S., Murai, K. 2007. The einkorn wheat (*Triticum monococcum*) mutant, maintained vegetative phase, is caused by a deletion in the *VRN1* gene. *Genes and Genetic Systems* 82, 167-170.

Singh, N., Smith, A. 1997. A comparison of wheat starch, whole wheat meal and oat flour in the extrusion cooking process. *Journal of Food Engineering* 34, 15-32.

Singh, RP., Hodson, D, Huerta-Espino, J., Jin, Y., Njau, P., Wanyera, R., Herrera-Foessel, S., and Ward, RW. 2008. Will Stem Rust Destroy The World's Wheat Crop? *Advances in Agronomy* 98, 272–309.

Singh, RP., Hodson, DP., Huerta-Espino, J., Jin, Y., Bhavani, S., Njau, P., Herrera-Foessel, S., Singh, PK., Singh, S., Govindan, V. 2011. The Emergence of Ug99 Races of the Stem Rust Fungus is a Threat to World Wheat Production. *Annual Review of Phytopathology* 49 (1), 465–481.

Slafer, GA., Sastorre, EH., Andrade, FH. 1994. Increase in grain yield in bread wheat from breeding and associated physiological changes. In Genetic improvement of field crops (Ed GA Slafer). Marcel Dekker, Inc., New York.

Song, QJ., Shi, JR., Singh, S., Fickus, EW., Costa, JM., Lewis, J., Gill, BS., Ward, R., Cregan, PB. 2005. Development and mapping of microsatellite (SSR) markers in wheat. *Theoretical and Applied Genetics* **110 (3),** 550-560

Spielmeyer, W., McIntosh, RA., Kolmer, J., Lagudah, ES. 2005. Powdery mildew resistance and Lr34/Yr18 genes for durable resistance to leaf and stripe rust cosegregate at a locus on the short arm of chromosome 7D of wheat. *Theoretical and Applied Genetics* **111**, 731-735.

Steer, T., Thane, C., Stephen, A., Susan Jebb, S. (2008) Bread in the diet: consumption and contribution to nutrient intakes of British adults. *Proceedings of the Nutrition Society* **67**, doi:10.1017/S0029665108000372.

Tesfamichael, H., Kebrom, PM., Chandler, SM., Swain, Rod, WK., Richards, RA.,Wolfgang, S. 2012. Inhibition of Tiller Bud Outgrowth in the *tin* Mutant of Wheat Is Associated with Precocious Internode Development. *Plant Physiology* **160(1)**, 308-318.

Trevaskis B, Hemming MN, Peacock WJ, Dennis ES (2006) *HvVRN2* responds to daylength, whereas *HvVRN1* is regulated by vernalization and developmental status. *Plant Physiology* **140**, 1397–1405.

Trevaskis, B., Hemming, MN., Dennis, ES., Peacock, WJ. 2007. The molecular basis of vernalization-induced Flowering in cereals. *Trends Plant Science* 12, 352–357.

Turner, A., Beales, J., Faure, S., Dunford, RP., Laurie, DA. 2005. The pseudo-response regulator *Ppd-H1* provides adaptation to photoperiod in barley. *Science* **310**, 1031–1034.

Uauy. C., Paraiso, F., Colasuonno, P., Tran, RK., Tsai, H., Berardi, S., Comai, L., Dubcovsky, J. 2009. A modified TILLING approach to detect induced mutations in tetraploid and hexaploid wheat. *BMC Plant Biology* **9**, 115–129.

Valarik, M., Linkiewicz, AM., Dubcovsky, J. 2006. A microcolinearity study at the earliness *per se* gene *Eps-A^{m}1* region reveals an ancient duplication that preceded the wheat-rice divergence. *Theoretical and Applied Genetics* **112**, 945-957.

Van Beem, J., Mohler, V., Lukman, R., van Ginkel, M., William, M., Crossa, J., Worland AJ. 2005. Analysis of genetic factors influencing the developmental rate of globally important CIMMYT wheat cultivars. *Crop Science* **45**, 2113-2119.

Vose, PB. 1983. Rationale of selection for specific nutritional characters in crop improvement with Phaseolus vulgaris L. a case study. *Plant and Soil* **72** 351-364.

Wanjugi, H., Coleman-Derr, D., Huo, N., Kianian, SF., Luo, M., Wu, J., Anderson, OD., Gu, YQ. 2009. Rapid development of PCR-based genome-specific repetitive DNA junction markers in wheat. *Genome* **52**, 576-587.

Weller, JL., Liew, LC., Hecht, VFG., Rajandran, V., Laurie, RE., Ridge, S., Wenden, B., Schoor, JKV., Jaminon, O., Blassiau, C., Dalmais, M., Rameau, C., Bendahmane, A., Mcknight, RC., Lejeune-Henaut, I. 2012. A conserved molecular basis for photoperiod adaptation in two temperate legumes. *PNAS* doi/10.1073/pnas.1207943110.

Wilhelm, EP., Turner. AS., Laurie, DA. (2009) Photoperiod insensitive Ppd-A1a mutations in tetraploid wheat (Triticum durum Desf.) *Theor Appl Genet* **118**, 285–294.

Worland, AJ., Borner, A., Korzun, V., Li, WM., Petrovic, S., Sayers, EJ., 1998. The influence of photoperiod genes on the adaptability of European winter wheats. *Euphitica* **100**, 385-394.

Worland, AJ., Appendino, ML., Sayers, EJ. 1994. The distribution in European winter wheats of genes that influence ecoclimatic adaptability whilst determining photoperiodic insensitivity and plant height. *Euphytica* **80**, 219–228.

Xue, S., Zhang, Z., Lin, F., Kong, Z., Cao, Y., Li, C., Yi, H., Mei, M., Zhu, H., Wu, J., Xu, H., Zhao, D., Tian, D., Zhang, C., Ma, Z. 2008. A high-density intervarietal map of the wheat genome enriched with markers derived from expressed sequence tags. *Theoretical Applied Genetics 117*, 181–189.

Yan L, Fu D, Li C, Blechl A, Tranquilli G, Bonafede M, Sanchez A, Valarik M, Dubcovsky J. 2006. The wheat and barley vernalization gene *VRN3* is an orthologue of *FT*. *PNAS* **103**, 19581–19586.

Yan L, Loukoianov A, Blechl A, Tranquilli G, Ramakrishna W, SanMiguel P, Bennetzen JL, Echenique V, Dubcovsky J. 2004a. The wheat *VRN2* gene is a Flowering repressor down-regulated by vernalization. *Science* **303**, 1640–1644.

Yan, L., Helguera, M., Kato, K., Fukuyama, S., Sherman, J., Dubcovsky, J. 2004b Allelic variation at the *VRN-1* promoter region in polyploid wheat. Theor Appl Genet 109:1677–1686

Yan L., Loukoianov A., Tranquilli G., Helguera M., Fahima T., Dubcovsky J. 2003. Positional cloning of the wheat vernalization gene *VRN1*. *PNAS* **100,** 6263-6268.

Yoshida, R., Fekih, R., Fujiwara, S., Oda, A., Miyata, K., Tomozoe, Y., Nakagawa, M., Niinuma, K., Hayashi, K., Ezura, H., Coupland, G., Mizoguchi, T. 2009. Possible role of EARLY FLOWERING 3 in clock-dependent floral regulation by SHORT VEGETATIVE PHASE (SVP) in *Arabidopsis thaliana*. *New Phytologist* 182, 838-850.

You, FM., Huo, N., Deal, KR., Gu, YQ., Luo, M-C., McGuire, PE., Dvorak, J., Anderson, OD. 2011. Annotation-based genome-wide SNP in the large and complex *Aegilops tauschii* genome using next generation sequencing without a reference genome sequence. *BMC Genomics* **12**:59. doi:10.1186/1471-2164-12-59.

Zadoks, JC., Chang, TT., Konzak, CF. (1974) A Decimal Code for the Growth Stages of Cereals, *Weed Research* **14**, 415-421.

Zagotta, MT., Shannon, S., Jacobs, CI., Meeks-Wagner, DR. 1992. Early-flowering mutants of Arabidopsis thaliana. *Australian Journal of Plant Physiology* **19**: 411–418.

Zakhrabekova, S., Gough, SP., Braumann, I., Müller, AH., Lundqvist, J.,Ahmann, K.,Dockter, C.,Matyszczak, I., Kurowska, M., Druka, A., Waugh, R., Graner, A., Stein, N., Steuernagel, B., Lundqvist, U., Hansson, M. 2012. Induced mutations in circadian clock regulator Mat—a facilitated short-season adaptation and range extension in cultivated barley. *Proceedings of the National Academy of Sciences*, USA **109**, 4326–4331.

Zikhali, M., Leverington-Waite, M., Fish, L., Simmonds, J., Orford, S., Wingen, LU., Goram, R., Gosman, N., Bentley, A., Griffiths, S. (2014) Validation of a 1DL earliness per se (eps) flowering QTL in bread wheat (Triticum aestivum). *Molecular Breeding 10.1007/s11032-014-0094-3*.

Appendix 3.1 the AB and D copies of TaELF3 colours show primer position and exons (purple)

```
TaELF3_1AL      --------------------------------------TATTTCTCCCCAACCGATC--- 1166
TaELF3_1BL      CCCTCCTCCTCCTCCGTCCCCGGGCCGCGGCCGGCAGATATTTCTCCCCAACCGATCGGG 7884
TaELF3cas1DL    -------------------------------------ATATTTCTCCCCAACCGATC--- 730
                                                      *******************

TaELF3_1AL      ---CGAATCCCGCTCGCCGCCCGATCCCGCTGCCCCCGTGCTCCGCGGCCCGGTCCGGAG 1223
TaELF3_1BL      ATCCGAATCCCGCTCGCCGCCCGATCCCGCTGCCCCCGTGCTCCGCGGCCCGGTCCGGAG 7944
TaELF3cas1DL    ---CGA-----------------ATCCCGCTGCCCCCGTGCTCCGCGGCCCGGTCCGGAG 770
                   ***                 *************************************

                           casTaELF3_BBF1
TaELF3_1AL      ACCCCGAAAAATCCGCCCTTTTCCCCTCCTCCTCTTCTTCTTCTTCTTCTTGATTCGGAG 1283
TaELF3_1BL      ACCCCGAAAAATCCGCCCTTTTCCGCTCCTCCTCTTCTT------------GATTCGGAG 7992
TaELF3cas1DL    ACCCCGAAAAATCCGCCCTTTTCCCCTCCTCCTCTTCTT------------GATTCGGAG 818
                ************************ **************            *********

                                                BBF4   DDF1a
TaELF3_1AL      ATCTCCTCTCC-----GTCCCCTCTCCCTCCCTCCCTCCCTCCCACCCTCTCTCTCCCTC 1338
TaELF3_1BL      ATCTCCTCTCC-----GTCCCCTCTCCCTCCCTCCCCCGG-------------------- 8027
TaELF3cas1DL    ATCTCCTCTCCTCTCCGTCCCCTCTCCCTCCCTCCCTCCCTCCCTCTCTCTCTCTCTCCC 878
                ***********     ******************** *

                               casTaELF3_AAF1  casTaELF3_BBF2  casTaELF3_DDF1
TaELF3_1AL      CC--CCGGCCGAGCG---ATGATGGCGTCCTAGCTAGTTGTCTAGCTGGCCGCGATGAGG 1393
TaELF3_1BL      ----CCGAGTGAGCGCGCATGATGGCGGCCTAGCTG--------GCTGGCGGCGATGAGG 8075
TaELF3cas1DL    CCGGCCGAGCGAGCGCGCATGATGGCGTCCTAGCTA--------GCTGGCCGCGATGAGG 930
                    ***   *****   ********* *******         ******  *********

TaELF3_1AL      AGGGCCGGCGGCAAGGACGGCGGGGAGGACAAGGTCATGGGCCCGCTCTTCCCCAGGCTC 1453
TaELF3_1BL      AGGGCCGGCGGCAAGGACGGCGGGGAGGACAAGGTCATGGGCCCGCTCTTCCCCAGGCTC 8135
TaELF3cas1DL    AAATCCGGCGGC------GGCGGGGAGGACAAGGTCATGGGCCCGCTCTTCCCCAGGCTC 984
                *   ********      ******************************************

                                       ! point of insertion for D2
TaELF3_1AL      CACGTCAACGACACCACGCTCAAGGGCGGCGGCCCGCGCGCGCCGCCCCGCAACAAGATG 1513
TaELF3_1BL      CACGTCAACGACACCACGCTCAAGGGCGGCGGCCCGCGCGCGCCGCCCCGCAACAAGATG 8195
TaELF3cas1DL    CACGTCAACGACACCACGCTCAAGGGCGGCGGCCCGCGCGCGCCGCCCCGCAACAAGATG 1044
                ************************************************************

                                                   casTaELF3_DDF2
TaELF3_1AL      GCCCTCTACGAGCAGTTCAGCGTCCCCTCCCAGCGCTTCGCCGCCAACGCCGCCAACACC 1573
TaELF3_1BL      GCCCTCTACGAGCAGTTCAGCGTCCCCTCCCAGCGCTTCGCCGCCAACGCCGCCAACACC 8255
TaELF3cas1DL    GCCCTCTACGAGCAGTTCAGCGTCCCCTCCCAGCGATTCGC---------CGCCAACACC 1095
                *********************************** *****         **********

TaELF3_1AL      GCCCCAGCCGCCGCCCACCGCCCCGCCGCCAGCTAC------GCCGCGGTCTCCTCCGCC 1627
TaELF3_1BL      GCCCCAGCCGCCGCCCACCGCCCCNNNNNNNNNNNCAGCTACGCCGCCGTCTCCTCCGCC 8315
TaELF3cas1DL    GCCCCCGCCGCCGCCCACCGCCCCGCCGCCAGCTAC------GCCGCCGTCTCCTCCGCC 1149
                ***** ******************           *      ***** ************

                        casTaELF3_AAF2      casTaELF3_AAR1
TaELF3_1AL      TCCGCCGGACAGGTATCCCTTCCTTCCTTCCTCCCACCCATCTTCTCCTTTT-CTTTCTT 1686
TaELF3_1BL      TCCGCCGGACAGGTTTCC------------CTCTCACCCATCTTCTCCTTTTTCTTTCTT 8363
TaELF3cas1DL    TCCGCCGGACAGGTATCC------------CTCTCAC----------------------- 1174
                ************** ***            *** ***

                  DDR3                DD_Rx
TaELF3_1AL      TTTTGCCTCTATGTATGCACGTATATATTTTTAGCCTGTCCGCTGATTGGATTGGATTGG 1746
TaELF3_1BL      TTTTGCCTGTATGTATGTATGTATGTATTTTTATCCTGTCCGCTGATTGGATTGGATTGG 8423
TaELF3cas1DL    -------------------------TATTTTTAGCCTGTCCGCTGATTGGATTGGATTGA 1209
                                         ******** ************************

TaELF3_1AL      ATTGGATTGGATTGGATTGGATTG-AAACCTAGATGCCGCCTGCCATGGCCGCCGGCGGT 1805
TaELF3_1BL      ATTGGATTGGATTGGATTGGATTGGAAACCTAGATTCCACCTGCCATGGCCGCCGGCGAT 8483
TaELF3cas1DL    A-------------------------AACCTAGATGCCACCTGCCATGGCCGCCGGCCAT 1244
                *                         ********* ** ******************  *

TaELF3_1AL      TGCTTCAGCAGCAGTGCAGTGGGGGCTTCACAGTGTCAGTGTTAGACTAGGATGCCTCTA 1865
TaELF3_1BL      TACT------GCTGTGC------------------TCAGTGTTAGACTAGGATGCCTCTA 8519
TaELF3cas1DL    TACTTCAGCAGCAGTGCAGTGGGGGCTTCACAGTGTCAGTGCTAGACTAG----CCTCTA 1300
                * **      ** ****                  ****** ********    ******

                   casTaELF3_BBF3          casTaELF3_DDF3
TaELF3_1AL      TTGGCTTGGCCGGCATGTCGTCTCGCCTTGCCGCTCGCTCTATTGATGCTCTTTTGATGT 1925
TaELF3_1BL      TTGGCTTGGCT----TGTTGACTCGCCTTGCCG----CTCTATTGATGCTCTTTT----- 8566
TaELF3cas1DL    TTGGCTTGGCTGCCATGTCGTCTCGCCTTGCCG----CTCTATTCATGCTCTTTTGATGT 1356
                **********     *** * ************    ******* **********
                                                         BBR3
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TaELF3_1AL        ATG----TATGTATGCGAATTTAGCGACACACGCATGGT----------------TGTAT 1965
TaELF3_1BL        -------CATGTATGCAAACTTAGCGACACACGCATGGTGATGAAACGCCCGTTTTGTAT 8619
TaELF3cas1DL      ATGTATGTATGTATGCGAATTTA--GACACACGCATGGT----------------TGTAT 1398
                          ******** ** ***  **************                ***** 
                                         casTaELF3_BBR1   casTaELF3_DDR1
TaELF3_1AL        GATTACGAGTGCCGTGAGATGCTTACGATGTACGTATGGTTGGCTCTCGACGA------- 2018
TaELF3_1BL        GATTACGAGTGCCATGAGATGCTTATGTACTACGTATGCTTGGCTCTCGACGACTGCTTG 8679
TaELF3cas1DL      GATTACCAGTGCCGTGAGATGCTTACTATGTACGTATGGTTGACTCTCGATGAGTGATTG 1458
                  ****** ****** ***********     ******** *** ******* **        
                      casTaELF3_DDF4                    casTaELF3_BBR2
TaELF3_1AL        -----------------GTGA------------------TTCTTTATCTGTTAGATACCTT 2044
TaELF3_1BL        TCGGGTATCTGACTGAGGTGACCGGAAATGGTCACTGCTTCTTTATCTGTTAGATATCTT 8739
TaELF3cas1DL      TCGGGTATCTGACAGAGGCGACCGGAAATGGTCACTGGTTCTTTATCTGTTAGATACCTT 1518
                                   * **                 ****************** ***

TaELF3_1AL        GCGTTGATTATCGCTTTCCGGAGTTTGGCAGTTTTCTTTTCTGAACGCTAGTGCAGTGAC 2104
TaELF3_1BL        CCGTTGATTATCGCTTTCCGGAGTTTGGCGGTTTTCTTTTCTGAACGCTAGTGCAGTGAC 8799
TaELF3cas1DL      CCGTTGATTATCGCTTTCCGGAGTTTGGCAGTTTTCTTTTCTGAACGCTAGTGCAGTGAC 1578
                   **************************** ******************************
                           caTaELF3_AAF3
TaELF3_1AL        GGTTATGGGGCGCATCCGGGTACATGGTTGATGATTCCCACGATAGGCATCAGGGATGTG 2164
TaELF3_1BL        GATTATGGGGCGCATCCGGGCACAGCGTTGATGATTCCCGCGAGTGGCATCAGGGATGTG 8859
TaELF3cas1DL      GATTATGGGGCGCATCCGGGCACAGCGTTGATGATTCCCACGAGTGGCATCAGGGATGTG 1638
                  * ***************** ***  ************* ***  ***************
                              CasTaELF3_AAR2     (AAR4)
TaELF3_1AL        GAATTGGAAGATTGTCTGTCACTTCTGTTTGCACTTGCACACAGCAAAGATGATGAGTT- 2223
TaELF3_1BL        GAATTGGAAGATTGTCTGTCACTTCTGTTTGCAGTTGCACACAACAAAGATGATGAGATG 8919
TaELF3cas1DL      GAGTTGGAAGATTGTCTGTCACTTCTGTTTGCAGTTGCACACAACAAAGATGATGAGATG 1698
                  ** ****************************** ********* ************* *

                             casTaELF3_DDR2 DDR4
TaELF3_1AL        --------------TTCAGTGAGACACGA------CTGGGC------------------- 2244
TaELF3_1BL        GAGCCTACGTATTATTGTTTGACACACAAACTTATCTGAGTTTGTTCTAAATTATTTAAG 8979
TaELF3cas1DL      GAGCCTACATATTACTGTTTGACAGACAAACTTATCTGATTTTGTTCTAAATT----AAG 1754
                               *    *** * ** *       ***

TaELF3_1AL        AATGTCTTC----ATTTGTAATTGTATCCTA---GAGTACATTCTTT--TAAACTACTAC 2295
TaELF3_1BL        AATGTCCACGAATAATTCAAGTTGCTTGTTGCACGGATGAGTTTTTAGTGAGACACGAC 9039
TaELF3cas1DL      AATGTCCACGACTAATTCAAGTTGCTTGCACC---GATGAGTT-TTTAGTGAGACATGAC 1810
                  ******  *    * **  * ***  *         *   ** ***  * *   *  **

TaELF3_1AL        T-----------------------------------------------------TATTAC 2302
TaELF3_1BL        TGGGCAATGTCTT-----------------------------------------TATTAC 9058
TaELF3cas1DL      TGGGCAATGTCTTCATTTGTAATTGTATCCTAGAGTACATTCTTTTAAAGTACTTATTAC 1870
                  *                                                     ******

TaELF3_1AL        TAACTTGCGCCTTTTT-CTTGTAGATTGGTGGGATCGACAGACCTCTCTTTCCATCATTT 2361
TaELF3_1BL        TAACTTGTACCTTTTTTCTTGTAGATTGGTGGGATCGACAGACCTCTCTTTCCATCATTT 9118
TaELF3cas1DL      TAACTTGTGCCTTTTT-CTTGTAGATTGGTGGGATCGACAGACCTCTCTTTCCATCATTT 1929
                  *******  ******* ******************************************
                        BBR2
TaELF3_1AL        TGTGTGCCTTCAAACGAACCTGTGCGTTTGCCCGAACACATCAAGACCAACTCGAGTGGG 2421
TaELF3_1BL        TGCGTGCCTTCAAATGAACCTGTGCGTTTGCCCGAACACATCAAGACCAACTCGAGTGGG 9178
TaELF3cas1DL      TGTGTGCCTTCAAACGAACCTGTGCGTTTGCCCGAACACATCAAGACCAACTCGAGTGGG 1989
                  ** *********** *********************************************
                CasTaELF3_BBF4 casTaELF3_DDR3            AAR2 this may be same as D2
TaELF3_1AL        CGGGATGGCCATGCTACATCTGGGAGGCTTTCCACCCTGCTTAAGAGCAAGGACGCCTAT 2481
TaELF3_1BL        CGGGATGGCCAGGCTATATCTGGGAGGCTTTCCACCCAGCTTAAGAGCAAGGACGCCTAT 9238
TaELF3cas1DL      CGGGACGGCCATGCTACATCTGGGAGGCTTTCCACCCAGCTTAAGAGCAAGGACGCCTAT 2049
                  ***** ***** **** ******************** **********************

TaELF3_1AL        GCTGCAGGATCGACTGCTGAGTGTAGTAGTTCACAGCGTAGAGACAATAACAGCAACAAC 2541
TaELF3_1BL        GCTGCAGGATCGACTGCTGAGTGTAGTAGTTCACAGCGTAGAGACAA---------CAAC 9289
TaELF3cas1DL      GCTGCAGGATCGACTGCTGAGTGTAGTAGTTCACAGCGTAGAGACAATAACAG---CAAC 2106
                  ***********************************************         ****
                           casTaELF3_BBR3                           AAR1
TaELF3_1AL        AACAACAACACGAAGAATTCTTCTGGGAAGAAGTTGACTCACGATGATGATTTTACGGTT 2601
TaELF3_1BL        AACAATAGCATGAAGAATTCTTCTGGGAAGAAGTTGACTAACGATGATGATTTTACGGTT 9349
TaELF3cas1DL      AACAACAACACGAAGAATTCTTCTGGGAAGAAGTTGACTAACGATGATGATTTTACGGTT 2166
                  ***** * ** ************************* ***********************

TaELF3_1AL        CCTTCTGTCTTCTGCTCTGGAGTGCGCCCTCGCTCCAACCATGAGGAAGTGAGGATCCAA 2661
TaELF3_1BL        CCTTCTGTCTTCTGCTCTGGAGCGCGCCCTCGTTCCAACCATGAGGAAGTGAGGATCCAA 9409
TaELF3cas1DL      CCTTCTGTCTTCTGCTCTGGAGTGCGCCCTCGTTCCAACCATGAGGAAGTGAGGATCCAA 2226
                  ********************** ********* ***************************
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                              casTaEF3_DDF5         DDR2
TaELF3_1AL        GAGAATTCCACACCCTTCCCAGCTACAAGTCCGTATAAGAGTGGGCCTACGCTGTCCAAA 2721
TaELF3_1BL        GAGAATGCCACACCCTTCCCAGCTACAAGTCCGTATAAGAGTGGGCCTACGGTGTCCAAA 9469
TaELF3cas1DL      GAGAATTCCACACCCTTCCCAGCTACAAGTCCGTATAAGAGTGGGCCTACAGTGTCCAAA 2286
                  ****** ********************************************   ********

               Rialto C Spark T  Sav has  T
TaELF3_1AL        CCAACTGCAAAATTTCCCAACACCGACAAGAGGTACCTGGAAGGAAGGAACGCGTCGGAC 2781
TaELF3_1BL        CCAACTGCAAAATTTCCCAACACCGACAAGAGGTACCTGGAAGGAAGGAACGCGTCGGAC 9529
TaELF3cas1DL      CCAACTGCAAAATTTCCCAACACCGACAAGAGGTACCTGGAAGGAAGGAACGCGTCGGAC 2346
                  ************************************************************

          Sav has  A              casTaELF3_DDR4
TaELF3_1AL        ACGAGATCAATGGACTCTCCAAGTATTATCAGGGACAAAGCACCAGCAAACACAACGACA 2841
TaELF3_1BL        ACGAGATCAAGGGACTCTCCAAGTATTATCAGGGACAAAGCACCAGCAAACACAACGACA 9589
TaELF3cas1DL      ACGAGAGCAATGGACTCTCCAAGTATTATCAGGGACAAAGCACCAGCAAACACAACGACA 2406
                  ****** *** ************************************************

                       casTaELF3_BBF5 CasTaELF3_AAF4Spa/Sav T
TaELF3_1AL        AACTTTTTGGAAGCTGAAGAGAGGACTTCATCATTTCAATTTCCTGCAGAGAAGACAATG 2901
TaELF3_1BL        AACTTTTTGGAAACTGAAGAGAGGACTTCATCGTTCCAATTTTCTGCAGAGAAGACAATG 9649
TaELF3cas1DL      AACTTTTTGGAAGCTGAAGAGAGGACTTCATCATTTCAATTTTCTGCAGAGAAGACAATG 2466
                  ************ ****************** ** ****** *****************

                              casTaELF3_BBR4
TaELF3_1AL        GGTAAAAGAGACGACAAAGGCTCTTCGTATAGTAGGGTAAAAGAGACGAGCAGTATAAAT 2961
TaELF3_1BL        GGTAAAAGAGATGACAAAGGTTCTTCGTATAGTAGGGTAAAAGAGACGAGCAGTATAAAT 9709
TaELF3cas1DL      GGTAAAAGAGACGACAAAGGCTCTTCGTATAGTAGGGTAAAAGAGACGAGCAGTATAAAT 2526
                  *********** ******** ***************************************

TaELF3_1AL        GTTTCTGATAAGCAACATTCCCGAAACGAGGGGCATCAGGCTAGAACAAGGAATGAGAAT 3021
TaELF3_1BL        GTTTCTGATAAGCAACATTCCCGAAACGAGGGGCATCAGGCTAGAACAAGGAATGAGAAT 9769
TaELF3cas1DL      GTTTCTGATAAGCAACATTCCCGAAACGAGGGGCATCAGGCTAGAACAAGGAATGAGAAT 2586
                  ************************************************************

                                                         casTaELF3_AA_R3
TaELF3_1AL        GCTGCTGAGTCTCAGAATGCTCCAAAGGCTGGAAATGGGCCATACTCTACTGACATCGCA 3081
TaELF3_1BL        GCTGCTGAGTCTCAGAATGCTGCAAAGGCTGGAAATGGGCCATACTCTACTGACGTCGCA 9829
TaELF3cas1DL      GCTGCTGAGTCTCAGAATGCTCCAAAGGCTGGAAATGGGCCATACTCTACTGACGTCGCA 2646
                  ********************* ******************************** *****

TaELF3_1AL        TGCAACGGCGCTTCTAAACTGTCGGAGAAAGGCCTAAGAGAGACTGGTGAAAAGAGAAAA 3141
TaELF3_1BL        TGCAACGGCGCTTCTAATCTGTCGGAGAAAGGCCTAAGAGAGACTGGTGAAAAGAGAAAA 9889
TaELF3cas1DL      TGCAACGGCGCTTCTAATCTGTCGGAGAAAGGCCTAAGAGAGACTGGTGAAAAGAGAAAA 2706
                  ***************** ******************************************
                         CasTaELF3_DDF6
TaELF3_1AL        AGATCAACCGGACATCACGATGTGCAGAGGGATGATTCCTCGGATTCCTCTGTGGAATCT 3201
TaELF3_1BL        AGATCAACCGGACATCACGATGTGCAGAGGGATGATTCCTCGGATTCCTCCGTGGAATCT 9949
TaELF3cas1DL      AGATCAACCGGACATCACGATGCGCAGAGGGATGATTCCTCGGATTCCTCTGTGGAATCT 2766
                  ********************** *************************** *********

TaELF3_1AL        CTGCCAGATCTGGAGATCTCTCCAGATGATGTTGTCGGTGCTATTGGTCCAAAGCATTTC 3261
TaELF3_1BL        CTGCCAGATCTGGAGATCTCTCCAGATGATGTTGTCGGTGCTATTGGTCCAAAGCATTTC 10009
TaELF3cas1DL      CTGCCAGATCTGGAGATCTCTCCAGATGATGTTGTCGGTGCTATTGGTCCAAAGCATTTC 2826
                  ************************************************************
                     casTaELF3_BBF6
TaELF3_1AL        TGGAAAGCAAGAAGAGCTATCGTCAAGTAAGTATTCACCACTTAGGTCTTGTCCTTTCTG 3321
TaELF3_1BL        TGGAAAGCAAGAAGAGCTATTGTCAAGTAAGTATTCACCACTTAGGTCTTGTCCTTTCTG 10069
TaELF3cas1DL      TGGAAAGCAAGAAGAGCTATCGTCAAGTAAGCATTCACCACTTAGGTCTTGTCCTTTCTG 2886
                  ******************** ********** ****************************

TaELF3_1AL        TCTTCGTGTTTTTGAAAGGTCTGTGTGCACATAAGCTTGGTGCTCAGCAAATGAGCCAGG 3381
TaELF3_1BL        TCTTCGTGTTTTTGAAAGGTCTGTGTGCACATAAGCTTGGTGCCCAGCAAATGAGCCAGG 10129
TaELF3cas1DL      TCTTCGTGTTTTTGAAAGGTTTGTGTGCACATAAGCTTGGTGCTCAGCAAATGAGCCAGG 2946
                  ******************** ********************** ****************
                         casTaELF3_AAF5
TaELF3_1AL        CAGTCGAGCGGATTAGATCTTCCCATTTATACATGCTGTATCATCTCAAATCACCCTACT 3441
TaELF3_1BL        CAGTCGAGCGGATTAGATCTTCCCATTTCTACATGCTGTATCATCTCAAATCACCCTACT 10189
TaELF3cas1DL      CAGTCGAGCGGATTAGATCTTCCCATTTCTACATTCTGTATCATCTCAAATCACCCTACT 3006
                  **************************** ***** ************************

                  DDF9_old       casTaELF3_BBR5   casTaELF3_DDR5
TaELF3_1AL        GTACACATGCAAACACAAACACGCATGCACATTTGTCATGTGCATTCTATGAACATCTCT 3501
TaELF3_1BL        GTGCACGTGCAAACACAAACGCACATGCACATTTGTCATGTGCATTCTATGAACATCTCT 10249
TaELF3cas1DL      GTACACGTGCAAACACAAACACGCATGGACATTTGTCATGTGCATTCTATGAACATCTCT 3066
                  ** *** ************* * **** ********************************
                            casTaELF3_DDF7
TaELF3_1AL        TTTCCTTTTTGACAGACTGATGCTT----------------------------------- 3526
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TaELF3_1BL          TTTCCTTTTTGACAGACTGATGCTT----------------------------------- 10274
TaELF3cas1DL        TTTCCTTTTTGACAGACTGATGCTTGGGCCTCTTTGATTCGTAGGATTTCCAAAACGCGG 3126
                    *************************

TaELF3_1AL          ------------------------------------------------------------
TaELF3_1BL          ------------------------------------------------------------
TaELF3cas1DL        GAATAGGAAAAACATGGGATTAGAGTGGAATGTCGTCTTGAATCCTACAGGATTGTACGA 3186


TaELF3_1AL          ------------------------------------------------------------
TaELF3_1BL          ------------------------------------------------------------
TaELF3cas1DL        GTGTTTGATTGTGCATAGAAAAAACGCAGGATTCTTTCAAAGAGGTTTGAGTGGATGGGA 3246


TaELF3_1AL          ------------------------------------------------------------
TaELF3_1BL          ------------------------------------------------------------
TaELF3cas1DL        TGTTTCCTATGAAATCTAGTGCAAATGAATCCTATGGAAAAATTCCTATGGTTTACAATC 3306


TaELF3_1AL          ------------------------------------------------------------
TaELF3_1BL          ------------------------------------------------------------
TaELF3cas1DL        CTACGAATCAAACAACCAAGATAGGAAAAATTCCTCAGGATTAGAATCCTCCAAAATTCC 3366

                                                                DDF
TaELF3_1AL          ------------------------------AAATGTAGTACTCCCATCCATTCCAAAATA 3556
TaELF3_1BL          ------------------------------AAATGTAGTACTCCCATCCGTTCCAAAATA 10304
TaELF3cas1DL        TTTGAGAATCCTTTGAATCAAAGAAGCCCTAAATGTAGTACTCCCATCCGTTCCAAAATA 3426
                                                  ******************* **********

                      BBF          casTaELF3_DDR6
TaELF3_1AL          TAAGGT--ATTAGTTTTTCAAAAGTCAAACATGTGCATGTTTGACCAAGTTTTTAGAAA 3614
TaELF3_1BL          TAAGGTGTATTAGTTTTTCAAAAGTCTAACATGTGCATGTTTGACCAAGTTTTTAGAAA 10364
TaELF3cas1DL        TAGTGT--ATTAGTTTTTCAAAAGTCAAACATGTGCATGTTTGACCAAGTTTTTAGAAA 3484
                    **  **  ****************** *********************************

                                                          CasTaELF3_AAR4
TaELF3_1AL          AAAGTGTCAATATATACAATAACAAATTTGTATCATTGGATCCATGACGGAAAGTATTTT 3674
TaELF3_1BL          AAAGTATCAATATATACAATAACAAATTTGTATCATTAGATCCATGACGAAAAGTATTTT 10424
TaELF3cas1DL        AAAGTATCAATATATACAATAACAAATTTGTATCATTAGATCCATGACGGAAAGTATTTT 3544
                    ***** ******************************* *********** **********

                         CasTaELF3_DDF8  casTaELF3_BBF7
TaELF3_1AL          TGTATTTTATTTTATTTTGTATTGTAGATGTCGATATTTTATTCTATAATCTTGGTCAAA 3734
TaELF3_1BL          TGTA-----------------TTGTACATGTTGGTATTTTATTCTATAATCTTGGTCAAA 10467
TaELF3cas1DL        TGTATTTTATTTTATTCTGTATTGTAGATGTCAATATTTTATTCTATAATCTTGGTCAAA 3604
                    ****                 ***** ****   **************************

TaELF3_1AL          CATACATAAGTTAGACTTGCACGAAAACTGATGCACCTTATATTCTGGAAGGAGGGAGTA 3794
TaELF3_1BL          CGTACATAAGTTAGACTTGCACGAAAACTGATGCACCTTATATTCTGGAAGGAGGGAGTA 10527
TaELF3cas1DL        CATACATAAGTTAGACTTGCACGAAAACTGATGCACCTTATATTCTGGAAGGAGGGATTA 3664
                    * ******************************************************* **
                                                  DDR9
TaELF3_1AL          TCTCTCTTAATCACTATAACTTCCTTTCTTGTTTTGTAATCACTTTTCTTTGAACTCTAT 3854
TaELF3_1BL          TCTCTCTTAATCACTATAACTTCCTTTCTTGTTTAGTAATCACTTTTCTTTGAACTCGAT 10587
TaELF3cas1DL        TCTCTCTTAATCACTATAACTTCCTTTCTTGTTTTCTAATCACTTTTCTTTGAACTCTAT 3724
                    **********************************  ********************* **
                    casTaELF3_BBR6
TaELF3_1AL          ACAGTCAGCAGCGGGTTTTTGCTGTCCAAGTGTTCGAGCTGCATCGACTGATCAAAGTGA 3914
TaELF3_1BL          GCAGTCAGCAGCGGGTTTTTGCTGTCCAAGTGTTCGAGCTGCATCGACTGATTAAAGTGA 10647
TaELF3cas1DL        ACAGTCAGCAGCGGGTTTTTGCTGTCCAAGTGTTCGAGCTGCATCGACTGATCAAAGTGA 3784
                     *************************************************** *******

TaELF3_1AL          GTCTGCGCCACCAAATATATAGTAGCCTGTGATTCTTACTCGCCACAAGCGGGCGGTTAG 3974
TaELF3_1BL          GTCTGCGCCACCAAATATATAGTAACC-----------------ACAAGCGGGTGGTTAG 10690
TaELF3cas1DL        GTCTGCGCCACCAAATATATAGTAGCCTGTGATTCTTACTCGCCACAAGCGGGTGGTTAG 3844
                    ************************ **                 ********* ******

TaELF3_1AL          CTTATTGATGTATTTTGTGTTGGGACGCTGATATAGCCATGTTATGTATGTGCTTGCAAG 4034
TaELF3_1BL          CTTATTGATATATTTTGTGTTGGGATGCTGATATAGCCATGTTATGTATGGGCTTGCAAG 10750
TaELF3cas1DL        CTTATTGATGTATTTTGTGTTGGGATGCTGATATAGCCATGTTATGTATGTGCTTGCAAG 3904
                    ********* *************** ************************ *********

                                          casTaELF3_AAF6 Spa and Sav have G
TaELF3_1AL          CAGGTGCAGAAGTTGATTGCAGCATCTCCACACCTACTTATTGAATGGGATCCGTGCCTT 4094
TaELF3_1BL          CAGGTGCAGAAGTTGATTGCAGCATCTCCACACCTACTTATTGAAGGGGATCCGTGCCTT 10810
TaELF3cas1DL        CAGGTGCAGAAGTTGATTGCAGCATCTCCACACCTACTTATTGAAGGGGATCCGTGCCTT 3964
                    ********************************************* **************
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TaELF3_1AL          GGCAGTGCCCTGGTGACAAGCAAGAAGAAGACGGCTGCAGCCAATGTGGAAAAGCAGCTT 4154
TaELF3_1BL          GGCAGTGCCCTTGTGACAAGCAAGAAGAAGACGGCTGCAGCCAATGTGGAAAAGCAGCTT 10870
TaELF3cas1DL        GGCAGTGCCCTGGTGACAAGCAAGAAGAAGACGGCTGCAGCCAATGTGGAAAAGCAGCTT 4024
                    *********** ************************************************

                                        casTaELF3_DDR7
TaELF3_1AL          CTATCAGCTAAAAGCAAAGATGACGATGATGCACAGCTTACCCTGCAGCAGGCGGAGTAC 4214
TaELF3_1BL          CTGTCAGCTAAAAGCAAAGATGACGATGATGCACAGCTTACCCTGCAGCAGGCGGAGTAC 10930
TaELF3cas1DL        CTATCAGCTAAAAGCAAAGACGACGATGATGCACAGCTTACCCTGCAGCAGGCGGAGTAC 4084
                    ** ***************** ***************************************

                   casTaELF3_DDF9 (DDF11) Kasp1 common casTaELF3_AAR5 casTaELF3_BBF8
TaELF3_1AL          TCGAAAGACAACACTGAAGGAAACCAGGCTTCACCATCTCAAGACAATGATGTAGTCGAG 4274
TaELF3_1BL          TCGAAAGATAACACTGAAGGAAACCAGGCTTCACCATCTCAAGACAATGACGTAGTCGAG 10990
TaELF3cas1DL        TCGAAAGATAACACTGAAGGAAACCAGGCTTCACGATCTCAAGACAATGATGTAGTCGAG 4144
                    ******** ************************* *************** *********

TaELF3_1AL          GTCCGGCATGAGAACCAAGCTGCATCAAACGGTGCGGTTAGCAGTAACCCTCCTGCTATG 4334
TaELF3_1BL          GTCCGGCATGAGAACCAAGCTGCATCAAACGGTGCGGTTAGCAGTAACCCTCCTGCTATG 11050
TaELF3cas1DL        GTCCGGCATGAGAACCAAGCTGCATCAAACGGTGCGGTTAGCAGTAACCCTCCTGCTATG 4204
                    ************************************************************
                                                                   Kasp2
TaELF3_1AL          CCTGCTCCTCCCGACAACAAGCAGAACAACTGGTGTGCTCCTCCGCCTCAGAATCAGTGG 4394
TaELF3_1BL          CCTGCTCCTCCCGACAACAAGCAGAACAACTGGTGTGCTCCTCCGCCTCAGAATCAGTGG 11110
TaELF3cas1DL        CCTGCTCCTCCCGACAACAAGCAGAACAACTGGTGTGCTCCTCCGCCTCAGAATCAGTGG 4264
                    ************************************************************

 Kasp Rialto/Sav C/T Vic/Fam          Kasp2 common casTaELF3_DDR8
TaELF3_1AL          CTCGTTCCCGTCATGTCTCCGTCGGAAGGGTTCGTCTACAAACCATACACAGGGCCGTGC 4454
TaELF3_1BL          CTCGTTCCCGTCATGTCTCCGTCGGAAGGGTTCGTCTACAAACCATACACAGGGCCGTGC 11170
TaELF3cas1DL        CTCGTTCCCGTCATGTCTCCATCGGAAGGGTTCGTCTACAAACCATACACAGGGCCATGC 4324
                    ******************** *********************************** ***

TaELF3_1AL          CCCCCGGCAGGAAGCATCTTGGCCCCGTTTTACGCAAGCTGTGCTCCTCTGAGCCTGCCA 4514
TaELF3_1BL          CCCCCGGCAGGAAGCATCTTGGCCCCGTTTTACGCAAGCTGTGCTCCTCTGAGCCTGCCA 11230
TaELF3cas1DL        CCCCCGGCAGGAAGCATCTTGGCCCCGTTTTACGCAAGCTGTGCTCCTCTGAGCCTGCCA 4384
                    ************************************************************

                                                              casTaELF3_DDF10
TaELF3_1AL          TCTACAGCTGGGGAATTCATGAATTCTCCATACGGCATCCCTATGCCTCACCAGCCGCAG 4574
TaELF3_1BL          TCTACAGCTGGGGAATTCATGAATTCTCCATACGGCATCCCTATGCCTCACCAGCCGCAA 11290
TaELF3cas1DL        TCTACAGCTGGGGAATTCATGAATTCTCCATACGGCATCCCTATGCCTCACCAGCCGCAC 4444
                    ***********************************************************

                  casTaELF3_BBR7
TaELF3_1AL          CACATGGGCGTCGGCGGCCCACCAGCCATGCCCCCGATGTACTTCCCGCCTTTCAGCGTG 4634
TaELF3_1BL          CACATGGGCGTCGGAGGCCCACCAGCCATGCCTCCGATGTACTTCCCGCCTTTCAGCGTG 11350
TaELF3cas1DL        CACATGGGCGTCGGCGGCCCACCAGCCATGCCTCCGATGTACTTCCCGCCTTTCAGCGTG 4504
                    ************** ***************** ***************************

TaELF3_1AL          CCAGTGATGAACCCGGTGGTCTCATCCTCTGCAGTGGAGCAGGTGAGCCGCGTGGCCGCA 4694
TaELF3_1BL          CCGGTGATGAACCCGGTGGTCTCATCCTCCGCAGTGGAGCAGGTGAGCCGCGTGGCCACA 11410
TaELF3cas1DL        CCAGTGATGAACCCGGTGGTCTCATCCTCTGCAGTGGAGCAGGTGAGCCGCGTGGCCGCA 4564
                    ** ************************** *************************** **

                           casTaELF3_AAF7        casTaELF3_DDR9(TaELF3_DDR8)
TaELF3_1AL          GCGCGACCCAACACTCATGTCGAGCACCACTCAAGGAGCTCGTGCAACATGAGGAACGAG 4754
TaELF3_1BL          GCGCGACCCAACACTCACGTCGAGCACCACTCGAGGAGCTCGTGCAACATGAGGAACGAG 11470
TaELF3cas1DL        GCGCGACCCAACACTCACATCGAGCACCACTCGAGGAGCTCGTGCGACATGAGGAACGAG 4624
                    *****************  ************* ************ **************
Ria,Spa, Cad, Bad, Sav have G    Blackhull Charger and Avalon A
TaELF3_1AL          GCCGTGTCGGCCGGCGGCGTCTGGAGGTTCCACTCGTCCCGCGGCAGCGAGCTGCAAGGG 4814
TaELF3_1BL          GCCGTGTCGGCCGGCGGCGTCTGGAGGTTCCACTCGTCCCGCGGCAGCGAGCTGCAAGGG 11530
TaELF3cas1DL        GCTGTGTCGGCCGGCGGCGTCTGGAGGTTCCACTCGTCCCGCGGCAGCGAGCTGCAAGGG 4684
                    ** *********************************************************
                           casTaELF3_BBF9
TaELF3_1AL          AGCAGCGCCGCCAGCAGCCCTTTTGACAGGCAGCAGGGCCAGGGCGAGGCGAGGGGCCCT 4874
TaELF3_1BL          AGCAGCGCCGCCAGCAGCCCTTTCGACAGGCAGCAGGGCCAGGGCGAGGCGAGGGGCCCT 11590
TaELF3cas1DL        AGCAGCGCCGCCAGCAGCCCTTGTGACAGGCAGCAGGGCCAGGGCGAGGCGAGGGGCCCT 4744
                    **********************  ************************************

                                        casTaELF3_AAR6
TaELF3_1AL          GCCGCGGCCGCACCTGCGGCGCCCCTCCCTACGTCGTCGGCCGGGAACGGGAACGCGGCC 4934
TaELF3_1BL          GCCGCGGCCGCACCTGCGGCACCACTCCCTACGTCGTCAGCCGGGAACGGGAACGCGGCC 11650
TaELF3cas1DL        GCCGCGGCCGCACCTGCGGCACCCCTCCCTACGTCGTCAGCCGGGAACGGGAACGCGGCC 4804
                    ******************** ** ************* **********************
                                       casTaELF3_BBR8
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TaELF3_1AL        CAGCAACCCCAGGTCTCCTCGGGCAGCCAGGAGAACCCGGTGGCGGCAGCGGCCCGTGTG 4994
TaELF3_1BL        CAGCAGCCCCAGGTCTCCTCTAGCAGCCAGGAGAACCCGGTGGCGGCAGCGGCCCGTGTG 11710
TaELF3cas1DL      CAGCAGCCCCAGGTCTCCTCGGGCAGCCAGGAGAACCCGGTGGCGGCAGCGGCCCGTGTG 4864
                  ***** **************  ***************************************

                        casTaELF3_AAF8
TaELF3_1AL        ATCCGGGTGGTCCCGCACACAGCGCGCACCGCGTCAGAGTCGGCGGCGCGCATCTTCCGG 5054
TaELF3_1BL        ATCCGGGTGGTCCCGCACACGGCGCGCACCGCGTCGGAGTCGGCGGCGCGCATCTTCCGG 11770
TaELF3cas1DL      ATCCGGGTGGTCCCGCACACGGCGCGCACCGCGTCGGAGTCGGCAGCGCGCATCTTCCGG 4924
                  ******************** ************* ******** ***************

TaELF3_1AL        TCGATCCAGATGGAGAGGCAGCAGAACGGCCCGTGACCGAGCGACCGCATGCAGTGGTTG 5114
TaELF3_1BL        TCGATCCAGATGGAGAGGCAGCAGAACGGCCCGTGACCGAGCGACCGCATGCGGTGCTTG 11830
TaELF3cas1DL      TCGATCCAGATGGAGAGGCAGCAGAACGGCCCGTGACAGAGCGACCGCATGCGGTGGTTG 4984
                  ************************************ ************** *** ***

                          casTaELF3_DDF11    (Barc62 MZ DDR2)
TaELF3_1AL        GCCGGCACAAAGAAAGAAAGGAAGGAAGAAAGCTTAGCCAATTAGCGCTTGGGAGTATGT 5174
TaELF3_1BL        GCCGGCACAAAGAAA---AGGAAGGAAGAAAGCTTAGCCAATTAGCGCTTGGGAGTATGT 11887
TaELF3cas1DL      GCCGGCACAAAGAAAGAAAGGAAGGAAGAAAGCTTAGCCAATTAGAGCTTGGGAGTATGT 5044
                  ***************   *************************** **************

TaELF3_1AL        TGTTATTTTTGAGCAGGCAGGCAG----CAAGCAAATAGCATTCCTATATAT--TTGTCC 5228
TaELF3_1BL        TGTTATTTTTGAGCAGGCA----------------ATAGCATTCCTATATAT--TTGTCC 11929
TaELF3cas1DL      TGTTATTTTTGAGCAGGCAGGCAGGCAGCAAGCAAATAGCATTCCTATATATATTTGTCC 5104
                  *******************                ****************  ******

                                                              Tandem repeat
TaELF3_1AL        CTCGGTGTCGGTAAAAGCGAATTTTTGGCGACTGTAAATATGCAAAGCAAAGCAGGACTT 5288
TaELF3_1BL        CTCGGCGTCGGTAAAAGCGAATTTTTGGCGACTGTAAATATGCAAAGCAAAGCAGGACTT 11989
TaELF3cas1DL      CTCTGCGTCGGTAAAAGCGAATTTTTGGCGACTGTAAATATGCAAAGCAAAGCAGGACTT 5164
                  *** * ******************************************************

casTaELF3_DDR10 (Barc62 MZ DDF2/DDR10)Grain genes marker barc62 not D specific
TaELF3_1AL        GC--------CAGAACAGAATGAGTGCTGGTTGGGCAAAGCAGGACTTGTATCTATCAAT 5340
TaELF3_1BL        G------------------------------------------------TATCTATCTAT 12001
TaELF3cas1DL      GTATGAAGGCCAGAACAGAATGAGTGCTGGTTGGGCAAAGCAGGACTTGTATCTATCTAT 5224
                  *                                                ******** **

                    casTaELF3_AAR7                          BBR
TaELF3_1AL        CTACCTATCTATTTAT-----------GCCAGAATGAAAACTGTAACTGTTAGTGTTAGG 5389
TaELF3_1BL        CTATTTATCTATCTAT-----------GCCACAATGAAAACTGTAACTGTTAGTTTTAGG 12050
TaELF3cas1DL      CTATCTATCTATCTATCTATCTACTATGCCAGAATGAAAACTGTAACTGTTAGTGTTAGG 5284
                  ***  ******* ***          **** ********************** *****

                                                 casTaELF3_BBF10
TaELF3_1AL        TGTATGTATGTCTCAGGCAAAAAGAAGTGAAACCTGGGAGTGATGGCTCTGCTATATTAT 5449
TaELF3_1BL        TGTAT----GTCTCAGGCAAAAAGAAGTGAAACCTGGGAGTGATGTCTCTGCTGTATTGT 12106
TaELF3cas1DL      TGTATGTATGTCTCAGGCAAAAAGAAGTGAAACCTGGGAGTGATGGCTCTGCTGTATTAT 5344
                  *****    ************************************ ******* **** *

TaELF3_1AL        CTATGTATGTGCAGCTATAGTGCCTGCTGATATCTTAT---------------------- 5487
TaELF3_1BL        CTATGTATGTGCAGCTATATTGCCTGCTGATATCTTAT---------------------- 12144
TaELF3cas1DL      CTATGTATGTCCAGCTATATTGCCTGCTGATATCTTATGGGCCTCTTTGATTCGTAGGAT 5404
                  ********** ******** ******************

TaELF3_1AL        ------------------------------------------------------------
TaELF3_1BL        ------------------------------------------------------------
TaELF3cas1DL      TTTCAAAACGCGGGAATATGAAAAACATGGGATTAGAGTGGAATGTCGTCTTGAATCCTA 5464

TaELF3_1AL        ------------------------------------------------------------
TaELF3_1BL        ------------------------------------------------------------
TaELF3cas1DL      CAGGATTGTACGAGTGTTTGATTGTGCATAGAAAAAACGCAGGATTCTTTTAAAGAGGTT 5524

TaELF3_1AL        ------------------------------------------------------------
TaELF3_1BL        ------------------------------------------------------------
TaELF3cas1DL      TGAGTGGATGGGATGTTGCCTATGAAATCTAGTGCAAAATGAATCCTATGGAAAAATTCC 5584

TaELF3_1AL        ------------------------------------------------------------
TaELF3_1BL        ------------------------------------------------------------
TaELF3cas1DL      TATGGTTTACAATCCTACGAATCAAACAACCAAGATAGGAAAAATTCCTCAGGATTAGAA 5644

TaELF3_1AL        ----------------------------------------------AAAAGAAATTTGGT 5501
TaELF3_1BL        ----------------------------------------------AAAAGAAATTTGGT 12158
TaELF3cas1DL      TCCTCCAAAATTCCTTTGAGAATCCTTTGAATCAAAGAAGCCCTATAAAAGAAATTTGGT 5704
                                                                **************
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TaELF3_1AL        ATGTTTCTTTTTTT-GCCCATTGTGTACTGTATTGTTTATTTTTGTATAT----TGGGCC 5556
TaELF3_1BL        ATGTTTCTTTTTTTTGCCCATTGTGTACTGTATTATTTATTTTTGTATATATATTGGGCC 12218
TaELF3cas1DL      ATGTTTCTTTTTTT-GCCCATTGTGTTCTGTATTATTTATTTTTGTATAT----TGGGCC 5759
                  ************** *********** ******* ***************    ******
                                     casTaELF3_BBR9
TaELF3_1AL        AACCTGCCAGATGATTATTGCCAACCCCAGGAAGTGAGCCAATACCTTACTGTTACAGTT 5616
TaELF3_1BL        AACCTGCCAGATGATTGTTGCCAATCCCAGGAAGTGAGCCACTACCTTACTGTTACAGTT 12278
TaELF3cas1DL      AACCTGCCAGATGATTATTGCCAACCCCAGGAAGTGAGCCAATCCCTTACTGTTACAGTT 5819
                  **************** ******* **************** * ****************

TaELF3_1AL        TTAAATTTGTGTTTGAACTTGGATTTGCAAATGCTGAAAGTAGCATATTGTATTTGAGAG 5676
TaELF3_1BL        TTAGATTTGTGTTTGAACTTGGATTTCCAAATGCTGAAAGTAGCATATTGTATTTGAGAA 12338
TaELF3cas1DL      TTATATTTGCGTTTGAACTTGGATTTGCAAATGCTGAAAGTAGCATATTGTATTTGAGAA 5879
                  *** ***** **************** ******************************** 

TaELF3_1AL        TTTTTTTACAACTTCCAAACACAGTTACCACATTTTGATTTGTATGACAGGTCAGATGTA 5736
TaELF3_1BL        TTTTTT-ACAACTTCCAGACACAGTTACCACATTTTGATTTGTATGACAGGTCAGATGTA 12397
TaELF3cas1DL      TTTTTT-ACAACTTCCAAACACCGTTACCACATTTTGATTTGTATGACAGGTCAGATGTA 5938
                  ****** ********** **** *************************************

TaELF3_1AL        GACTAAACGAATTGTTCTGTCATTTATTATTTTCTAGTGAAAGGGAATGCGATTCTTATT 5796
TaELF3_1BL        GACTAAACTAATTGTTCTGTCATTAATTATTTTCTAGTGAAAGGGAACGCGATTCTTATT 12457
TaELF3cas1DL      GACTAAACGAATTGTTCTGTCATTTATTATTTTCTAGTGAAAGGGGGCGCGATTCTTATT 5998
                  ******** *************** ********************   ************

TaELF3_1AL        CCAACCTAACAATAATAATACTAGTTTGTAGCTTCTCAAGTCATTTATATACA--TGAAA 5854
TaELF3_1BL        CCAACCTAACAATAATAATACTAGTTTGTAGCTTCTCAAGTCATTTATATATACCTGAAA 12517
TaELF3cas1DL      CCAACCTAACAATAATAATACTAGTTTGTAGCTTCTCAAGTCATTTATATACA--TGAAA 6056
                  *************************************************** *  *****

TaELF3_1AL        AACACATTAGTTATTCTTCTTCCCATAAAAACAACATAGATTTTATAACACATCAGATTC 5914
TaELF3_1BL        AACACATTAGTTATTCTTCTTCCCATAAAAACAACATAGATTTTATAACACATCAGATTC 12577
TaELF3cas1DL      AACACATTAGTTA-----------------------------------CACATCAGATTC 6081
                  *************                                   ************
                                                 CasTaELF3_DDR11
TaELF3_1AL        AAAATTCACCCATGGAATAAAAACACTCTCAGAAAGGAAGATCTGCTCCCATCAAAAAAA 5974
TaELF3_1BL        AAAATTCACCCATGGAATAAAAACACTCTCAGAAAGGAAGATCTGCTCCCATCAAAAAAA 12637
TaELF3cas1DL      AAAATTCACCCATGGAATAAAAACACTCTTAGAAAGGAAGATCTGCTCCCATTAAAAAAA 6141
                  ***************************** ********************** *******

TaELF3_1AL        GAAAAAAGGAAAAGAAA---GGAGCATCTGCTTTCTCACTATATTGGATTGATTCAACAA 6031
TaELF3_1BL        GAA----GGGAAAAAAA---GGAACATCTGCTTTCTCACTATATTGGATTGATTCAACAA 12690
TaELF3cas1DL      GAAAAAAGGAAAAAAAAAAAGGAGCATCTGCTTTCTCACTATATTGGATTGATTCAACAA 6201
                  ***    ** *** ***   *** ************************************
                            casTaELF3_AAR8
TaELF3_1AL        GAATAAAACATTCGCCGCCGTGACACAAGGCGATGTGCGTAAAGCTTGCGATAAAAAAAA 6091
TaELF3_1BL        GAATAAAACAATCGCCGCCGCGACACAAGGCGATGTGCGTAAAGCTTGCGATATAAAAAA 12750
TaELF3cas1DL      GAATAAAACAATCGCCGCCGCGACACGAGGCGATGTGCGTAAAGCTTGCGATAAAAAAAA 6261
                  ********** ********* ***** ************************** ******
                                casTaELF3_AAR
TaELF3_1AL        AGAATCGACTGGCACTCTATTCTGTACCGAAAACTCAAAACACAAAGATTGTTTTGCTAC 6151
TaELF3_1BL        -GAATCAACTGGCGCTCTATTCTGGACCCAAAAC-CAAAACACAAAGATTGTTTTGCTAC 12808
TaELF3cas1DL      AGAATCGACTGGCGCTCTATTCTGTACCCAAAACTCAAAACACAAAGATTGTTTTGCTAC 6321
                   ***** ****** ********** *** ***** *************************

TaELF3_1AL        GACACACTTCATCTGTTATATCTACACACACACACACACTACTAGGCTAGCACCACAGCA 6211
TaELF3_1BL        TACACACTTCATCTGTTATATCTACACACACAC------TACTAGGCTAGCACCACAGCA 12862
TaELF3cas1DL      GACACACTTCATCTGTTATATCTACACACACAC------TACTAGGCTAGCACCACAGCA 6375
                   ********************************      *********************

TaELF3_1AL        ATGCCCAAAAAGGCTGGCTCTCTGTTATTGCACCGCCTCCTGCGAATCACTCCTGTTCCT 6271
TaELF3_1BL        ATGACCAAAAAGGCTGGCTCTCTGTTATTGCACCGCCTCCTGCGAATCATTCCTGTTCCT 12922
TaELF3cas1DL      ATGACCAAAAAGGCGGGCTCTCTGTTATTGCACCGCCTCCTGCGAATCACTCCTGTTCCT 6435
                  *** ********** ********************************** **********

TaELF3_1AL        GCGACCGAAACCGCACCTACACACAAACTCAGGGACCGGACCCTCGGCCCCGGCGACCCA 6331
TaELF3_1BL        GCGACCGAAACCGCACCTACACACAAACTCCGGGACCGGGCCCTCGGCCCCGGCGACCCA 12982
TaELF3cas1DL      GCGACCGAAACCGCACCTACACACAAACTCAGGGACCGGGCCCTCGGCCCCGGCGACCCA 6495
                  ****************************** ******** ********************

TaELF3_1AL        GGGATGCGCGGCCACGGCCTGCAGGGTCATACGATCTCCCGGATCTGCGAGGAAAGCACA 6391
TaELF3_1BL        GGGATGCGCGGCCGCGGCCTGCAGGGTCATACGATCTCCCGGATCTGCGAGGAAAGCACA 13042
TaELF3cas1DL      GGGATGCGCGGCCACGGCCTGCAGGGTCATACGATGTCCCGGATCTGCGAGGAAAGCACA 6555
                  ************* ********************* ************************
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                 casTaELF3_BBR10
TaELF3_1AL       AACGACACCACTGTTAACACAGCAAGCACACCTTC------------------------- 6426
TaELF3_1BL       AGCAACACCACTGTTAACACAGCAAGCACACCTTCCGATGCATAAAGACCCAGATTGGAT 13102
TaELF3cas1DL     AACGACGCCACTGTTAACACAGCAAGCACACCTTCCGATGCATAGAGACCCAGATTGGAT 6615
                 * * ** ****************************

TaELF3_1AL       -ATTGCAAAAT--AGAAAAACCCTGCAAGGAACACCTTTGTAGAGCAGCCTCTGCATCAA 6483
TaELF3_1BL       GATTGCGAAA---AAAAAAACCCAGCAAGGAACACCTTTGTAGAGTAGCCTCTGCATCAA 13159
TaELF3cas1DL     GATTGCAAAATAAAAAAAAACCCAGCAAGGAACACCTTTGTAGAGCAGCCTCTGCATCAA 6675
                  ***** ***   * ******** ********************* **************

TaELF3_1AL       GTCGGCGAGCTGGGGGCTCGTGTCGCCGGGTATTTCCACCGGATCATTGGCGATCTGTCC 6543
TaELF3_1BL       GTCGGCGAGCTGGGGGCTCGTGTCGCCGGGTATTTCCACCGGATCATTGGCGATCTGTCC 13219
TaELF3cas1DL     GTCGGCGAGCTGGGGGCTCGTGTCGCCGGGTATTTCCACCGGATCATTGGCGATCTGTCC 6735
                 ************************************************************

TaELF3_1AL       CACAGCAGCGGAGCGACCTTGGTGAGTCTATGCGGTAGGTAAACTGAGAAGGGAGTAACG 6603
TaELF3_1BL       CACAGCAGCGGAGCGACCTTGGTGAGTCTCTGCGGTAGGTAAACTGAAAAGGGAGTAACG 13279
TaELF3cas1DL     CACAGCAGCAGAGCGACCTTGGTGAGTCTATGCGGTAGGTAAACTGAGAAGGGAGTAACG 6795
                 ********* ******************* ***************** ************

TaELF3_1AL       TATATTTCGCACCTTGTCGTAAGTTTCCTGCAGAGTTTCTCCAAGGAATGGATATTTCCC 6663
TaELF3_1BL       TATATTTCGCACCTTGTCGTAAGTTTCCTGCAGAGTTTCTCCAAGGAATGGATATTTCCC 13339
TaELF3cas1DL     TATATTTCGCACCTTGTCGTAAGTTTCCTGCAGAGTTTCTCCGAGGAATGGATATTTCCC 6855
                 ****************************************** *****************

TaELF3_1AL       GGTGATCATGCAATACAGGGTAACACCGACTGCCCATGTATCAGCTGTTCTGCCATGGTA 6723
TaELF3_1BL       CGTGATCATGCAATACAGGGTAACACCGACTGCCCAGGTATCAGCTGTTCTGCCATGGTA 13399
TaELF3cas1DL     GGTGATCATGCAATACAGGGTAACGCCGACTGCCCATGTATCAGCTGTTCTGCCATGGTA 6915
                  *********************** *********** ***********************

TaELF3_1AL       GGCTGAACCTGCAGCGGAAGGGAGGCAGAAAATTGTTCATCACATTAAGCAAGCTCATGC 6783
TaELF3_1BL       GGCTGAACCTGCAGCGCAAGGGAGGCGGAAAATTGTTCATCACATTAAGCAAGCTCATGC 13459
TaELF3cas1DL     GGCTGAACCTGCAGCGGAAGGGAGGCGGAAAATTGTTCATTACATTAAGCAAGCTCATGC 6975
                 **************** ********* ************* *******************

TaELF3_1AL       CATGGCCAGAGAATATTTTAGCAACTTCTTATATTTATTGGCATCACACCCACAACCCAA 6843
TaELF3_1BL       CATGGCCAGAGAATATTTTAGCAACTTGTTATATTTATTGGCATCACACCCACAACCCAA 13519
TaELF3cas1DL     CATGGCCAGAGAATATTTTAGCAACTTCTTATATTTATTGGCATCACACCCACAACCCAA 7035
                 *************************** ********************************

TaELF3_1AL       GCCCTTTGGTTGCTTACAGTTGTTTGGGGCTATGGGTTTGTTTATCTTTATCTGCTGCAG 6903
TaELF3_1BL       CCCCTTTTGTTGCTTACAGTTGTTTGGGGCTATGGGTTTGTTTATCTCAATCTGCTGCAG 13579
TaELF3cas1DL     GCCCTTTTGTTGCTTACAGTTGTTTGGGGCTATGGGTTTGTTTATCTCAATCTGCTGTAG 7095
                  ****** ***************************************  ******** **

TaELF3_1AL       TTATGCAATCATTTAGCTGTGGAAACACCTACAGCACCATGCTACCAATATTCCAAAAAC 6963
TaELF3_1BL       TTGTGCAATCATTTAGCTGTGGAAACACCTACAGCACCATGCTACAAATATTCCAAAAAC 13639
TaELF3cas1DL     TTGTGCAATCATTTAGCTGTGGAAACACCTACAGCACCATGCTACCAATATTCCAAAAAC 7155
                 ** ***************************************** ***************

TaELF3_1AL       CACTGGTGTTGTACTTCAGATGGATACTTTGGTAACTGGCTGATTGTGCGTGCCGCCTTT 7023
TaELF3_1BL       CACTGGTGTTGTACTTCAGATGGATGCTTTGGTAACTGGCTGAATGTGTGTGCCGCCTTC 13699
TaELF3cas1DL     CACTGGTGTTGTACTTCAGATGGATACTTTGGTAACTGGCTGACTGTGCGTGCCGCCTTC 7215
                 ************************* ***************** **** **********

TaELF3_1AL       TATAACTCAAATCAAAGTCATGTAACTGTACCTTGACAGCACTCTGGTGCAGTGAAAACT 7083
TaELF3_1BL       TATAACTCAAATCAAAGTCATGTAACTGTACCTTGACAGCACTCTGGTGCAGTGAAAACT 13759
TaELF3cas1DL     TATAACTCAAATCAAAGTCATGTAACTGTACCTTGACAGCACTCTGGTGCAGTGAAAACT 7275
                 ************************************************************

TaELF3_1AL       GGAGTACCCGGAGACCTCCAAAGCATATCATCGTCATCCTGCAGCATAATCAAGTACCCC 7143
TaELF3_1BL       GGAGTACCTGGAGACCTCCAAAGCATATCATCGTCATCCTGCAGCATAATCAAGTACCGC 13819
TaELF3cas1DL     GGAGTACCTGGAGACCTCCAAAGCATATCATCGTCATCCTGCAGCATAATCAAGTACCAC 7335
                 ******** ************************************************* *

TaELF3_1AL       AATGTGTAAAGCACCAAGCTAGGAGGCTCGACAACCCTACTAAAAATGGTTTACAACACT 7203
TaELF3_1BL       AATGTGTAAAGCACCAAGCTAGGAGGCTCAACAACCCTACTAAAAATGGTTTACAACACT 13879
TaELF3cas1DL     AATGTGTAAAGCACCAAGCTAGGAGGCTCGACAACCCTACTAAAAATGGTTAACAACACT 7395
                 ***************************** ********************* ********

TaELF3_1AL       GAATCATCAGACTACATTGTCTACTCGACTAATGTTCAAAATTCCCAGAGTAAGTGACAA 7263
TaELF3_1BL       GAATCATCAGACTACATTGTCC-CTCGACTAATGTTCAAAATTCCCAGAGTAAGTGACGA 13938
TaELF3cas1DL     GAATCATCAGACTACATTGTCTACTCGACTAATGTTCAAAATTCCCAGAGTAAGTGACGA 7455
                 *********************  *********************************** *
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TaELF3_1AL          TATCGTTCACGTATGCAATTTGCAATCTTAGATTTTATACAAGAACAAATTGTGAAGCCC 7323
TaELF3_1BL          TATCGTTCGCGTATGCAATTTACAATCTCAGATTTTCTAGAAGAACAAATTGTGAAGCCC 13998
TaELF3cas1DL        TATCGTTCGCGTACGCAATTTGCAATCTCAGATTTTATAGAAGAACAAATTGTGAAGCCC 7515
                    ******** **** ******* ****** ******* ** ********************

TaELF3_1AL          AAGATTATATACTTTGCTAGACTAAAAAACTTCACCCTGCCAGTGAGAATAAATTTACTG 7383
TaELF3_1BL          AAGATTAT--ACTTTGCTAGACTCAAAAACTTTACCCTGCCAGTGAGAATAAACTTACTG 14056
TaELF3cas1DL        AAGATTAT--ACTTTGCTAGACTCAAACACTTTACCCTGCCAGTGAGAATAAACTTACTG 7573
                    ********  ************* *** **** ******************** ******

TaELF3_1AL          GCATAAATAAAAAATACAACTACAATATTAAAAAAGGACCTCAAATATCTGGCTAACACT 7443
TaELF3_1BL          GAATAAATAAAAAATACAACTACAATATTAAAAGAGGACCTCAAATATCTGGCTAACACT 14116
TaELF3cas1DL        GAATAAATAAAAAATACAACTACAATATTAAAAGAGGACCTCAAATATCTGGCTAACACT 7633
                    * ******************************* **************************

TaELF3_1AL          GAAGTCCCCTATCTTCACATTGCCAGTACTTGTGACCAAGAGGTTGTCTGGTTTAATATC 7503
TaELF3_1BL          GAAGTCCCCTATCTTCACATTGCCAGTACTTGTGACCAAGAGGTTGTCCGGTTTAATATC 14176
TaELF3cas1DL        GAAGTCCCCTATCTTCACATTGCCAGTACTTGTGACCAAGAGGTTGTCCGGTTTAATATC 7693
                    ************************************************ ***********

TaELF3_1AL          ACCATGAATAATGTTCTGCATAAAAACACAAGAAAAATAAGTTTTGTATCAAGCACACAG 7563
TaELF3_1BL          ACCATGAATAATGTTCTGCATATAAACACAAGAAAATTAAGTTTTGTATCAAGCACACAG 14236
TaELF3cas1DL        ACCATGAATAATGTTCTGCATATAAACACAAGAAAATTAAGTTTTGTATCAAGCACACAG 7753
                    ********************** ************* ***********************

TaELF3_1AL          TGCAAAAT---------------------------------------------------- 7571
TaELF3_1BL          TGCAAAATGCATAACATATAGCGCAAATGAACAGCCAGAACCACATGTATAT--CCATGA 14294
TaELF3cas1DL        TGCAAAATGCATAACATATAGTGCAAATGAACAGCCAGAACCACATGTATATATCCATGA 7813
                    ********

TaELF3_1AL          ------------------------------------------------------------
TaELF3_1BL          GAGCGTGCAAATGTGTGAAAGTAGGGGAACATGAAACATCAACAAACACCTGCTTAAGAA 14354
TaELF3cas1DL        AAGCGTGCAAATGTGTGAAAATAGGGGAACATGAAACATCAACAAACACCTGCTTAAGAA 7873

TaELF3_1AL          ---------TTGTGACATGGAATGTAAACTATTGGTAGAAACCTATTCCGGCGATCCATT 7622
TaELF3_1BL          GTGTAAAATTTGTGACATTGAATGTTAAGTTTTGGTAGAAACATATTCCGACGATCCATT 14414
TaELF3cas1DL        GCGAAAAAATTGTGACATGGAATGTAAACTTTTGGTAGCAACCTATTCCGACGATCCATT 7933
                             ********* ****** ** * ******* *** ******* *********

TaELF3_1AL          ATGTACCAAAGTGTGTGCACAAACACATATACTGAATTAGAATTCAACGGTGGAATAT-- 7680
TaELF3_1BL          ATGTACCAAAGTGTGTGCATAAACACATGTACTTAATTAGAATTCAACGGTGGAATAT-- 14472
TaELF3cas1DL        ATGTACCAAAGTGTGTGCACAAACACATATACTTAATTAGAATTCAACGGTGGAATATCC 7993
                    ******************* ******** **** ************************

TaELF3_1AL          ------GCCAACTACGAATAAGTGAGCTTCATATGGCAACAGACAAATCATGCTTTGATG 7734
TaELF3_1BL          ------GCCAACTACGAATAAGTGAGCTTCATATGGCAACAAACACATCATGCTTTGATG 14526
TaELF3cas1DL        GAATATGCCAACTACGAATAAGTGAGCTTCATATGGCAACAGACACATCATGCTTTGATG 8053
                          *********************************** *** **************

TaELF3_1AL          CATATCGCCGCCCTAACTATTTATTAGATGCCACATTTATATGTAAATACAATCAGAAAA 7794
TaELF3_1BL          CATATCGCCGCCCTAGCTATTTATTAGATGCCACATTTATACGTAAATACAATCAGAAAA 14586
TaELF3cas1DL        CATATCGCCACCCTAATTATTTATTAGATGCCACATTTATACGTAAATACAATCAGAAAA 8113
                    ********* *****  ************************ ******************

TaELF3_1AL          GTATATTTAAAACCATAAACAAGACCACAAGCATTATACTCTAGAAGAAAGCAGGTTTCA 7854
TaELF3_1BL          GTATATTTAAAACCATAAACAAGACCACAAGCATTATACTCTAGAAGAAAGCATGTTTCA 14646
TaELF3cas1DL        GCATATATAAAACCATAAACAAGAACACAAGCATTATACTCTAGAAGAAAGCAGGTTTCA 8173
                    * **** ***************** **************************** ******

TaELF3_1AL          CATCTCCCCTGTTTTCT-GTCATTGGCTTTAAATAGGACTCTGGTTTTCTCTGCAAGAAA 7913
TaELF3_1BL          CATCTCCCCTGTTTTTTTATCATTGGCTTTAAATAGGGTTCTGGTTTTCTATGCAAGAAA 14706
TaELF3cas1DL        CATCTCCCCTGTTTTCT-ATCATTGGCTTTAAATAGGGCTCCGGTTTTCTCTGCAAGAAA 8232
                    *************** *  ******************  ** ******** *********

TaELF3_1AL          CTCAACAACCAAGCACTGTACTAAGAAATATGGAAGCTGAAAGCTCAACCCTAAACGTTC 7973
TaELF3_1BL          CTCAACAACCAAGCACTGTATTAACAAATATG-AAGCTGAAAACTA---CCTAAACATTG 14762
TaELF3cas1DL        CTCAACAACCAAGCACTGTACTAAGAAATATGGAAGCTGAAAGCTCAACCCTAAACGTTC 8292
                    ******************** *** ******* ********* **    ******* **

TaELF3_1AL          CTACGAAAGCAGCAAGCATACCATTCATACGCAAGTCGGTACATTTGACTGATATATTAT 8033
TaELF3_1BL          CTATGAAGGCAGCAAGCATACTATTCATACGCAAGTCGGTACATTTGACTGATATATGAA 14822
TaELF3cas1DL        GTACGAAGGCAGCAAGCATACTATTCATATGCAAGTCAGTACATTTGACTGATATATGAT 8352
                     ** *** ************* ******* ******* ******************* *
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TaELF3_1AL      GCCTCCTAAAGCATGAGGTGAGCATTGATTATAAAACCCAGGCTAATGTTTGCCTGTGCA 8093
TaELF3_1BL      GCTTCCTAAAGCATGATGTGAGCATTGATTATAAAGCCCAAGCTAATGTTTGCCTGTGCA 14882
TaELF3cas1DL    GCTTCCTAAAGCATGAGGTGAGCATTGATTATAAAACCCACGCTAACGTTTGCCTGTGCA 8412
                ** ************* ****************** **** ***** *************

TaELF3_1AL      ATCAGGTAGCTCGGAGACAGAACAACTCAGTCAGTAGCTAAGCAAACATGGACTTAACAG 8153
TaELF3_1BL      ATCAGGTAGCTCGGAGACAGAACAACTCAGTCAGTAGCTAAGCAAACATGGACT-AACAG 14941
TaELF3cas1DL    ATCAGGTAGCTCGGAAACAGAACAACTCAGTCAGTAGCTAAGCAAACATGGACT-AACAG 8471
                *************** ************************************** *****

TaELF3_1AL      TTTAACACTATGAACAGAAAATCTGTCTACTAAGATAATTTACGCCGACCATTTGAGCTT 8213
TaELF3_1BL      CTTAACACTATGAACAGAAAATCTGTCTACTAAGATAATTTACGCCAACCATTTGAGCTT 15001
TaELF3cas1DL    TTTAACACTATGAACAGAAAATCTGTCTACTAAGATAATTTACGCCGACCATTTGAGCTT 8531
                 ********************************************* *************

TaELF3_1AL      GCTGGTCAGCTTCACGCCAACATAACTAGGTTCAGTGGAAGGGAAAAAATATGTGAAAGC 8273
TaELF3_1BL      GCTGGTCAGCTTCACGCCAACATAACTAGGTTCAGTGGAAGGGAAAAAATATGTGAAAGC 15061
TaELF3cas1DL    GCTGGTCAGCTTCACGCCAACATAACTAGGTTCAGTGGAAGGGAAAAAATATGCGAAAGC 8591
                ***************************************************** ******

TaELF3_1AL      TAAAACATGCTGCTTCAAATAATGATTGTCTAACAAACTTAGAGCTCTTCAAATATCTTT 8333
TaELF3_1BL      TAAAACATGATGCTTCAAATAATCATTGTCTACAAAACTTAGAGCTCTTCAAATATCTTT 15121
TaELF3cas1DL    TAAAACATGCTGCTTCAAATAATCATTGTCTAACAAACTTAGAGCTCTTCAAATATCTTT 8651
                ********* ************* ********  **************************

TaELF3_1AL      GTTGAAATTTCTATTTGACATGATCAAAGTGCTAATGAAATAGACACTGTTATTATATTA 8393
TaELF3_1BL      GTTGAAATTTCTATTTGACATGATCAAAGTGCTAATGAAATAGACACTATTATAATATTA 15181
TaELF3cas1DL    GTTGAAATTTCTATTTGACATGATCAAAGTGCTAATGAAATAGGCACTGTTATAATATTA 8711
                ******************************************* **** **** ******

TaELF3_1AL      TTAGCACAGAATTAACCATGATGAACCATTCCTTGGTGAAGAGTTTAAAAAG--TCTTAC 8451
TaELF3_1BL      TTAGCACAGAATTAACCATGATGAATCATTCCTTGGTGAAAAGTTAAAAAAAAATCTTAC 15241
TaELF3cas1DL    TTAGCACAGAATTAACCATGATGAACCATTCCTTGGTGAAAAGTTTAAAAAG--TCTTAC 8769
                ************************* ************** **** *****   ******

TaELF3_1AL      ATGAGAGTGAAGATACATAACACCAGAGACAATGTCCCGCAAGTACTTCCTGGAAGTAGC 8511
TaELF3_1BL      ATGAGAGTGAAGATACATAACACCAGAGACAATGTCCCGCAAGTACTTCCTGGAAGTAGC 15301
TaELF3cas1DL    ATGAGAGTGAAGATACATAACACCAGAGACAATGTCCCGCAAGTACTTCCTGGAAGTAGC 8829
                ************************************************************

TaELF3_1AL      TTCTCCTAAACCTATGCCGTTATTGCACACCATTTTCCCCTCAACATACTCAAGAACTGC 8571
TaELF3_1BL      TTCTCCTAAACCTATACCGTTATTGCACACCATTTTCCCCTCAACAAACTCAAGAACTGC 15361
TaELF3cas1DL    TTCTCCTAAACCTATACCGTTATCGCACACCATTTTCCCCTCAACATACTCAAGAACTGC 8889
                *************** ******* ********************** *************

TaELF3_1AL      CAACGGGAAGGGAAAAGAGTAAATTGCAATCGTGTAAAATAACGACCAAGATGACAACAA 8631
TaELF3_1BL      CAATGGGAAGGGAAAAGAGTAAATTGCAATCGTGTAAAATAATGACAAAGATGACAACAA 15421
TaELF3cas1DL    CAATGGGAAGGGAAAAGAGTAAATTGCAATCGTGTAAAATAACGACAAAGATGACAACAA 8949
                *** *************************************** *** ************

TaELF3_1AL      GCCTGCTAAAATAGCGCCATGTTAGAATAATAAAGCAAAACAACGAGAGCAACAATAAAT 8691
TaELF3_1BL      GCCTGCTAGAATAGCGCCATGTTAGAATAATAAAGCAAAACAATGAGAGCATCAATAAAT 15481
TaELF3cas1DL    GCCAGCTAAAATAGCGCCATGTTAGAATAATAAAGCAAAACAATGAGAGCATCAATAAAT 9009
                *** **** ********************************** ******* ********

TaELF3_1AL      ACCCATGTAGAATTTATCTGTGTTTGGGTCGTCAATCACCTCAATGAGATTTACTATATT 8751
TaELF3_1BL      ACCCATGTAGAATTTATCTGTGTTTGGGTCGTCAATCACCTCAATGAGATTTAGTATATT 15541
TaELF3cas1DL    ACCCATGTAGAATTTATCTGTGTTTGGGTCATCAATCACCTCAATGAGATTTACTATATT 9069
                ****************************** ********************** ******

TaELF3_1AL      GGGATGATCCAACATTTTCATGAGGGATACCTGTATCCGATGCAATAAAAGGGTAGCTAA 8811
TaELF3_1BL      GGGATGATCCAACATTTTCATGAGGGATACCTGTATCCGATGCAATAAAGGGA-AGCTAA 15600
TaELF3cas1DL    GGGATGATCCAACATTTTCATGAGGGATACCTGTATCCGATGCAATAAAAGGGTGGCTAA 9129
                ************************************************* **   *****

TaELF3_1AL      TTAGAGAACTTGGAAAACAAATATGGTAGTTGATTCTCAAGTAAAAACAGGATGCGGTAC 8871
TaELF3_1BL      TAAGAGAACTTGGAAAACAAATACGGTAGTTGATTCTCAAGTAAAATCAGGATGTGGTAC 15660
TaELF3cas1DL    TTAGAGAACTTGGAAAACAAATAAGGTAGTTGATTCTCAAGTAAAATCAGGATGTGGTAC 9189
                * ********************* ********************** ******* *****

TaELF3_1AL      ACTGTATATATGCAACATTTGACAAATGCTACTAATAATATGCTTCTGCCTTTTGACAGA 8931
TaELF3_1BL      ACTGTATATATGCAACATTTGACAAATGCTACTAATAATATGCTTCCGCCTTCTGACAGA 15720
TaELF3cas1DL    ACTGTATATATGCAACATTTGACAAATGCTACTAATAACATGCTTCCGCCTTCTGACAGA 9249
                ************************************** ******* ***** *******
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TaELF3_1AL         AAAATAACTGAATTTTTTAGTACAGTTATTATATAGTGGTGATGGCAAAATCCTTTGGAG 8991
TaELF3_1BL         AAAATAACTGAATTTTTTAGTACAGTTAT---ATAGTGGT-ATGGCAAAATCCTTTGGAG 15776
TaELF3cas1DL       AAAATAACTGAATTTTTTAGTACAGTTA--ATATAGTGGT-ATGGCAAAATCCTTTGAAG 9306
                   ****************************    ******** **************** **

TaELF3_1AL         CATCCCAAGGCAAATTTAGCACAATTCAGCTTCTTGATAACAAACATCAGAGCCAGTGAA 9051
TaELF3_1BL         CATCCCAAGGCAAATTTAGCACAATTCAGCTTCTTGATAACAAACATCAGAGCCAGTGAA 15836
TaELF3cas1DL       CATCCCAAGGCAAATTGAGCACAATTCAGCTTCTTGATAACAAACATCAGAGCCAGTGAA 9366
                   **************** *******************************************

TaELF3_1AL         ACTAAAGCGAAGGAAAATGGTCACAGGTAATATTGAAATAAACAAAAAAAGACGCATACT 9111
TaELF3_1BL         ACTGAAGCGAAGAAAAATGGTCACAGGTAATCTTGAAATAAACAAAAAA-GACGCATACT 15895
TaELF3cas1DL       ACTAAAGCGAAGGAAAATGGTCACAGGTAATATTGAAATAAACAAAAAAAGACGCATACT 9426
                   *** ******** ****************** ***************** **********

TaELF3_1AL         AAATGGGTGCACAATCCCAAATAGATTTCTTCTGT-AGCTGTAAATAATGTGTGCCTATA 9170
TaELF3_1BL         AAATGG-TACACACTCCCAAATAAATTTCTTCTGTTAGCTGTAAATAATGTGTGCCTATA 15954
TaELF3cas1DL       AAATGG-TGCACACTCCCAAATAGATTTCTTCTGT-GGCTGTAAATAATGTGTGCCTATA 9484
                   ****** * **** ********* ***********  ***********************

TaELF3_1AL         GAGAAAGTACTAACAG-------------------------------------------- 9186
TaELF3_1BL         GAGAAAGTACTAACAGAATGAGATTTGCAAGGTATGATCAACTTGGTTAACCAATGTTAG 16014
TaELF3cas1DL       GAGAAAGTACTAACAGAATGTGATTTGCAAGGTATGATCAACTTGGTTAAACAATGTTAA 9544
                   ****************

TaELF3_1AL         -------------TATTTATATCTTCAAAGCTCAGACAAGTACATTCCCAGAGAACTTTG 9233
TaELF3_1BL         ATAGATCATGCAGTATTTATATCTTCAAAGCTCACGCAAGTACATTCCCAGAGAACTTTG 16074
TaELF3cas1DL       ATAGATCATGCAGTATTTATATCTTCAAAGCTCACACAAGTACATTCCCAGAGAACATTG 9604
                                *********************  ******************** ***

TaELF3_1AL         CACACGCCATAACAACACAGCAAAGTGACAGGTCTTATAGAGGGAAATACTAGTTTAACA 9293
TaELF3_1BL         CACACGCCATAACAACACAGCAACGTGATAGGTATTATACAGGGAAATACAACTTTAACA 16134
TaELF3cas1DL       CACACGCCATAACAACACAGCAAAGTGACAAGTATTATACAGGGAAATACTAGTTTAACA 9664
                   *********************** **** * ** ***** ********** * *******

TaELF3_1AL         AAGAGTTACTCACTTCCCGAAGAACATCTGTCATGGCCGTTTCTGACTGCACAACACGCA 9353
TaELF3_1BL         AAG--TTACTCACTTCCCGAAGAACATCTGTCATGGCCGTTTCTGACCGCACAACACGCA 16192
TaELF3cas1DL       AAG--TTACTCACTTCCCGAAGAACATCTGTCATGGCCGTTTCTGACCGCACAACACGCA 9722
                   ***  ****************************************** ************

TaELF3_1AL         CTTTCAACATGTAGGGTTTACTCAACACCTGAAATAGATAGAGTTCCGTCAAGTAGACAT 9413
TaELF3_1BL         CTTTCAACATGTAGGGTTTACTGAACACCTGAAATAGATAGAGTTCCGTCAAGTAGACAT 16252
TaELF3cas1DL       CTTTCAACATGTAGTGTTTACTCAACACCTGAAATAGATAGAGTTCTGTCAAGTAGACAT 9782
                   ************** ******* *********************** *************

TaELF3_1AL         AGATAGCACTGTGCAGCGGGTGCAGAAAGAAATGTCGAAACAACCTACCTTTATTGCATA 9473
TaELF3_1BL         AGATAGCACTGTGCAGCGGGCGCAGAAAGAAATGTCGAATAAAATCACCTTTATCGCATA 16312
TaELF3cas1DL       GGATCGCACTGTGCAGTGGGCGCAGACAGAAATGTCGAATAAAATTACCTTTATTGCATA 9842
                    *** *********** *** ***** ************  **   ******** *****

TaELF3_1AL         TAACCTTCCGTCCTTGATGTTTCGGTATTTAACCTTGTTTGTTTAGAATTAGAATGAAAT 9533
TaELF3_1BL         TAACCTCCCATCCTTGATGTTTTGGTATTTAACCTAGTTTGTTTAGAATTAGAATGAAAT 16372
TaELF3cas1DL       TAGCCTTCCGTCCTTGATGTTTCGGTATTTAACCTTGTTTGTTTAGAAT------GAAAT 9896
                   ** *** ** ************ ************ *************      *****

TaELF3_1AL         CAAAGGAGAGGTAATCAGCGAGGGAAGT---AGTGGTACATAAATAGGTAGCA-----GC 9585
TaELF3_1BL         CAAAGGAGAAGTAATCAGCGAGGGAAGTGGTAGTAGTAGATAAATAGGTAGCACAGTTAG 16432
TaELF3cas1DL       CAAAGGAGAAGTAATCAGCGAGGGAAGTGGTAGTAGTAGATAAATAGGTAGCACACTTAG 9956
                   ********* ******************   *** *** **************

TaELF3_1AL         ACACTTGACAAGGGTCTGTTGTTGTTATTACCACTTTGCCATAGCTCCCAGCACCAATCT 9645
TaELF3_1BL         ATAAAAAGCAGAGGTCTGCTGTTGTTGTTACCACTTTGCCGTAGCTCCCAGCACCAATCT 16492
TaELF3cas1DL       GTAACAAGCAGAGGTCTGCCGTTGTTGTTACCACTTTGCCGTAGCTCCCAGCACCAATCT 10016
                     *     **  ******  ****** ************* *******************

TaELF3_1AL         TGCCCAGGTGAACATACTGGTTGATCATCTTACAGCCGGTTGTTTCGTCCTAAGGCAATG 9705
TaELF3_1BL         TGCCCAGGTGAACATACTGGTTGATCATCTTACAGCCGGTTGTTTCGTCCTAAGGCAATG 16552
TaELF3cas1DL       TGCCCAGGTGAACATACTGGTTGATCATCTTACAGCCGGTTGTTTCGTCCTAAGACAATG 10076
                   ****************************************************** *****

TaELF3_1AL         CCAAAAGGAGAAGAGGGGAGTGATGATTATACTTGTCAATTCAAAAGATAAAAAGGG--A 9763
TaELF3_1BL         CCAAAAGGAGGAGAGAACAA-AGTGATTATGCCGCTCGATTCAAAGGGTAGAAAGAACAA 16611
TaELF3cas1DL       CCAAAAGGAGAAGAGGGAAG---TGATTATACTAGTCAATTCAAAAGATAAAAAGGAAAA 10133
                   ********** ****   *    ******* *   ** ******* * ** ****    *
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TaELF3_1AL       AAAAAATGCTCTCATACAA--GCCATGAACCATT--GAT----------------TGACT 9803
TaELF3_1BL       GAAAAATGCTCTCATGCAA--GCCATGAACCATTCTGATGGCCACATTGTACTCTTGGCT 16669
TaELF3cas1DL     AAAGAATGCTCTCATACAAAAGCCTTGAACCATTGTGATGGCCACATTGTACTCTTGGCT 10193
                  ** *********** ***  *** *********  ***                ** **

TaELF3_1AL       AGGCACG-----------------------CAACGG-GCATGGCA-----TTGCT----- 9829
TaELF3_1BL       AGAAATAATCCATTGTACTAAAATTATGCTCAGCGGAGCATGGCTCGTGTTTGCTTGTTT 16729
TaELF3cas1DL     AGAAATA------------------------ATC----CATTGTAC----TCCCTC---- 10217
                 **  *                          * *    *** *       *  **

TaELF3_1AL       -----------------------AT----------------------------------C 9832
TaELF3_1BL       CACAACGACTCAGCGCGCGCTAAATTCACCAACGGAGCGGGAGGATTTATTTGTAGGGAC 16789
TaELF3cas1DL     -----------------------------------------------------------C 10218
                                                                            *

TaELF3_1AL       AAATCA---------------AAACCTGGT------------------CA-AGTTGTTGG 9858
TaELF3_1BL       AAACCATTGGAGAAATGAAATGAATTTAGTACTGTAGTAAAAAAAAAACAGAGTTGTTGG 16849
TaELF3cas1DL     GTCCCA---------------AAAT--------------------------ACTTGTCGG 10237
                     **                **                            * **** **
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Appendix 4.1 *TaBradi2g28010* (BF485305) primer positions are highlighted

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                                                                     ngs_F1
D_TaBradi2g28010          ----------------------------TGAAGTAACCATATGAATGTTGTGAATTTGTT 32
B_TaBradi2g28010          ----------------------------------------ATGAATGTTGTGAATTTGTT 20
A_TaBradi2g28010          GATCGTTTTAGGTAATTTCTACGAAGCTTGAAGTAACC--ATGAATGTTGTGAATTTGTT 118
                                                                  ********************

D_TaBradi2g28010          TTTGTTGTCTTGAGGTCTAATAATAATTTTT-GCTTCAGTGGGAAAATTTTACACATTGA 91
B_TaBradi2g28010          TTTGTTGTCTTGAGGTCTAATAATAATTTTTTGCTTCAGTGGGAAAATTTTACACATTGA 80
A_TaBradi2g28010          TTTGTTGTCTTGAGGTCTAATAATAATTTTTTGCTTCAGTGGGAAAATTTTACACATTGA 178
                          ******************************* ****************************
                            D_F1               A_F1
D_TaBradi2g28010          CTTTGGAGACTGTTTCGAGGCATCAATGAATCGAGAAAAGTTCCCTGAAAAAGTAAGTAG 151
B_TaBradi2g28010          CTTTGGAGACTGTTTTGAGGCATCAATGAATCGAGAAAAATTCCCTGAAAAAGTAAGTAG 140
A_TaBradi2g28010          CTTTGGAGATTGTTTTGAGGCGTCAATGAATCGAGAAAAGTTCCCTGAAAAAGTAAGTAG 238
                          ********* ***** ***** ***************** ********************
                                                                  B_F2
D_TaBradi2g28010          TCCGTGTTCTGTGCTTTATTCCTTGCCAATCACCTGATAGGTTGATGCTATAGTTTTGTT 211
B_TaBradi2g28010          GCCGTGTTCTGTGCTTTATTCCTTGCCAATCACCTGATAGTTTGATGCTATAGTTTTGTT 200
A_TaBradi2g28010          GCCGTGTTCTGGGATTTATTCCTTGCCAATCACCTGATAGGTTGATGCTCTAGTTTTGTT 298
                           ********** * ************************** ******** **********

D_TaBradi2g28010          GAGTCTTATCTTGTATTGTAACTGTTATTGAATGCGTGGCATTTTAACTTTTTTTTACTG 271
B_TaBradi2g28010          GAGTCTTGTCTTGTATTGTAACTGTTATTGAATGCGTGGCATTTCAACTTCTTTT-ACTG 259
A_TaBradi2g28010          GAGTCTTATCTTGTATTGTAACTGTTATTGAATGCGTGTCATTTTAACTCTTTTTTACTG 358
                          ******* ****************************** ***** ****  **** ****

D_TaBradi2g28010          CACTCACA--TTTTGTATGTATGGTGTAGGTACCATTCCGTTTGACTAGAATGCTCGTGA 329
B_TaBradi2g28010          CACTCACACATTTTGTATGTATGGTGTAGGTACCATTCCGTTTGACTAGAATGCTCGTGA 319
A_TaBradi2g28010          CACTCACACATTTTGTATGTATGGTGTAGGTACCATTCCGTTTGACTAGAATGCTTGTGA 418
                          ********  ********************************************* ****

D_TaBradi2g28010          AAGCTATGGAAGTTAGTGGTATTGAGGGTACTTTCAGAACAACTTGTGAAAATGTGATGC 389
B_TaBradi2g28010          AAGCTATGGAAGTTAGTGGTATTGAGGGTACTTTCAGAACAACTTGTGAAAATGTGATG- 378
A_TaBradi2g28010          AAGCTATGGAAGTTAGTGGTATTGAGGGTACTTTCAGAACAACTTGTGAAAATGTGATGC 478
                          ***********************************************************

D_TaBradi2g28010          AAGTCCTACCGAACAAACAAGGACAGCGTCATGGCTATGATGGAGGTAAGTAATACATAT 449
B_TaBradi2g28010          AAGTCCT-CCGGACAAACAAGGACAGCGTCATGGCTATGATGGAGGTAAGTAATACATAT 437
A_TaBradi2g28010          AAGTCCT-TCGAACAAACAAGGACAGCGTCATGGCTATGATGGAGGTAAGTAATACATAT 537
                          *******  ** ************************************************

                        A_R1        D_R1                    ngs_R1
D_TaBradi2g28010          TCTATAGCCCGTAGCACCTTTGCCTGGCCAATATTATATACTCCATCCGTACCAAAATAT 509
B_TaBradi2g28010          TCTATAGCCTGTAGCACCTTTGCCTGGCCAATATTATATACTCCATCCATACCAAAATAT 497
A_TaBradi2g28010          TCTATAGCTTGTAGCACCATTGCCTGGCCAATATTATATACTCCATCGGTACCATAATAT 597
                          ********  ******** ****************************  ***** *****
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Appendix 4.2 TaBradi2g25820 (BE44333)

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                                                     F1
X_BE44333          ----------TATCATCTTCGTGAAGACAAAAGCGCAACGTGTCCATTTCTCAGCTGTTG 50
Y_BE44333          --------------------------ACAAAAGCACAACGTGTTGAGTTCTCAGTTGTCG 34
D_BE44333          ATCTCACTCATATCATCTTCGTGAAGACAAGAGCACAACATGCTGAGTTCGCAGCTGTTG 360
                                             **** *** **** **    * *** *** *** *

                         F2                    F3
X_BE44333          ATGGAGAATATTTGCAACATCACAAATTGTAGTGTGCTTCAACCGAGACGTGGACGATCA 110
Y_BE44333          ATGGAGAATATTTGCAACATCACAAATTGTAGTGTGCTTTGACCGAGGCATGGACGATCA 94
D_BE44333          ATGAAGAATATTTGCAACATCACAACTTGTAGTGTGCTTTGACTGAGACGTGGACGATCA 420
                   *** ******************** ************   ** *** * **********

                                               Ngs F1
X_BE44333          GATTGCTTTTATTTGCAACAACCACTACACTAGATTGGATGTTTCAAATATTACTTGTCA 170
Y_BE44333          TATTGCTTTTATTTGCAACAACTACTGCACTAGATTGGATGTTTCAAATATTACTTGTCA 154
D_BE44333          GATTGCTTTTATT-GCAACAACCACTACACTAGATTGGATGTTTCAAATATTACTTGTCA 479
                    ************ ******** *** **********************************

                   F4
X_BE44333          TTTCTAATAAATGTCGGCAGTTTTGACATATTTGCCAAACAGACTATTAATTGCCAATCA 230
Y_BE44333          TTTCTAATAAATGTCGGCAGTTTTGATATATTTGCCAAACAGACTATTAAC-GCGAATCA 213
D_BE44333          ATTCTAATAAATGTCGGCTGTATTGACATATTTGCCAAACAGACTATTAAC-GCAAATC- 537
                    ***************** ** **** ***********************  ** ****

X_BE44333          AAGTATTATTGCTGCACAGGAACTGGTGTATTGCGGATAATCACTAAGATATTATGTTGG 290
Y_BE44333          AAGTATTATTGCTGCACAGGAACTGGTTTATTGCGGATAATCACTAAGATAATATGTTGG 273
D_BE44333          -AGTATTATTGCTGCACAGGAACTGGTTTATTGCGGATAATCACTAAGATATTATGTTGG 596
                    ************************** ********************** ********

                                R1
X_BE44333          GCACAAAGGGAAACAACGTGAGCTGCATTCTTCAGGCGGCTTTATTTTTAAATGTACATC 350
Y_BE44333          GCACAAAGGGAAACAACGTCAGCTGCATTCTTCAGGCGGCTTTATTTTTAAATGTACAGC 333
D_BE44333          GCACAAAGGGAAACAACATGAGCTGCATTCTTCAGGCGGCTTTATTTT-AAATGTACAGC 655
                   ***************** * *************************** ********* *

X_BE44333          TCACTATTAATTTCCACAGGGAAAACAAAACCTAGAATTTACACATGTAACAGTATATAC 410
Y_BE44333          TCACTATTAATTTCCACAGGGAAAACAAAACCTAGAATTTACACATGTAACAGTATATAC 393
D_BE44333          TCACTATTAATTTCCACAGGGAAAACAAAACCTAGAATTTACACATGTAA-------TAC 708
                   **************************************************       ***

X_BE44333          TGCCAAAATTAGCAGCGAGCATCGGTACTTGGGGCTTGCATTATTGTCAAAAGTACTGA 470
Y_BE44333          TGCCAATATTAGCAGCAAGCATCGGTACTTGGGGCTTGCATTATTGACAA-AGTACTGA 451
D_BE44333          TGCCAAAATTAGCAGCGAGCATCGGTACTTGGGGCTTGCATTATTGACAAAAGTACTGA 767
                   ****** ********* ***************************** *** ********

X_BE44333          GTT-CTGACATCCAGCAGTCACTATGATGGTTGCACAAAAGATTTTGTTTCCATTTCTCA 529
Y_BE44333          GTTTCTGACATCCAGTAGTCACTATGATGGTTGCACAAAAGGTTTTGTTTCCATTTCTCA 511
D_BE44333          GTT-CTGACATCCAGTAGTCACTATGATGGTTGCACAAAAGGTTTTGTTTCCATTTCTCA 826
                   *** *********** ************************ ******************

X_BE44333          TATAGATGTTCATCAGCTCAGTCAACTAGCCTCTTCAGAGGCCGGAACGAACTTGAGTGA 589
Y_BE44333          TATAGATGTTCATCAGCTCAGTCAACTAGCCTCTTCAGAGGCCGGAACGAACTTGAGTGA 571
D_BE44333          TATAGATGTTCATCAGCTCAGTCAACTAGCCTCTTCAGAGGCCGGAACGAACTTGAGTGA 886
                   ************************************************************

X_BE44333          GATACTGTTGACGCAGTGTCGCTCATCAGTCGGCGTGTTGAACCCCTCCC---TTGAACT 646
Y_BE44333          GATACTGTTGACGCAGTGTCGCTCATCAGTCGGCGTGTTGAACCCCTCCCCCTTTGAACA 631
D_BE44333          GATACTGTTGACGCAGTGTCGCTCATCAGTCGGCGTGTTGAACCCCTCCCC-TTTGAACA 945
                   **************************************************   ******

X_BE44333          CAT-CGCCCAGCTGCCCATCACA-GCAGCACATGTGATCTCAACTCGCCTCCCATCAGG 704
Y_BE44333          CATGCCCCCAGATGTCCTTCACAAGCAGCACATGTGATCTCAATGCGCCTCCCATCAGG 690
D_BE44333          CATGC-CCCAGATGTCCTTCACAAGCAGCACATGTGATCTCAATTCGCCTCCCATCAGG 1003
                   *** * ***** ** ** ***** ******************   **************

X_BE44333          ATCCGCCTA--GAGTATTAAACGATGAAATGTCACCGCCGTCAGCATCAGGGCATGGAAT 762
Y_BE44333          ATCCGCCTATAGAGTATTAAGCGAAGAAATGTCACCGCCGTCAGCATGAGGGCATGGAAT 750
D_BE44333          ATCCGCCTA--GAGTATTAAACGATGAAATGTCACCGCCGTCAGCATCAGGGCATGGAAT 1061
                   *********  ********* *** ********************** ************

                    R2
X_BE44333          GCATAGAGGAGAAGAAAGGCATCGGTTCCTAGTCAAACCACTGGGAATGTATGAGAGAAT 822
Y_BE44333          GCATAGAGGAGAAGAAAGGCATCGGTTCCTAGTCAAACCACTGGGAATGGATGAGAGAAT 810
D_BE44333          GAATAGAGGAAAAGAAAGGCATCGGTTCCTAGTCAAACCACTGGGAATGGATGAGAGAAT 1121
                   * ******** ************************************** **********
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X_BE44333       CGTACCGTCCGTTTTATGGCTCCAGGAAATCCTTCATAGAATGCTGGCCAACCACACCCT 882
Y_BE44333       CGTACCGTCCGTTTTATGGCTCCAGGAAATCCTTCATAGAATGCTGGCCAACCACACCCT 870
D_BE44333       CGTACCGTCCGTTTTATGGCTCCAGGAAATCCTTCATAGAATGCTGGCCAACCACACCCT 1181
                ************************************************************

                                                       R3
X_BE44333       GAGTTGAACTTCGTAGATGATTTGTACAAGGGGGTTCCGCAGCCAGCACATCCGTAAATA 942
Y_BE44333       GAGTTGAACTTCGTAGATGATTTGTACAAGGGGGTTCCGCAGCCAGCACATCCGTAAATA 930
D_BE44333       GAGTTGAACTTCGTAGATGATTTGTACAAGGGGGTTCCACAGCCAGCACATCCGTAAATA 1241
                ************************************** *********************

                              ngsR1
X_BE44333       CCCTCACTGAAGAACTTGTCATATTCACCTGTTCCAGGATACCTGAAACAAATATAGTCA 1002
Y_BE44333       CCCTCATCGAAGAACTTGTCATATTCACCTGTTCCAGGAAACCTGAAACAAATATAGTCA 990
D_BE44333       CCCTCACTGAAGAACTTGTCATATTCACCTGTTCCAGGATACCTGAAACAAATATAGTCA 1301
                ******  ******************************* ********************

                                                             R4
X_BE44333       AATGAAAATTTATCACA-TGTAAGCTCTTTT-TTTTTCACAATTACGCTATTGTTAGTTT 1060
Y_BE44333       AATGAAAATTTATCACAACGGAAGCTCTTTTATTTTTCACAGTTACGCTATTGTTAGTTT 1050
D_BE44333       AATGAAAATTTATCACA-CGGAAGCTCTTTC-TTTTTCACAGTTATGCTATTGTTAGTTT 1359
                *****************  * *********  ********* *** **************

X_BE44333       AACAGACTACCATATGTAAGATGGCATAGACAAGTATTTTTTTTCGTAAACGGTAACCA 1119
Y_BE44333       AACAGACTACCATATGTAAGATGGC--AGACAAGTATTTTTTT---------------- 1091
D_BE44333       AACAGACTACCATATGTAAGATGGCATAGACCAGTAAAAAAAAATACGAAACGG-AACCA 1417
                *************************  **** ****
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Appendix 4.3 TaBradi2g15630

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                                                     casTaBradi2g15630_DDF1
1BL_TaBradi2g15630          ---ACAG---GGGGGATTCCCTGCTAGTATTGAATTATATA-AAAAATCA 838
1AL_casTaBradi2g15630       ---AAAAACCGGCGAATTCCCTGCTGGTGTTGCTTCATATACAAAAACCA 5641
1DLcasTaBradi2g15630        TACAAAAACAGGCGAATTCCCTGCTAGTATTGCTTCATATACAAAAACCA 5797
                               * *    ** * ********** ** ***  * ***** ***** **

1BL_TaBradi2g15630          CTTGAGATTAGAGTCCAGAGGGGGAGGGTAGTACCACTGTCCACTGCCAT 888
1AL_casTaBradi2g15630       CTTGAGATTAGAGGCCAG---GAGAGGGTA----CAG----CACTGCCAT 5680
1DLcasTaBradi2g15630        CTCCAGATTAGAGTCCAG---GAGAGGGTA---CTAG----CACTGCCAT 5837
                            **  ********* ****   * *******     *     *********

1BL_TaBradi2g15630          GCTCCATCCTGTGAGCCTCATCATCATCATAACCCACCGCGTCTCCCCTA 938
1AL_casTaBradi2g15630       GCTCCATCCTGTGAGCCTCATCATCCTCATAATCCACCGCGTCTCCCCTA 5730
1DLcasTaBradi2g15630        GCTCCATCCTGTGAGCCTCATCATCATCATAA------------------ 5869
                            ************************* ******

1BL_TaBradi2g15630          TCCAGATATATCACCATCACCCAGACCACAACCCCCCGCTTCACCCTCAC 988
1AL_casTaBradi2g15630       TCCAGATATATCACCATCACCCAGACTACAACCCCC-GCTTCACCCTCAC 5779
1DLcasTaBradi2g15630        TCCAGATATATCACCATCACCCAGACTACAACCCCC-GCTTCACCCTCAC 5918
                            ************************** ********* *************

1BL_TaBradi2g15630          CCGGACACACCAGCAACCACCCATTTCCGTGCACAGCAAACAACGGCCTA 1038
1AL_casTaBradi2g15630       CCAGACACACCAGCAACCACCCATTTCTGTGCACAGCAAACAACACCATA 5829
1DLcasTaBradi2g15630        CCAGGCACACCAGCCACCACCCATTTCTGTGCACAGCAAACAATAGCCTA 5968
                            ** * ********* ************ ***************   * **

1BL_TaBradi2g15630          CCACTC----TCTTCCAAAGCCACAA-AGCCTTCCGCAGTTTCGTGTGTC 1083
1AL_casTaBradi2g15630       CTACTCTCGCTCTTCCAAAGACACAACAGCCTTTCGTAGTTCCGTGTATC 5879
1DLcasTaBradi2g15630        CCACTC----TCTTCCAAAGCCACAA--GCCTTCCGCAGTTTCGTGTATC 6012
                            * ****    ********** *****  ***** ** **** ***** **

1BL_TaBradi2g15630          ATCAGCATATGAAATTTTTTGTCAGCCACCA-------------CCTCCT 1120
1AL_casTaBradi2g15630       ATCAGCATATGAAGATTTT-GTCAGCCACCAAGATATCTGCTCTCCTCCT 5928
1DLcasTaBradi2g15630        ATCAGCATATGAAATTTTT-GTCAGCCACCA-------------CCTCCT 6048
                            ************* **** ***********             ******

1BL_TaBradi2g15630          GGTACCATCAGCATATCAAAAAATTGTCAG----------GTACCACACT 1160
1AL_casTaBradi2g15630       GGTACCATCACCATATGGAAAATCTGTCAGCTACCAACAAGTCCCACACT 5978
1DLcasTaBradi2g15630        GGTACCATCACCATATGGAAAATCTGTCAGCTACCAACAAGTCCCACACT 6098
                            ********** *****  ****  ******          ** *******

1BL_TaBradi2g15630          ATTGGACACACGCAGCAGAAGAGAAAAGAAAAGAGACCTCCTGTGCTACA 1210
1AL_casTaBradi2g15630       ATTGGACACACACACAGCACAAGAGAAAAGA-----GACTTCCTGTGCTACA 6023
1DLcasTaBradi2g15630        ATTGGACACACACACAGCAGAAGAGAAAAGA-----GACTTCCTGTGCTACA 6143
                            *********** ***** ***********     *** ************

1BL_TaBradi2g15630          CGAGCCTGTCTTTCCCGAGGGATAAACATAGATAGGCAACCCAATCCACA 1260
1AL_casTaBradi2g15630       CGAGCCTGTCTTTCCTGAGCGATAAACATAGATAGACAATCCAATCCACA 6073
1DLcasTaBradi2g15630        CGAGCCTGTCTTTCCTGAGGGATAAACATAGATAGACAATCCAATCCACA 6193
                            *************** *** *************** *** **********

                              casTaBradi2g15630_DF2
1BL_TaBradi2g15630          TGTTCCTCCGGTGGTGTTCCTTCGCCCGCTCCTGCGGGCTAAA-GATATG 1309
1AL_casTaBradi2g15630       TGTTCCTCCGGTGGTGTTCCTTCGCCCGCTCCTGCAGGCCAAAAGATATG 6123
1DLcasTaBradi2g15630        TGTTCCTCCGGTGGTGTTCGTTGGCTCACT-----------AAAGATATG 6232
                            ******************* ** ** * **           ** ******

1BL_TaBradi2g15630          AGCGGGGTTTAGCTAGCACCCCC---GGCCACGGCCATTCACACGTGCTC 1356
1AL_casTaBradi2g15630       AGGAATGTGTAGC-AGCGCC------------GGCCATTCACACGTGCGC 6160
1DLcasTaBradi2g15630        AGGAACATTTAGC-AGCCCCGGCCAGGGCCACGGCCATTCACACGTGCTT 6281
                            **     * **** *** **            ****************
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1BL_TaBradi2g15630          CTTCCTCCTCCCAGCTCCGCTTTTACAGCTGCTCTCTGATGAGCAGAGCC 1406
1AL_casTaBradi2g15630       CT-CCTCCTCCTTGCTCTGCCTTTGCAACTGTTCTCTGATGAGCAGAGCC 6209
1DLcasTaBradi2g15630        CTTCCTCCTCCCAGCTCTGCTTTTGCAGCTGTTCTGTGATGAGCAGAGCC 6331
                            ** ********  **** ** *** ** *** *** **************

1BL_TaBradi2g15630          GGATCAGCTGCCCGCCCCTGCCCTCCTCCCGCCGGTCGAGGCCGGAACGG 1456
1AL_casTaBradi2g15630       AGA---GCTGCCTGCCCCTGCCCTCCTCCCGCCGGTCGAGGCCGGAACGG 6256
1DLcasTaBradi2g15630        AGA---GCTGCCTGGCCTTGCCCTCCTCCTGCCGGTCGAGGCCGGAACGG 6378
                             **    ****** * ** *********** ********************

1BL_TaBradi2g15630          ACAGTGATGAGTGCACGGAGTCATGCTTGTGAGACTCGGATTCGTGGTAT 1506
1AL_casTaBradi2g15630       ACAGTGATGAGTGCACGGAGTCATGCTTGTGAGACTCGGATTCGTGGTAT 6306
1DLcasTaBradi2g15630        ACAGTGATGAGTGCACGGAGTCATGCTTGTGAGACTCGGATTCGTGGTAT 6428
                            **************************************************

1BL_TaBradi2g15630          TAGCAACCTTCGCCGCGTTCACTCTTAAGCGAGGCAAGGGGCCTAAGAAA 1556
1AL_casTaBradi2g15630       TAGCAACCTTCGCCGCGTTCACTCTTAAGCGAGGCAAGGGGCCTAAGAAA 6356
1DLcasTaBradi2g15630        TAGCAACCTTCGCCGCGTTCACTCTTAAGCGAGGCAAGGGGCCTAAGAAA 6478
                            **************************************************
                                                      casTaBradi2g15630_DDR1
1BL_TaBradi2g15630          GGTACTCCTCTACTTCTCCACTCCATCAATGATTCCTTCTGTTTATCTGA 1606
1AL_casTaBradi2g15630       GGTACTCCTCTACTTCTCCACTGCGTCAATAGTTCCTTTTGTTAATCTGA 6406
1DLcasTaBradi2g15630        GGTACTCCTCTAGTTCTCCACTCCGTCAATGGTTCCTTCTGTCCATCTGA 6528
                            ************ ********* * *****  ****** ***  ******

1BL_TaBradi2g15630          ATTT------CAAGCTTATGCCTCACCTCTTTCAGACAATGGCCAAGCAG 1650
1AL_casTaBradi2g15630       ATTTTTCGCTCAAGCTTATGCCTCGCTTCTTTCAGACAATGGCCAAGCGG 6456
1DLcasTaBradi2g15630        ATTTCTCGCTCAAGCTTATGCCTGGCCTCTTTCAGACAATGGCCAAGCGG 6578
                            ****      *************  * ********************* *

1BL_TaBradi2g15630          GCAAGGGGAAGGAGAAGGCTCGGCATACTGGACATGTATGTACACGCATC 1700
1AL_casTaBradi2g15630       GCAAGAGGAAGGAGAAGGCTCGGCATACTGGACATGTATGTACATGCATC 6506
1DLcasTaBradi2g15630        GCAAGAGGAAGGAGAAGGCTCGGCATACTGGACATGTATGTACACGCATC 6628
                            ***** ************************************** *****
                                                casTaBradi2g15630_DF3
1BL_TaBradi2g15630          CACTGCCCACGAC----GCAGTTTAAAGCAAAGAACTGTTGGTTGTGCGT 1746
1AL_casTaBradi2g15630       CCCTGCCGATGACTGGCGCAGTTCAAAGCAAAGAACTACTGGTTGTGCGT 6556
1DLcasTaBradi2g15630        CACTGCCC---------GCAATTTACAGCAAAGAACTATTGGTTCTGCGT 6669
                            * *****          *** ** * ***********  ***** *****

1BL_TaBradi2g15630          GTTGCTCATC-CTTCTGCCTGCCCAAATGTTGATTATTTCAGGGGGAGAA 1795
1AL_casTaBradi2g15630       GTTGCTCATC-CTTCTGTCTGTCCAACTGTTGATTATTTCAGGGGGAGAA 6605
1DLcasTaBradi2g15630        CTTGTTCATCGCTTCTGC------------TGATTATTTCAGGGGGAGAA 6707
                             *** ***** ******            ********************

1BL_TaBradi2g15630          AGAAGGCGAGGAGGAAGAGGTTAAGACGATCAGCGGCATAATCAACTCGG 1845
1AL_casTaBradi2g15630       AGAGGACGAGGAGGAAGAGGTTAAGACGATCAGCGGCTTAATCAACTCGG 6655
1DLcasTaBradi2g15630        AGAAGACGAGGAGGAAGAGGTTAAGACGATCAGCGGCATAATCAACTCGG 6757
                            *** * ******************************* ************

1BL_TaBradi2g15630          CCCCGTCGGTGGACGACGACGATGAGGACGACATGTTCTCGGAGATCGAG 1895
1AL_casTaBradi2g15630       CCCCGTCGGTGGATGACGACGATGAGGACGACATGTTCTCGGAGATCGAG 6705
1DLcasTaBradi2g15630        CCCCGTCGGTGGACGACGACGATGAGGACGACATGTTCTCGGAGATCGAG 6807
                            ************* ************************************

1BL_TaBradi2g15630          AGCCTCCTGGGCGGGGAGGTCGACATCCCGATACCGGGCGACAGGTTCGA 1945
1AL_casTaBradi2g15630       AGCCTCCTGGGCGGGGAGATCGACATCCCGATACCGGGCGACAGGTACGA 6755
1DLcasTaBradi2g15630        AGCCTCCTGGGCGGGGAGGTCGACATCCCGATACCGGGTGACAGGTACGA 6857
                            ****************** ******************* ******* ***

1BL_TaBradi2g15630          ---------GCGGTCCCGGTACAACGCGCACATGGCCAGCAACGCCGCCG 1986
1AL_casTaBradi2g15630       CGTCAAGGAGCGGTCCCGTTACAACGCGCACATGGCCAACAACGCCGCCG 6805
1DLcasTaBradi2g15630        CGTCAAGGAGCGGTCCCGGTACAACGCGCACATGGCCAACAACGCCGCCG 6907
                                     ********* ******************* ***********
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                                          casTaBradi2g15630_DR2
1BL_TaBradi2g15630        AGATGGAGCGGCTGCGCGGCCTGGTGAGGGAGCTGGAGGAGCGGGAGGTG 2036
1AL_casTaBradi2g15630     AGATGGAGCGGCTGCGCGGCCTGGTCAGGGAGCTGGAGGAGCGGGAGGTG 6855
1DLcasTaBradi2g15630      AGATGGAGCGGCTGCGTGGCCTGGTGAGGGAGCTGGAGGAGCGGGAGGTG 6957
                          **************** ******** ************************

1BL_TaBradi2g15630        AAGCTGGAGGGCGAGCTGCTCGAGTACTACGGCCTCAAGGAGCAGGAGAC 2086
1AL_casTaBradi2g15630     AAGCTCGAGGGCGAGCTGCTCGAGTACTACGGCCTCAAGGAGCAGGAGAC 6905
1DLcasTaBradi2g15630      AAGCTCGAGGGCGAGCTGCTCGAGTACTACGGCCTCAAGGAGCAGGAGAC 7007
                          ***** ********************************************

1BL_TaBradi2g15630        CGACGTCACCGAGCTGCAGAAGCAGCTCAAGATCAAGACGGTGGAGGTCG 2136
1AL_casTaBradi2g15630     CGACGTCACCGAGCTGCAGAAGCAGCTCAAGATCAAGACGGTGGAGGTCG 6955
1DLcasTaBradi2g15630      CGACGTCTCCGAGCTGCAGAAGCAGCTCAAGATCAAGACGGTGGAGGTCG 7057
                          ******* ******************************************

1BL_TaBradi2g15630        ACATGCTCAACCTCACCATCAGCTCGCTGCAGGCGGAGAGGAAGAAGCTG 2186
1AL_casTaBradi2g15630     ACATGCTCAACCTCACCATCAGCTCGCTGCAGGCCGAGAGGAAGAAGCTG 7005
1DLcasTaBradi2g15630      ACATGCTCAACCTCACCATCAGCTCGCTGCAGGCCGAGAGGAAGAAGCTG 7107
                          ********************************** ***************

1BL_TaBradi2g15630        CAGGAGGACGTGGCCCGCGGCACGGCCGCCAAGAAGGAGCTCGACGCGTC 2236
1AL_casTaBradi2g15630     CAGGAGGACGTGGCCCGCGGCGCGGCGGCCAAGAAGGAGCTCGACGCGTC 7055
1DLcasTaBradi2g15630      CAGGAGGACGTGGCCCGCGGCGCGGCCGCCAAGAAGGAGCTCGACGCGTC 7157
                          ********************* **** ***********************

1BL_TaBradi2g15630        CAGGAGCAGGATCAAGGAGCTGCAGCGGCAGATACAGATGGAGGCCAACC 2286
1AL_casTaBradi2g15630     CAGGAGCAGGATCAAGGAGCTGCAGCGGCAGATACAGATGGAGGCCAACC 7105
1DLcasTaBradi2g15630      CAGGAGCAGGATCAAGGAGCTGCAGCGGCAGATACAGATGGAGGCCAACC 7207
                          **************************************************

1BL_TaBradi2g15630        AGACCAAGGGCCAGCTGATGCTGCTCAAGCAACAGGTGATGGGGCTCAGG 2336
1AL_casTaBradi2g15630     AGACCAAAGGCCAGCTGATGCTGCTGAAGCAACAGGTGATGGGGCTCAGG 7155
1DLcasTaBradi2g15630      AGACAAAAGGCCAGCTGATGCTGCTGAAGCAACAGGTGATGGGGCTCAGG 7257
                          **** ** ***************** ************************
                                        casTaBradi2g15630_DF4
1BL_TaBradi2g15630        GCCAAGGAGGAGGAGGTGGCCAAGAAGGACGCCGAGATCGAGCAGAAGCT 2386
1AL_casTaBradi2g15630     GCCAAGGAGGAGGAGGTGGCCAAGAAGGACGCCGAGATCGAGCAGAAGCT 7205
1DLcasTaBradi2g15630      GCCAAGGAGGAGGAGGTGGCCAAGAAGGACGCCGAGATCGAACAGAAGCT 7307
                          ***************************************** ********

1BL_TaBradi2g15630        CAAGAAGCTCAAGAACCTGGAGGTGGAGGTGCTTGAGCTGAGGAGGAAGA 2436
1AL_casTaBradi2g15630     CAAGAAGCTCAAGAACCTGGAGGTGGAGGTGCTTGAGCTGAGGAGGAAGA 7255
1DLcasTaBradi2g15630      CAAGAAGCTCAAGAACCTGGAGGTGGAGGTGCTTGAGCTGAGGAGGAAGA 7357
                          **************************************************
                                          casTaBradi2g15630_DR3
1BL_TaBradi2g15630        ACAAGGAGCTGCTGTACGAGAAGAGGGACCTCATGGTGAAGCTGGATGCA 2486
1AL_casTaBradi2g15630     ACAAGGAGCTGCTGTATGAGAAGAGGGACCTCATGGTGAAGCTGGATGCA 7305
1DLcasTaBradi2g15630      ACAAGGAGCTGCTGTATGAGAAGAGGGATCTCATGGTGAAGCTGGATGCA 7407
                          **************** *********** *********************

1BL_TaBradi2g15630        GCACAGGGAAAAATAACAGAGGTATAGCACTACTCTGCTTCTGTTACTGT 2536
1AL_casTaBradi2g15630     GCACAAGGAAAAATAACCGAGGTATAGCACCACTCTGTTTCTGTTACTAT 7355
1DLcasTaBradi2g15630      GCACAAGGAAAAATAACAGAGGTATAGCACTACTCTG------TTACTAT 7451
                          ***** *********** ************ ******      ***** *

1BL_TaBradi2g15630        TACTCTGCAAAGTTTGTAAAGGCTTTTGCATTTTAGTACATGACACAAGA 2586
1AL_casTaBradi2g15630     TACTCTGCAAAGTTTGTAAAGCCTTTTGCATTTTAGTACATGACACAAGA 7405
1DLcasTaBradi2g15630      TACTCTGCAAAGTTTGTAAAGCCTTTTGCATTTTAGTACATGACACAAGA 7501
                          ********************* ****************************

1BL_TaBradi2g15630        ATATTCAGCAGCAGTTTTTTTTTCTAGCCTAATCATTTGCATGGTCCTA 2636
1AL_casTaBradi2g15630     ATATTCAGCAGCAGTTTTTTT---CTAGCCTAATCATTTGCATGGTCCTA 7452
1DLcasTaBradi2g15630      ATATTCAGCAGCAGTTTTTTT----TAGCCTAATCATTTGCATGGTCCTA 7547
                          *********************    *************************
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1BL_TaBradi2g15630         GACGGTCCAAGTTTCTGTGGCAGGCTAGCAGTGGTTCTGCTACGTTTGTT 2686
1AL_casTaBradi2g15630      GACGGTCCAAGTTTCTGTGGCAGACTAGCAGTGGTTCTGCTACGTTTGTT 7502
1DLcasTaBradi2g15630       GACGGTCCAAGTTTCTGTGGCAGGCTAGCAGTGGTTCTGCTACGTTTGTT 7597
                           *********************** **************************

1BL_TaBradi2g15630         GGATTTGTCTCTATCCGTGTAGTGTACAGGCCTATCCTCTTAGTTTGTCT 2736
1AL_casTaBradi2g15630      GGATTTGTCTCTATCCCTATAGTGTACAGGCCTATCCTCTTAGTTTGTCT 7552
1DLcasTaBradi2g15630       GGGTTTGTCTCTATCCGTGTAGTGTACAGGCCTATCCTCTTAGTTTGTCT 7647
                           ** ************* * *******************************

1BL_TaBradi2g15630         CTAGTTCAAAATTAGGATTTTGCTTTTGTTTTCACTTGTAAAAGGTAGGA 2786
1AL_casTaBradi2g15630      CTAGTTCAAAATTAGGATTTTGCTTTTGTTTTCACTTGTAAAATGTAGGA 7602
1DLcasTaBradi2g15630       CTAGTTCAAAATTAGGATTTTGCTTTTGTTTCCACTTGTAAAAGGTAGGA 7697
                           ******************************* *********** ******

1BL_TaBradi2g15630         -CCTAATGATATGCACTCTCCTTTATATTGCTTTTGTCCTACAAAAACAA 2835
1AL_casTaBradi2g15630      ACCTAATGACATGCACTCTCTTTTGTATTGCTTTTTTCCTA---AAACAA 7649
1DLcasTaBradi2g15630       -CCTAATGATATGCACTCTCTTTTATATTGCTTTTTTCCTA----AAAAA 7742
                            ******** ********** *** ********** *****    ** **

1BL_TaBradi2g15630         ACAAACAAATCAGTAAGATTCATGAGAAGGACCGCAAGTTTTGACTTTAC 2885
1AL_casTaBradi2g15630      ACAAACAAATCAGTAAGATTCATGAGACGGACCGCAAGTTTTGACTTTGC 7699
1DLcasTaBradi2g15630       ACAAACCAATCAATAAGACTCATGAGACGGACCGCAAGTTTTGACTTTAC 7792
                           ****** ***** ***** ******** ******************** *

1BL_TaBradi2g15630         TATTAAACATGACAGCATGATTTTTACCATGACATTGTTATCTGGGCAAG 2935
1AL_casTaBradi2g15630      TATTAAACATGACAGCATGATTTTCACCATAACATTGTTATCTGGGCAAG 7749
1DLcasTaBradi2g15630       TCTTAAACATGACAGCATGATTTTCGCCATAACATTGTTATCTGGGCAAG 7842
                           * **********************  **** *******************

1BL_TaBradi2g15630         AAATTGAACATTTTTCTAGTATCGGGGTAAATGCAATTTTCTTCCCTGTT 2985
1AL_casTaBradi2g15630      AAAGTGAACAGTTTGCTCATATCAGGATAAATGCAATTCTCTTCCCTGTT 7799
1DLcasTaBradi2g15630       AAATTGAACGGTTTGCTCCTATCAGGATAAATGCAATTTTCTTCCCTGTT 7892
                           *** *****  *** **  **** ** *********** ***********

1BL_TaBradi2g15630         CAGTAGAACTAGCAGTCAGCTGAGGTGCTTTTCTTTATTGAGAG------ 3029
1AL_casTaBradi2g15630      CAGTAGAACAAACAGTCAGCTGAGGTGTTCTTCTATATTGAGAG------ 7843
1DLcasTaBradi2g15630       CAGTAGAACAAACAGTCAGCTGAGGTGCTTTTCTATGTTGAGAGAATGAG 7942
                           ********* * *************** * **** * *******
                                            casTaBradi2g15630_DF5
1BL_TaBradi2g15630         --TTAGTATTTCAGACCCACATCACAATTCCTGAAGTTCTACAAACGAAG 3077
1AL_casTaBradi2g15630      --TTAGTATTTCAGACCCAAATCACAATTCCTGAAGTTCTACAAAGGAAG 7891
1DLcasTaBradi2g15630       AGTTAGTATTTCAGATCCAAATCACAATTCCAGAAGTTCCACAAATGAAG 7992
                             ************* *** *********** ******* ***** ****

1BL_TaBradi2g15630         AATGGCAGTACATAGTAATTAAGTTTTAGCCAAATA-------------- 3113
1AL_casTaBradi2g15630      AATGC---TACCTAGTAATTAATTTTTAGCCAAGTAGTATTAGATAGTAT 7938
1DLcasTaBradi2g15630       AATGC---TACTTAGTAATTAATTTTTAGCCAAGTGTCAG-----ATTGT 8034
                           ****    *** ********** ********** *

1BL_TaBradi2g15630         ------------CTTTTTCATGACATACTTCTCCAATAATGTACATATGA 3151
1AL_casTaBradi2g15630      ATTTAATACTACCTTTTTCATGACATACTTCTCCAATAATGTACTTATGA 7988
1DLcasTaBradi2g15630       ATTTAATA----CTTTTTCATGGCATACTTCCTCAATAATGTACATATGA 8080
                                       ********** ********  *********** *****


1BL_TaBradi2g15630         CATATCATCATCA--------TGCAGAGTGATGTAGTTGCCCATGCAAGA 3193
1AL_casTaBradi2g15630      CATATCATCATCA--------TGCAGAGTGATGTAGTTGCCCATGCAAGA 8030
1DLcasTaBradi2g15630       CATACCATCATCAATTCATCATGCAGAGTGATGTAGTTGCCCATGCAAGA 8130
                           **** ********        *****************************
                                   casTaBradi2g15630_DR4
1BL_TaBradi2g15630         GAGGAGATCAACAACCTCAGGCACACAAACGAGGACCTGACAAAGCAAGT 3243
1AL_casTaBradi2g15630      GAGGAGATCAACAACCTCAGACACACAAACGAGGACCTGACAAAGCAAGT 8080
1DLcasTaBradi2g15630       GAGGAGATCAACAACCTGAGACATACAAACGAGGACCTGACAAAGCAAGT 8180
                           ***************** ** ** **************************
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1BL_TaBradi2g15630          GGAAGGCCTACAGATGAACAGATTCAGTGAAGTGGAAGAGCTGGTGTACC 3293
1AL_casTaBradi2g15630       GGAAGGCCTACAAATGAACAGATTCAGTGAAGTAGAAGAGCTGGTGTACC 8130
1DLcasTaBradi2g15630        GGAAGGCCTACAAATGAACAGATTCAGTGAAGTAGAAGAGCTGGTGTACC 8230
                            ************ ******************** ****************

1BL_TaBradi2g15630          TGCGCTGGGTCAACGCCTGTCTGCGATTCGAGCTCCGCAACTACCAGACG 3343
1AL_casTaBradi2g15630       TGCGCTGGGTCAACGCCTGTCTGCGATTCGAGCTCCGCAACTACCAGACA 8180
1DLcasTaBradi2g15630        TGCGCTGGGTCAACGCCTGTCTGCGATTCGAGCTCCGCAACTACCAGACA 8280
                            *************************************************

1BL_TaBradi2g15630          CCATCAGGCAAAATCTCTGCCCGCGACCTCAGCACGAAGCTCAGCCCAAA 3393
1AL_casTaBradi2g15630       CCATCTGGGAAGATCTCTGCCCGCGACCTCAGCACGAAGCTCAGCCCAAG 8230
1DLcasTaBradi2g15630        CCATCTGGGAAGATCTCTGCCCGCGACCTCAGCACGAAGCTCAGCCCAAG 8330
                            ***** ** ** *************************************

1BL_TaBradi2g15630          GTCGCAGGAGAGGGCCAAACAGATGATGCTCGAATTCGGGTCCGAACGAG 3443
1AL_casTaBradi2g15630       GTCGCAGGAGAGGGCCAAACAGATGATGCTCGAATTCGGGTCCGAACGAG 8280
1DLcasTaBradi2g15630        GTCGCAGGAGAGGGCCAAACAGATGATGCTCGAATTCGGGTCTGAACGAG 8380
                            ***************************************** ********

1BL_TaBradi2g15630          GCCAGGGCGATACCGACCTTGACAGCGTTTCCTCCGCACCTTCTTCCCCC 3493
1AL_casTaBradi2g15630       GCCAGGGCGACACTGACCTTGACAGTGTTTCCTCCGCGCCTTCTTCCCCC 8330
1DLcasTaBradi2g15630        GCCAGGGCGACACTGACCTTGACAGTGTCTCCTCCGCACCTTCTTCCCCC 8430
                            ********** ** *********** ** ******** ************

1BL_TaBradi2g15630          AGAAGCGAAGACTTCGACACCGCCTCGATCGACAGCTCTTCCAGCAGATA 3543
1AL_casTaBradi2g15630       AGAAGCGAAGACTTCGACACCGCCTCGATCGACAGCTCTTCCAGCAAATA 8380
1DLcasTaBradi2g15630        AGAAGCGAAGACTTCGACACCGCCTCGATCGACAGCTCTTCCAGCAGATA 8480
                            ********************************************** ***

1BL_TaBradi2g15630          CAGCTTCCTAAGCAAGAGGCCGAACCTGATGCAGAAACTCAAGAAGTGGG 3593
1AL_casTaBradi2g15630       CAGCTTCCTAAGCAAGAGGCCGAACCTGATGCAGAAACTCAAGAAGTGGG 8430
1DLcasTaBradi2g15630        CAGCTTCCTAAGCAAGAGGCCGAACCTGATGCAGAAACTCAAGAAGTGGG 8530
                            **************************************************

1BL_TaBradi2g15630          GAAGGAGCAAGGACGACGGCAGCTATCTGTCATCCCCGTCGTCGCGGTCC 3643
1AL_casTaBradi2g15630       GAAGGAGCAAGGATGACGGCAGCTATCTGTCATCCCCGTCGTCGCGGTCC 8480
1DLcasTaBradi2g15630        GAAGGAGCAAGGATGACGGCAGCTATCTGTCATCCCCGTCCTCGCGGTCC 8580
                            ************* ************************** *********

1BL_TaBradi2g15630          CTGACCAGCAGCTCTCCGAAGAGGAGCCAGAAACCAAAGGGGCCCCTGGA 3693
1AL_casTaBradi2g15630       CTGACCAGCAGCTCTCCGAAGAGGAGCCAGAAACCAAAGGGGCCCCTGGA 8530
1DLcasTaBradi2g15630        CTGACCAGTAGCTCTCCGAAGAGGAGCCAGAAACCAAAGGGGCCCCTGGA 8630
                            ******** *****************************************

1BL_TaBradi2g15630          GTCTCTCATGATCAGAAATGCAGGAGATGGCATGTCCATCACAACGTTTG 3743
1AL_casTaBradi2g15630       GTCTCTCATGATCAGAAATGCAGGAGATGGTATGTCCATTACAACATTCG 8580
1DLcasTaBradi2g15630        GTCTCTCATGATCAGAAATGCAGGAGATGGTATGTCCATTACAACATTTG 8680
                            ****************************** ******** ***** ** *

1BL_TaBradi2g15630          GAAAAAGGGACCAAGAATCCGGTGATGCAGATGATGCAAATGTTGCATCT 3793
1AL_casTaBradi2g15630       GAAAAAGGGACCAAGAATCCGGTGACGCAGATGATGCAAATGTTGCGTCT 8630
1DLcasTaBradi2g15630        GAAAAAGGGACCAAGAATCCGGTGACGCAGATGATGCAAATGTTGCATCT 8730
                            ************************* ******************** ***

                              casTaBradi2g15630_DF6
1BL_TaBradi2g15630          TCATTCCAGCTGATGTCGAAGAATGTCGAAGGCTTCGCTGATGAGAAGTA 3843
1AL_casTaBradi2g15630       TCGTTCCAGCTGATGTCGAAGAATGTCGAAGGCTTCGCTGATGAGAAGTA 8680
1DLcasTaBradi2g15630        TCATTCCAGTTGATGTCGAAGAATGTGGAAGGCTTTGCTGATGAGAAGTA 8780
                            ** ****** **************** ******** **************

1BL_TaBradi2g15630          CCCCGCTTACAAAGACCGGCATAAGCNNNNNNNNNNNNNNNNNNN----- 3888
1AL_casTaBradi2g15630       CCCCGCTTACAAAGACCGGCATAAGCTTGCGACGGAACGGGAGAAGGCGA 8730
1DLcasTaBradi2g15630        TCCCGCTTACAAAGACCGGCATAAGCTTGCGACGGAACGGGAGAAGGCGA 8830
                             *************************

1BL_TaBradi2g15630          ----AGAGAAGGCCGAGCAAGCCAGAGCACAGAGGTTTGGTGGTGGCTAC 3934
1AL_casTaBradi2g15630       TCAAAGAGAAGGCCGAGCAAGCCAGAGCGCAAAGGTTTGGTGGTGGCTAT 8780
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1DLcasTaBradi2g15630        TCAAAGAGAAGGCCGAGCAAGCCAGGGCACAAAGGTTTGGTGGTGGCTAT 8880
                                ********************* ** ** *****************

1BL_TaBradi2g15630          AGTTCAGTTCTGGTTCCCTCCCCGAGAGCTGCACTCCCCCCAAAACTCGC 3984
1AL_casTaBradi2g15630       AGTTCAGTTCTGGTTCCCTCCCCGAGAGCTGCACTCCCCCCAAAACTCGC 8830
1DLcasTaBradi2g15630        AGTTCAGTTCTGGTTCCCTCCCCGAGAGCTGCACTCCCCCCAAAACTCGC 8930
                            **************************************************
                                                   casTaBradi2g15630_DR5
1BL_TaBradi2g15630          TCAAATAAAGGAGAAGAAGGCCCCCACAGTTAATTCTGAACCTGGTGAGC 4034
1AL_casTaBradi2g15630       TCAAATAAAGGAGAAGAATGCCCCCACAGTTAATTCTGAACCTGGTGAGC 8880
1DLcasTaBradi2g15630        TCAAATAAAGGAGAAGAAGGCCCCTGCAGTTAATTCTGAACCTGGTGAGC 8980
                            ****************** *****  ************************

1BL_TaBradi2g15630          AATCTAGTGATGTCCCGAACAACCCCCTGGCTGTCACCCAGTTGAAGCTT 4084
1AL_casTaBradi2g15630       AATCTAGTGATATCCCGAACAACCCCCTGGCTGTCACCCAGTTGAAGCTT 8930
1DLcasTaBradi2g15630        AATCTAGTGATATCCCGAACAACCCCCTGGCTGTCACCCAGTTGAAGCTT 9030
                            *********** **************************************

1BL_TaBradi2g15630          GCCCAAATTGAGAAGAGAGCTCCAAGAGTCCCCGTCCACCACCCACGGC 4134
1AL_casTaBradi2g15630       GCCCAAATTGAGAAGAGGGCTCCAAGAGTCCCCGTCCACCACCCACAGC 8980
1DLcasTaBradi2g15630        GCCCAAATTGAGAAGAGGGCCCCAAGAGTCCCCGTCCACCACCCACGGC 9080
                            ***************** ** ************************** **

1BL_TaBradi2g15630          ATCGGCCGCCGCTGCTTCAGGAGCTACCAGTACTGCGAGCGGTGGACCAC 4184
1AL_casTaBradi2g15630       ATCGGCCGCCGCTGCTTCAGGAGCTACCAGTACTGGGAGTGGTGGACCAC 9030
1DLcasTaBradi2g15630        NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN 9130


1BL_TaBradi2g15630          CGATGCCGCCACGCCCACCAGGTGCACCTCCTCCCCCACCACCTCCAGGG 4234
1AL_casTaBradi2g15630       CGATGCCGCCACGCCCACCAGGTGCACCTCCTCCACCACCACCTCCAGGG 9080
1DLcasTaBradi2g15630        NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN---------- 9170

1BL_TaBradi2g15630          AGACCCGGTGGCCCTCCGCCGCCACCGCCGCCTCCCGGTTCTCTATCCAA 4284
1AL_casTaBradi2g15630       AGACCCGGTGGCCCTCCGCCGCCACCGCCGCCTCCCGGTTCTCTATCCAA 9130
1DLcasTaBradi2g15630        -------------------NNNNNNNNNNNNNNNNNNNNNNNNNNATCCAA 9201
                                                                        ******
1BL_TaBradi2g15630          GAGCCTTGCTGGTGGCGACAAGGTGCACCGTGCTCCGGAGGTCGTGGAGT 4334
1AL_casTaBradi2g15630       GAGCCTTGCTGGTGGTGACAAGGTACACCGTGCTCCGGAGGTCGTGGAGT 9180
1DLcasTaBradi2g15630        GAGCCTTGCTGGTGGTGACAAGGTGCACCGTGCTCCGGAGGTCGTGGAGT 9251
                            *************** ******** *************************

1BL_TaBradi2g15630          TCTATCAGAGTCTCATGAAACGTGAAGCCAAGAAGGACACCACCTCTTTG 4384
1AL_casTaBradi2g15630       TCTATCAGAGTCTCATGAAACGTGAAGCTAAGAAGGACACCACCTCTTTG 9230
1DLcasTaBradi2g15630        TCTATCAGAGTCTCATGAAACGTGAAGCCAAGAAGGACACCACCTCTTTG 9301
                            **************************** *********************

                               casTaBradi2g15630_DF7
1BL_TaBradi2g15630          GGATCAAAATCATCGAATGTTTCTGATAACAGAAGCAACATGATTGGAGA 4434
1AL_casTaBradi2g15630       GGATCAAAATCATCGAATGTTTCTGATAACAGAAGCAACATGATTGGAGA 9280
1DLcasTaBradi2g15630        GGATCAAAAACATCGAATGTTTCTGACAACAGAAGCAACATGATCGGAGA 9351
                            ********* **************** ***************** *****
1BL_TaBradi2g15630          GATTGAGAACAGATCAACATTCCTATTAGCTGTAAGTATCTTCGGATGGC 4484
1AL_casTaBradi2g15630       GATTGAGAACAGATCAACATTCCTATTAGCTGTAAGTATCTTCAGATGGC 9330
1DLcasTaBradi2g15630        GATTGAGAACAGATCAACATTCCTATTAGCTGTAAGTATCTTCAGATGGC 9401
                            ******************************************* ******

                            casTaBradi2g15630_DR6
1BL_TaBradi2g15630          CCACCGCGCATAAAAATCCTGCCAAATCCATGTCGTC-ATCATTAGTGCA 4533
1AL_casTaBradi2g15630       CCATCACGCATAAAAATCCTGCCAAATCCATGTCGTCCATCATTAGTGCA 9380
1DLcasTaBradi2g15630        CCGCCTTGCATAAAAATCCTGCCAAATCCATGCCGTCCATCATTAGTGCA 9451
                            **  *  ************************* **** ************

1BL_TaBradi2g15630          GCTCATTGTAGTCAGTAGGTATAACTTCAATATAATCAGCTCATTATGAC 4583
1AL_casTaBradi2g15630       GCTCATTGTAGTCAGTAGGTATAACTTCAATATGATCAGCTCATTATGAC 9430
1DLcasTaBradi2g15630        GATCATTGTAGGCAGTAGGTATAACTTCAATATAATCAGCTCATTATGAC 9501
                            * ********* ********************* ****************
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1BL_TaBradi2g15630          GAATATTGTGAAAAACATGGAATGTTTCAGGTCAAAGCTGATGTGGAGAC 4633
1AL_casTaBradi2g15630       GAATATTGTCAAAA-CATGGAATGTTTCAGGTCAAAGCTGATGTGGAGAC 9479
1DLcasTaBradi2g15630        GAATATTGTCAAAAACATGGAATGTTTCAGGTCAAAGCTGATGTGGAGAC 9551
                            ********* **** ***********************************

1BL_TaBradi2g15630          ACAAGGAGAATTTGTCGAGTCCCTAGCGAGCGAGGTCCGGGCAGCAAGAT 4683
1AL_casTaBradi2g15630       ACAAGGAGAATTTGTTGAGTCCCTCGCGGGTGAGGTCCGAGCAGCAAGAT 9529
1DLcasTaBradi2g15630        ACAAGGAGAATTTGTTGAGTCCCTGGCGAGTGAGGTCCGAGCAGCAAGAT 9601
                            *************** ******** *** * ******** **********

1BL_TaBradi2g15630          TCGCCAATATCGATGATGTTGTTGCATTTGTACATTGGCTGGATGAGGAG 4733
1AL_casTaBradi2g15630       TCGCGAATATCGACGATGTTGTTGCATTTGTACACTGGCTGGATGAGGAG 9579
1DLcasTaBradi2g15630        TCGCGAATATCGATGATGTCGTTGCATTTGTACACTGGCTGGATGAGGAG 9651
                            **** ******** ***** ************** ***************

1BL_TaBradi2g15630          TTGTCATTCTTGGTAAGACCCCATTAATTTATCCATGTTAGATATTGTAC 4783
1AL_casTaBradi2g15630       TTGTCATTCTTGGTAAGACCCCATTACTTTATCCATGTTAGATAGTGTAC 9629
1DLcasTaBradi2g15630        TTGTCATTCTTGGTAAGACCCCATTAATTTATCCATGTTAGATATTGTAC 9701
                            ************************** ***************** *****

1BL_TaBradi2g15630          TTAGGCTGCACATGATCTACTACTAAAAGGATCAATTAAACTTTTTTTTA 4833
1AL_casTaBradi2g15630       TTAGGCTGCACATGATCAACTCCTAAAAAGATCAATTAA-CCTTTTTTTA 9678
1DLcasTaBradi2g15630        TTAGGCTGCACATGATCAACTACTAAAAAGATCAATTAACCTTTCTTTTA 9751
                            ***************** *** ****** ********** * ** *****

1BL_TaBradi2g15630          GGTTGATGAGAGAGCAGTGCTAAAGCACTTCGATTGGCCAGAGAGCAAAA 4883
1AL_casTaBradi2g15630       GGTTGATGAGAGAGCAGTGCTAAAGCATTTCGATTGGCCAGAGAGCAAAA 9728
1DLcasTaBradi2g15630        GGTTGATGAGAGAGCAGTGCTAAAGCATTTCGATTGGCCAGAGAGCAAAA 9801
                            *************************** **********************

1BL_TaBradi2g15630          CTGATGCATTAAGAGAGTCCGCCTTTGAGTATCAGGACCTGGTGAAACTA 4933
1AL_casTaBradi2g15630       CTGATGCATTAAGAGAGGCCGCCTTTGAGTATCAGGACCTGGTGAAACTA 9778
1DLcasTaBradi2g15630        CTGATGCATTAAGAGAGGCCGCCTTTGAGTATCAGGACCTGGTGAAACTA 9851
                            ***************** ********************************

                             casTaBradi2g15630_DF8
1BL_TaBradi2g15630          GAGAATAAGGCCACATCCTTCGTCGACGATCCAAAACTTCCATGTGAAGA 4983
1AL_casTaBradi2g15630       GAGAATAAGGCCACATCCTTCGTCGACGATCCAAAACTTCCATGTGAAGA 9828
1DLcasTaBradi2g15630        GAGAACAAGGCCACATCCTTTGTCGACGATCCAAAACTTCCATGTGAAGA 9901
                            ***** ************** *****************************

1BL_TaBradi2g15630          AGCTCTCAAGAGGATGTATTCGTTGCTTGAGAAGTAAGTGGCTTCTCTGA 5033
1AL_casTaBradi2g15630       AGCTCTCAAGAGGATGTATTCGTTGCTTGAGAAGTAAGTGCCTTCTCTGA 9878
1DLcasTaBradi2g15630        AGCTCTAAAGAGGATGTATTCGTTGCTTGAGAAGTAAGTGCCTTCTCTGA 9951
                            ****** ********************************* *********

1BL_TaBradi2g15630          ACTAGTATGTTCACAAAATAGCATAGTTCTTCAGAGTAAATCGGTAATAA 5083
1AL_casTaBradi2g15630       ACTAGTATGTTCCCAAA-TAGCATAGTTCTTCAGGGTAAATCAGTAATAA 9927
1DLcasTaBradi2g15630        ACTAGTATGTTCCCAAA-TAGCATAGTTCTTCAGAGTAAATCGGTAATAA 10000
                            ************ **** **************** ******* *******

1BL_TaBradi2g15630          CTGTTCAGAAAATAATTGGCATT--TTTTGTGAATTCCAAGATGTTT--- 5128
1AL_casTaBradi2g15630       TTTTTCAGAAAATAATTGGCAATATTTTTGCGAATTCCAAGATGTTTGTG 9977
1DLcasTaBradi2g15630        TTTTTCAGAAAATAATTGGCAATA-TTTTGCGAATTCCAAGATGTTTGTG 10049
                             * ****************** *  ***** ****************
                                                     casTaBradi2g15630_DR7
1BL_TaBradi2g15630          --------------ACCCTAAGAATCATAATTTCAGTGAACAAACTAATG 5164
1AL_casTaBradi2g15630       AGAAGTGTTGGTCTACCCTAAGAATCATAATTTCAGTGAACAAACTAATG 10027
1DLcasTaBradi2g15630        ATAAGTATTGGTTTACCCTAAGAATCATAATTTCAGTGAACTAATTAGTG 10099
                                          *************************** ** ** **

1BL_TaBradi2g15630          TCATACTTCTGGCAGAGTGGAGCAGAGTGTTTACGCACTTCTTCGTACAA 5214
1AL_casTaBradi2g15630       TCATATTTCTGGCAGAGTGGAGCAGAGTGTTTATGCACTTCTTCGTACAA 10077
1DLcasTaBradi2g15630        TCATACTTCTGACAGAGTGGAGCAGAGTGTTTACGCACTTCTTCGTACAA 10149
                            ***** ***** ********************* ****************
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1BL_TaBradi2g15630          GAGACATGACCACCGCACGGTACAAGGAGTATGGAATACCAGTCGATTGG 5264
1AL_casTaBradi2g15630       GAGACATGACCACCGCACGGTACAAGGAGTATGGAATACCAGTTGATTGG 10127
1DLcasTaBradi2g15630        GAGACATGACCACCGCACGGTACAAGGAGTATGGAATACCAGTCGATTGG 10199
                            ******************************************* ******

1BL_TaBradi2g15630          CTATCTGATTCAGGAAAAGTTGGCAAGGTGCA------------------ 5296
1AL_casTaBradi2g15630       CTATCTGATTCTGGAAAAGTTGGCAAGGTGCACATTTCTAGAGTCTAAAG 10177
1DLcasTaBradi2g15630        CTATCTGATTCAGGAAAAGTTGGCAAGGTGTGCATCTCTAGA-------- 10241
                            *********** ******************

1BL_TaBradi2g15630          -----------TATGTTGGCAGCCTTACTTATTTGAAAGAGCATACAATT 5335
1AL_casTaBradi2g15630       TCTAAACTACTTATGTTGGCAGTCTTACTTA----AAAGAGCATACAATT 10223
1DLcasTaBradi2g15630        ------CTACTTATGCTGGCAGCCTTACTTACTTGAAAGAGCATACAATT 10285
                                       **** ****** ********     ***************

1BL_TaBradi2g15630          -------CTTTATAAAG-----ATATAAGTTTTGAGTCAGAACATGAAAT 5373
1AL_casTaBradi2g15630       ACTAATTCCTCATGAAGCTGTAGTACAGGTTTCGAGTCAGAATATGAATC 10273
1DLcasTaBradi2g15630        ACTAATTCATTATAAAGAT---GTATAAGTTTTGAATCGGAATATGCAAT 10332
                                   * * ** ***       ** * **** ** ** *** *** *

1BL_TaBradi2g15630          AAGATTTGAATCAAAGTTTAACTTCATACCTTGGTTGCAGATCAAACTGG 5423
1AL_casTaBradi2g15630       AAGATTTTAATCAAAGTTTAATCTCATATGTTGGTTGCAGATCAAACTGG 10323
1DLcasTaBradi2g15630        AAGATTTGAATCAAAGTTTAACTTCATATGTTGGTTGCAGATCAAACTGG 10382
                            ******* *************  *****  ************************

                casTaBradi2g15630_DF9
1BL_TaBradi2g15630          CGTCTGTTCAGCTGGCAAAGAAGTACATGGAGAGGGTCACCTCGGAGCTC 5473
1AL_casTaBradi2g15630       CATCCGTTCAGTTGGCGAAGAAGTACATGGAGAGGGTCACCTCGGAGCTC 10373
1DLcasTaBradi2g15630        CATCCGTTCAGCTTGCAAAGAAGTACATGGAGAGGGTCACCTCGGAGCTC 10432
                            * ** ****** * ** *********************************

1BL_TaBradi2g15630          GACGCGTTGCAGGGCACTGAGAAAGAGCCCAACAGGGAGTTCCTGCTCCT 5523
1AL_casTaBradi2g15630       GACGCGTTGCAGGGCACCGAGAAAGAGCCCAACAGGGAGTTCCTGCTTCT 10423
1DLcasTaBradi2g15630        GACGCGCTGCAGGGCACCGAGAAAGAGCCCAACAGGGAGTTCCTGCTTCT 10482
                            ****** ********** ***************************** **

1BL_TaBradi2g15630          CCAGGGCGTCAGATTCGCCTTCCGAGTTCATCAGGTATAAATAACTATCC 5573
1AL_casTaBradi2g15630       CCAGGGCGTCAGATTCGCCTTCCGAGTTCATCAGGTATA--TAACTGTCC 10471
1DLcasTaBradi2g15630        CCAGGGCGTCAGATTCGCTTTCCGAGTTCATCAGGTATG--TACTT---- 10526
                            ****************** *******************    **  *

1BL_TaBradi2g15630          AAA-CTTACATTTCCACAGTATGAGTATATAATTACAGGTAAACCGGAGA 5622
1AL_casTaBradi2g15630       AAAACTTACATTTCAACAGTATGTGTATATAATTACAGGTAAACTGGAGA 10521
1DLcasTaBradi2g15630        ----CTTA----TCAACAATATGAGTAT----TTACAGGCAAA-TGGAA- 10562
                                ****    ** *** **** ****    ******* ***  ***

                                casTaBradi2g15630_DR8
1BL_TaBradi2g15630          CATTTCAAATCAAGAACTTACCGTTCGCCATTGCTTAGTTTGCCGGAGGC 5672
1AL_casTaBradi2g15630       TATTTCAAATCAAGAACTTACCATTCGCCATTGCGCAGTTTGCCGGAGGC 10571
1DLcasTaBradi2g15630        -ATTTCAAATCGAGAGCTTACGGTTCGCCATTGCGCAGTTTGCCGGAGGC 10611
                             ********** *** ***** ****************  **************

1BL_TaBradi2g15630          TTCGACGCGGACAGCATGAAAGTCTTCGAGGAGCTGAGAAGCAAGATGAG 5722
1AL_casTaBradi2g15630       TTCGACGCGGACAGCATGAAAGTCTTTGAGGAGCTGAGAAGCAAGATGAG 10621
1DLcasTaBradi2g15630        TTCGACGCGGACAGCATGAAAGTCTTTGAGGAGCTGAGAAGCAAGATGAG 10661
                            ************************** ***********************

1BL_TaBradi2g15630          CAGCACGCAGGCGCCCGCTCCGCCGGCATCCGACACATAGTGCGGAGTCT 5772
1AL_casTaBradi2g15630       CAGCACGCAGGCACCCGCTCCACCGGCATCTGACACATAGTGCGGAGTCT 10671
1DLcasTaBradi2g15630        CAGCACGCAGACACCCGCTCCACCGGCATCTGACACATAGTGCGGAGTCT 10711
                            ********** * ******** ******** *******************

1BL_TaBradi2g15630          TCAGGATTGCGCGCTCC---GGTCAGGTTAATTT-------ATAAGTAGT 5812
1AL_casTaBradi2g15630       TCAGGATTGCGCGCTCCTCCGGTCAGGTTAATTCGGAGGGCACAATTAGT 10721
1DLcasTaBradi2g15630        TCAGG----------------------TTAACTTCGAGGGCACAACTAGT 10739
                            *****                      **** *        * ** ****
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1BL_TaBradi2g15630         TGGCTAGCTAAACTGTACAAAAGAGAAGTGTAAATTCCAGTGTTGTCTTA 5862
1AL_casTaBradi2g15630      TGGCTAGTTAAACTGTACAAAAGAGAACTGTAAATTCCAATGTTGTCTTA 10771
1DLcasTaBradi2g15630       TGGCTAGCTAAACTGTACAAAAGAGAAGTGTAAATTCCAGTGTTGTCTTA 10789
                           ******* ******************* *********** **********

1BL_TaBradi2g15630         ATCAAGTTGTATATGTCAAGTCTACAGGTTCAGATCATCATACTATAAGC 5912
1AL_casTaBradi2g15630      ATCAAGTTGTATATGTCAAGTCTACAGGTTCAGATCAT---ACTATAAGC 10818
1DLcasTaBradi2g15630       ATCAAGTTGTATATGTCAAGTCTACAGGTTCAGATCAT---ACTATAAGC 10836
                           **************************************   *********

                                          casTaBradi2g15630_DF10
1BL_TaBradi2g15630         ATACCAGATTTTTTGTC-----CATGTTTGTTTGTTCGGCTGAAATTCTG 5957
1AL_casTaBradi2g15630      ATACCAGGTTTTTTGTCTTAATCAAGTTTGTTTGTTTGGCTGAAATTCTG 10868
1DLcasTaBradi2g15630       ATACCAGATTTTTTGTC-----CAAGTTTGTTTGTTCGGCTGCAATTCTG 10881
                           ******* *********     ** *********** ***** *******

1BL_TaBradi2g15630         TAACCGGGCATTGTGTAAAAAGCGAACCACAGTAATGAGATACTACCTA- 6006
1AL_casTaBradi2g15630      TAACCGGGCAGTTTGTAAAAAGTGAACCACAGTAATGAGATACTACCTAC 10918
1DLcasTaBradi2g15630       TAACCGGGCAGTTTGTAAAAAGTGAACCACAGTAATGAGATACTAC-TAC 10930
                           ********** * ********* *********************** **

1BL_TaBradi2g15630         --------------------------------------------------
1AL_casTaBradi2g15630      TACCTCCGTCTAGGTGAATAAGTCATTCGCGTAGTTCTAGGTCATCGATT 10968
1DLcasTaBradi2g15630       --------------------------------------------------


1BL_TaBradi2g15630         --------------------------------------------------
1AL_casTaBradi2g15630      TGAGAAATTAAATATGTGTTATATGTCATGAAAAGTATATCACTAGATTT 11018
1DLcasTaBradi2g15630       --------------------------------------------------


1BL_TaBradi2g15630         --------------------------------------------------
1AL_casTaBradi2g15630      CTACAAGGATGTAGTTTCTAAATATATGTTTTTTGTCACAAAGAATACAT 11068
1DLcasTaBradi2g15630       --------------------------------------------------


1BL_TaBradi2g15630         --------------------------------------------------
1AL_casTaBradi2g15630      ATTTAGATAGTTAAATCGTCAACCTGTAACTACGCGAATGACTTATTCAT 11118
1DLcasTaBradi2g15630       --------------------------------------------------


1BL_TaBradi2g15630         --------------------GTTTTTGTTACTTCCAATTTGGCAATCTGT 6036
1AL_casTaBradi2g15630      CGAGACGGAGGTAGTACCTAGTTTTGGCTACTTCCAGTTTGGCAATCTGT 11168
1DLcasTaBradi2g15630       -----------------CTAGTTTTTGCTACTTCCAATCTGGCAATCTGT 10963
                                               ***** * ******** * ***********
                                                    casTaBradi2g15630_DR9
1BL_TaBradi2g15630         TGCAGTTGAAATGTCTGCATCAGTCTTCAGAGCAAAACTCGTCAGATTGA 6086
1AL_casTaBradi2g15630      TGCAGTTGAGATGCCTGCTCCAGTCTTCAGAGCAAAACTCGTCAGATTAA 11218
1DLcasTaBradi2g15630       TGCAGTTGAAATGTCTGCATCAGTCTTGAGAGAAAAACTCGTCAGATTAA 11013
                           ********* *** ****  ******* **** *************** *

1BL_TaBradi2g15630         AATGCCTTGAACTGAAT--------------------------------- 6103
1AL_casTaBradi2g15630      AATGCCTTGAACTCAATCCGGCTAGCTCCCGGGGATGGCGGGTAATGCT 11268
1DLcasTaBradi2g15630       AATGCCTAGAACTCAATCCGGCGAGCTCCCTAGGACGGGCGGGTAATGCT 11063
                           ******* ***** ***
                                             casTaBradi2g15630_DR9
1BL_TaBradi2g15630         ----------------TCAGACAAATCCGGAGAGACTTGTGCTGAAGAAA 6137
1AL_casTaBradi2g15630      TAGGGTCGATTGCAATTCAGACAAATCCGGAGAGACTTGTGCTGAAGAAA 11318
1DLcasTaBradi2g15630       -AATATCATACGCAATGTATGCAAAACCGGAGTAACTTGTGCTGAAGAGA 11112
                                             *  **** ******  ************** *

1BL_TaBradi2g15630         AAGGATTTT-ACATGGCATCGGTGGGCAGAACAGCAGACACCCAACGTGG 6186
1AL_casTaBradi2g15630      AGGGATTTTTACATGGCATCGGGGGGCGGAACAGCCGAAAACCAACGTGG 11368
1DLcasTaBradi2g15630       A-GGATTCTTACATGGCACCGGTGGGCAGAACAGCAGAAACCCAACGTG- 11160
                           * ***** * ******** *** **** ******* ** * ********
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1BL_TaBradi2g15630         TGAGCGAGGCTGCGAGGCAGTGCAGGGCTGAGCCACCGGAGACCGGACCG 6236
1AL_casTaBradi2g15630      TGAGCGAGGC--------ACTGCAGGGCTGAGCCGCCGGA-------CCG 11403
1DLcasTaBradi2g15630       ---GCGAGGT--------ACTGCAGGGCTATGTGGCCGGAG-------CG 11192
                              ******         * *********  *   *****        **

1BL_TaBradi2g15630         ACCCTGCGAACAA-----CAGATGACGG-TGAGCCAGTGAAGAATCCAAG 6280
1AL_casTaBradi2g15630      ACCCTGCGAAAAA-----CAGATG---G-TGAGCCAGTGGAGAATCCAAG 11444
1DLcasTaBradi2g15630       ACCCTGCGAACAAAACAACAGAAGGTGGCTGCGCCAAAGCAGATTCCAGT 11242
                           ********** **      **** *   * ** ****  * *** ****

1BL_TaBradi2g15630         TGAGTTAGGTGCCGTGCTCTGGGCCGGAGAGCGAGCCGGGAGAAGGTGGG 6330
1AL_casTaBradi2g15630      TTATTTAGGTTCCGTGCTCTGAGCCGGAGTGAGAGCCGGGAGAAGGTGGG 11494
1DLcasTaBradi2g15630       TGAGTTAGGTGCCGTGCTCTGGGCCGGGGAGCGAGCCGGGAGAAGGTGGA 11292
                           * * ****** ********** ***** * * *****************

1BL_TaBradi2g15630         GTTTGCGGCGCCGCCGTCTGAAGGCCGAGAGAGAGG--GAGGGAGAAGAT 6378
1AL_casTaBradi2g15630      GTTTGCGGCGGCGCCGTCTGAAGGCCGAGAGAGCG--------AGAAGAG 11536
1DLcasTaBradi2g15630       GTTTGCGGCGCCGCCGTCTGAAGGCCGAGGGAGAGAAAGAGGGAGAAGAG 11342
                           ********** ****************** *** *        ******

1BL_TaBradi2g15630         AACCCACCGCGTGGAATGGGGCGGCTGCGCTCGGTTCGCCGGAGCCGCCT 6428
1AL_casTaBradi2g15630      AACCCACCGCGTGGAATGGGGCGGCTGCGCTCGGTTCGCCGGAGCCGCCT 11586
1DLcasTaBradi2g15630       AACCCACCGCGTGAAATGGGGCGGCTGCGCTCGGTTCGCCGGAGCTGCTT 11392
                           ************* ******************************* ** *

1BL_TaBradi2g15630         CGGCTTGCGTCCGCGCTCAAAAACGACGGAGGCCAGGGAGGAGTCAGGCG 6478
1AL_casTaBradi2g15630      CGGCTTGCGTACGCGCTCAAAAACGACGGAGGCCAGGGAGGAGGCAGGTG 11636
1DLcasTaBradi2g15630       CGGCTTGCGTCAACGCTCAAAAACGACGGAGAACTGGG-GGAATCAGGTG 11441
                           **********   ******************  * ***  ***  **** *

1BL_TaBradi2g15630         GCCGCGCCGCCGCCGGGAGGG-AACCTGGCCGGCGACAATGGCCGTCTTT 6527
1AL_casTaBradi2g15630      GCAGAGCCGCCGCCGGGAGGGGAACCTGGCCGGCGACAATGGCTG----- 11681
1DLcasTaBradi2g15630       GCAGCGCCGCCGCCGGGAGGGGAACCTGGCCGGCGACAATGGCCAGCAAT 11491
                           ** * **************** *********************

1BL_TaBradi2g15630         TTTTTTAGGGAAAGGCGACACTGGCCATCGTACTAGTCGTGAACTCGTGA 6577
1AL_casTaBradi2g15630      ------------------------CCATCGTGCTACTCTTTTTTTTCTTT 11707
1DLcasTaBradi2g15630       AGT--------------------ACTCTCTTTCTCCTTTTCTTTTTCTGT 11521
                                                   *  ** * **   *  *    *  *

                        casTaBradi2g15630_DR10
1BL_TaBradi2g15630         T--CACTCGGCGGCGTGGACGGGGTTAGGTATGGGCCTTCTGGGG-CGCA 6624
1AL_casTaBradi2g15630      C--AAATCGGCGGCGTGGACGGGGTTAGTTATGGGCCTTCTTGG--CG-- 11751
1DLcasTaBradi2g15630       TTTCACTAGGCGGCGTAGACGGGGTTAGCTATGGGCCTTCTGGGCGCGCA 11571
                               * * ******** *********** ************ **  **

1BL_TaBradi2g15630         A-GGCCCGGAAGG----AGCAACTCCCATTAAACCAGCCCACCTTATTT- 6668
1AL_casTaBradi2g15630      --GGCC----AAG----AGCACCTCCCACTAAACCAGCCCGCCTTTCCCT 11791
1DLcasTaBradi2g15630       ATGGCCCGCGAGGCAAAAACACCTTCCACAAAACCAGGCCACCT------ 11615
                             ****    * *    * ** ** ***  ******* ** ***
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Appendix 4.4 TaBradi2g14970

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1DL_TaBradi2g14970      -GCCGGACTCCGCCGCGCATTAATGCCGCCCCAT-CCGACGCGGGCGGGCGGGGCACGGG 90
1AL_TaBradi2g14970      -GCCGGACTCCGCCGCGCATTAATGCCTCCCCATTCCGACGCCGGCGGG----GCACGGG 83
1BL_TaBradi2g14970      GACCGGACTCCGCCGCGCATTAATGCCGCCCCATTCCGGCGCGGGCGGG----GCACGGG 356
                          ************************ ****** *** *** ******     *******

1DL_TaBradi2g14970      AGGGG---------CGGTGGTGGACCGATTGGTCGGGCGGCGGTGCGTACCGGTGGGGGC 141
1AL_TaBradi2g14970      AGGGGTGGCGCGAGCGGTGGTGGACCGATTGGGCGGGCGGCGGTGCGTACATGTGGGGGC 143
1BL_TaBradi2g14970      AG------------CGACAGGGGATCAGACGGGTGGGCGGT--TCCTCGACGGCACCGGC 402
                        **            **   * *** *    **  ******    * *       *    ***

1DL_TaBradi2g14970      GCCCGTGAGGTGAGTGAGTGAGTGACACCGCGCGCGCGGCGCCGGCGGCGTGGTTGGGGC 201
1AL_TaBradi2g14970      GGGCGTGAGGTGAGTGAGTGA----CACCGCGCGCGCGGCGCCGGCGGCGTGGTTGGTG- 198
1BL_TaBradi2g14970      --CCGTGGGGTGAGCGAGTGG----CACCGCGCGC-CGGC--CAGCGGCGTCGTTGG-GC 452
                           **** ****** *****     ********** ****   * ******* ***** *
                                    casTaBradi2g14970_DF1
1DL_TaBradi2g14970      AAAACTGTCGACCGGCCGCTGGCGAGGAGGGAAGAGGACGGATCTTGTTGCCAACTTAAT 261
1AL_TaBradi2g14970      ---------GGCCAGCGGCCGGCGAGGAGGAAGGAGGACGGATCTTGTTGCCGACTTAAT 249
1BL_TaBradi2g14970      ATAGCCGTGGGCCAGCCGCCGGGGAGGATGAAGGAGGGCGGATCTTGTTGCCGACTTAAT 512
                                 * ** ** ** ** ***** * * **** ************** *******

1DL_TaBradi2g14970      TTCAGGATCACGGCCGCTCGGTTTCTC-ATTAAC---ACTAGCAGTACCATGCT-GATTT 316
1AL_TaBradi2g14970      TTCAGGATCACGGCCCCTCGGTTTCTC-ATCAACGGGAGAAGCAGTACCATGTT-GATTT 307
1BL_TaBradi2g14970      TTTAGGATCACGGCCCCTCCGTTTCTGGATTGG----AGGGGCCGGGC-ATGTTTGATTT 567
                        ** ************ *** ******  **        *    ** *   * *** * *****

1DL_TaBradi2g14970      ATT--------TTCCTCCTGTCTGAATT---AACTGTTGCCAACGACTGAATATCATCAC 365
1AL_TaBradi2g14970      ATTACACTAGTTTTCTCTTGTCTGAATTAGTAACTGATGCCAACGACTGAACATCACCAC 367
1BL_TaBradi2g14970      ATT----------TCTCTTATCTGAATT---AACTGACGGCGACCAC-GAGTA------- 606
                        ***           *** * ********   *****  * * ** ** **   *

1DL_TaBradi2g14970      TTCACTCATTTCATTCGT---CGCTGTAAAAGGGAGGAGGCTCGCCGGTGATTGGGG--- 419
1AL_TaBradi2g14970      TTCAGTCATTTCATTCGTGCTCGCTGTAAAAAGGAGGAGGCTCGCCGGTGATTGGGGTCC 427
1BL_TaBradi2g14970      --------------------------------GGAGGAGGATCACGG------------- 621
                                                        ******** ** * *

1DL_TaBradi2g14970      -CGAGTCCT--CCTTTCCTTTCCTCGATCTCTACTTGTGCCCAGTGGTGATTGCAGGAGC 476
1AL_TaBradi2g14970      TCCTTTCCTTTCCTTTCCTTTCCTCGATCTCTACCTGTGCCCAGTGGTGACTGCAGGAGC 487
1BL_TaBradi2g14970      ---------------CCCCTTCCCCGATTGTT--------------------------GT 640
                                       ** **** ****    *                           *

1DL_TaBradi2g14970      ATTTGTTTTGCGTTCCCGACGACAGGAA---------AATCGAGTCCTCCTTGGATCCTG 527
1AL_TaBradi2g14970      ATTTGTTTTGCGTTCCCGACGACGAAAATGGGATGGGAGTCGAGACCTCATTGGATCCTG 547
1BL_TaBradi2g14970      ATTTGGTTTGCCTTCCCGACGACAAAAATG----------TGAGTCCTCCTTGGATCCTG 690
                        ***** ***** ***********   **              *** **** **********

1DL_TaBradi2g14970      CGCGCCCTGCTAAATTTTCTTCAAATATTGCGGC-TTCTAGGCTCTGACCAGCTCGGTTT 586
1AL_TaBradi2g14970      CGCGACCTGCTTAAATTTCTTCAAATATTGCGGC-TTCTAGGCTCTGACCAGCTCGGTTT 606
1BL_TaBradi2g14970      CGCGCCCTGCTCAATTTTCTTCAAGTATTTCGGCGTTCTCACTTCTGACCAGCTCGGTCT 750
                        **** ****** ** ********* **** **** ****     *************** *

1DL_TaBradi2g14970      CATCATCGCCGCTGCCTTAAAA-ACAGCACCAC------TCACATGT---GCATCTTTCC 636
1AL_TaBradi2g14970      CATCATCGCCGCCGCCTTGAAA-ACAGCACTAC------TCACATGT---GCATCTTTCC 656
1BL_TaBradi2g14970      CATCATCACTCCT-CCTTAAAATACAGT-CCACATCTTTTCCCGTGTCAAGAAGCTTCCG 808
                        ******* *  * **** *** ****  * **      ** * ***    * * *** *

1DL_TaBradi2g14970      TCGTGTCCACAACAAGTTCACATGTGCAGTGAA--ATCCTCGTGCA-----AGTCTCCGT 689
1AL_TaBradi2g14970      TCGTGTCCACAACAAGTTCACATGTGCAGTGAA--ATCCTCGTGCA-----AGTCTCCGT 709
1BL_TaBradi2g14970      TTTCATTAACGA-AACTCTGCAC-TGCACTGCACCGCACTTGTGCAGTGAAAGTCTTCTT 866
                        *    *  ** * ** *   **  **** ** *     ** *****      ***** * *

1DL_TaBradi2g14970      TTCCACTTGCAAAGTTCATGGGGATATTCTGCCTTGCTTCCCTTT-----GAGTTCAGAA 744
1AL_TaBradi2g14970      TTCCACTTGCAAAGTTCATCGGGATATTCTGCCTTGCTTCCTTGT-----GAGTTCAGAA 764
1BL_TaBradi2g14970      TTCCACTTGCAAAGTTCATCGGGATATTCTGCCTCGCTTCCTTTCCCTGCGAGTTCAGAA 926
                        ******************* ************** ****** *        *********

                  casTaBradi2g14970_DF2   ngs_F1
1DL_TaBradi2g14970      GAGGAAACAGCGAAGGAAGAACGCCAGCCACAAGATCAGAGGATCACCTCCTGATTCACG 804
1AL_TaBradi2g14970      GAGGAAACAGCAAAGGAAGAACGCCAGCCACAAGATCAGAGGATCACCTCCTGATTCACG 824
1BL_TaBradi2g14970      GGGGAAACAGCAAAGGAAGAACGCCAGCCACAAGATCAGAGGGTCATCTCCTGATTCACG 986
                        * ********* *****************************  *** ************
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1DL_TaBradi2g14970        TGACCCTGCCCTGAAAAGTCACAAAGTCCTCGTCACCTTTCCCACTCTTCCACTAGTCCC 864
1AL_TaBradi2g14970        TGACCCTGCCCTGAAAAGTCACAAAGTCCTTGACACCTTTCCCACTCTTCCACTAGTCCT 884
1BL_TaBradi2g14970        TGACCCTGCCCCGAAAAGTCACAAAGTACTCCACACCTTTCCCACTCTTCCACTAGTCCT 1046
                          *********** *************** **   **************************

1DL_TaBradi2g14970        TTTTCCCATGATCATTGTTCTGAAGTA----TACTGAGCTTTACAGAGGGCCGTGACCCG 920
1AL_TaBradi2g14970        TTTTCCCATGATCATTGTTCTGAAGTA----TACTGAACTTTACAGAGGGCCGTGACCCG 940
1BL_TaBradi2g14970        TTTCCCCATGATCATTGTTCCGAAATACTACTACTGAGCTTTACAGAGGGCCGTGACCCG 1106
                          *** **************** *** **     ****** **********************

                                                                 casTaBradi2g14970_DR1
1DL_TaBradi2g14970        TG------AGAGAGGGG-AAAAAGCCCGTGCTCTTTTTTGCTCGACCTGTAA----ATTC 969
1AL_TaBradi2g14970        TGACCGTCAGAGAGCGA-AAAAAGTCCGTGCTCTTTTT-GCTCCATGTATAACTTCATTC 998
1BL_TaBradi2g14970        TGACCGTGAGAGAGGGGGAAAAAGTCCGTGCTCTTTTT-GCCCCATGTATAA----ATTC 1161
                          **      ****** *  ****** ************* ** * *  * ***     ****

                                          casTaBradi2g14970_DF3
1DL_TaBradi2g14970        ATCAGTGATTTTGGGCCAAGTCATGTGCCTTCCATGCTCCAATCTAGTCTACCAGTTAAT 1029
1AL_TaBradi2g14970        ATCAGTGATTT-GGGCCAGGTCATGTGC-------------------------AGTTAAC 1032
1BL_TaBradi2g14970        ATCAGTGATTT-GGGCCAAGTCATGTGC-------------------------AGTTAAC 1195
                          *********** ****** *********                         ******

1DL_TaBradi2g14970        GGATT-CTGAAGATTCCATGGTTGCTGATCGTTCTCAACTTCTCATCTTGTTGCAGTTGC 1088
1AL_TaBradi2g14970        GGATTTCTGAAGGTTCCATGGTTGCTGATCGTTCTGAACTTCTCATCTTGTTGCAGTTGC 1092
1BL_TaBradi2g14970        GGATTTCTCAAGGTTCCATGGTTGCTGATGCTTCTCAACTTCTCGTCTTGTTGCAGTTGC 1255
                          ***** ** *** ****************  **** ******** ***************
                                 Exon2
1DL_TaBradi2g14970        AGGTGGACTGCGAATGTCATCGATGCAGTTCAGCAGCGTGCTGCCCCTGGAGGGCAAAGC 1148
1AL_TaBradi2g14970        AGGTGGACTGCGAATGTCATCGATGCAGTTCAGCAGCGTGCTGCCCCTGGAGGGCAAAGC 1152
1BL_TaBradi2g14970        AGGTGGACTGCGAATGTCATCGATGCAGTTCAGCAGCGTGCTGCCCCTGGAGGGCAAGGC 1315
                          ********************************************************* **

1DL_TaBradi2g14970        GTGCATCTCCCCCGTCAGGAGAGAGGGCTCCGCCTCCGAGCGCCTCAAGGTCGGGGACAG 1208
1AL_TaBradi2g14970        GTGCGTCTCCCCCGTCAGGAGAGAGGGCTCCGCCTGCGAGCGCCTCAAGGTCGGGGACAG 1212
1BL_TaBradi2g14970        GTGCGTCTCCCCCG----------------NNNNNNNNNNNGCCTCAAGGTCGGCGACAG 1359
                          **** *********                            ************* *****

1DL_TaBradi2g14970        CAGCAGCATCAGGCACGAGAGGGCCTCCAGGAGGATGTGCAACGGTGGCAGGGGCCCCGC 1268
1AL_TaBradi2g14970        CAGCAGCATCAGGCACGAGAGGGCCTCCAGGAGGATGTGCAACGGTGGCAGGGGCCCCGC 1272
1BL_TaBradi2g14970        CAGCAGCATCAGGCACGACAGGGCCTCCAGGAGGATGTGCAATGGCGGCAGGGGCCCCGC 1419
                          ****************** *********************** ** **************
                                                               casTaBradi2g14970_DR2
1DL_TaBradi2g14970        CGCCACCGGCGCGCAGTGCGTGCTCACCTCCGACGCCAGCCCAGCAGACACCCTTGTGAG 1328
1AL_TaBradi2g14970        CGCTACCGGCGCGCAGTGCGTGCTCACCTCCGACGCCAGCCCGGCAGACACCCTTGTAAG 1332
1BL_TaBradi2g14970        CGCCACCGGCGCGCAGTGCGTGCTCACCTCCGACGCCAGCCCGGCAGACACCCTTGTAAG 1479
                          *** ************************************** ************** **

1DL_TaBradi2g14970        TTTCATTCCATCCGAACCAGATGATGATCGAATTGCAATGGAGACACTCTGTTATGTTAG 1388
1AL_TaBradi2g14970        TTTCATTCCA-----GTCAGATGATGGTTGAGTTGCAA-GGAGACACTCTGTTATGTTAG 1386
1BL_TaBradi2g14970        TTT-------------------GATGATCGAGTTGCAATG-AGACACTCTGTTATGTTAG 1519
                          ***                   **** * ** ****** * ******************
                                                                      ngs_R1
1DL_TaBradi2g14970        CATCTCTGACTTTTTGATGCAAAAAAAAA------CACCTGCAGGTTCTCCGGACGTCCT 1442
1AL_TaBradi2g14970        CATCTCTGACTTTTTGATGCAAAAAAAAAA-----CATCTGCAGGTTCTCCGGACGTCCT 1441
1BL_TaBradi2g14970        CATCTCTGATGTTTTCATGCAAAAAAAAAATAAAAATACCTGCAGGTTCTCCGGACGTCCT 1579
                          ********* **** ************        * **********************

1DL_TaBradi2g14970        TCCGCAGGAATTACGCCGATCCGAACGAGGTCGCGGCCGTCATACTCGGCGGTGGCACCG 1502
1AL_TaBradi2g14970        TCCGGAGGAATTACGCCGATCCGAACGAGGTTGCTGCGGTCATACTCGGCGGTGGCACCG 1501
1BL_TaBradi2g14970        TCCGGAGGAATTACGCCGATCCGAACGAGGTGGCGGCCGTCATACTCGGCGGTGGCACCG 1639
                          **** ************************** ** ** **********************

1DL_TaBradi2g14970        GGACTCAGCTCTTCCCTCTCACAAGCACAAGGGCCACACCTGCTGTAAGATGACACATTT 1562
1AL_TaBradi2g14970        GGACTCAGCTCTTCCCTCTCACAAGCACAAGGGCCACACCTGCTGTAAGATTACACATT- 1560
1BL_TaBradi2g14970        GGACTCAGCTCTTCCCACTCACAAGCACAAGGGCCACACCTGCTGTAAGATGACACATT- 1698
                          **************** ********************************** *******

1DL_TaBradi2g14970        CATCATCCAGTTCTATGTTTTTAACTGTCTTGCTCTTTT-CTATTACAGGTTGATAGTTT 1621
1AL_TaBradi2g14970        CATCTTCCAGTCATATGTTTTTTACT-------TTTTTT-TTATTTCAAGTTGATAGTTT 1612
1BL_TaBradi2g14970        CATCATCCAGTTCTATGTTTTTAACTGTCTTGCTCTTTTTCTATTACAGGTTGATAGTTT 1758
                          **** ******  ********* ***       * ****  **** ** ***********
                          casTaBradi2g14970_DF4
1DL_TaBradi2g14970        GACACTAGTACATCTCAGTTCCAGAAATGAATTTAAA-AAAATCTGTGTTACTTACAGAA 1680
1AL_TaBradi2g14970        GATACTAGTACGTCTCAGTTGCAAAAG-GAATGAAAATAAATTCTCTGTCATTTGCAGAA 1671
1BL_TaBradi2g14970        AACACTAGCACATCTCAGTTGCAGAAATGAATTTTAG-AAAATCTGTGTTACTTACAGAT 1817
                           * ***** ** ******** ** **  ****    *  *** *** *** * ** ****
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1DL_TaBradi2g14970      ATGTTCTA-------------------------------------GAA-------CAT-- 1694
1AL_TaBradi2g14970      ACGTTCTA-------------------------------------GAT-------CAT-- 1685
1BL_TaBradi2g14970      ATGTTGTACCGTAGATTTCGATAAAGGGTGCTTTATTACTTAAAGGAAGTTCTACCGTAG 1877
                        * *** **                                     **        * *

1DL_TaBradi2g14970      ----TTCCCAGTTTTAGGTAGATAGGAATGAGAAAGCTTTATTCAAATTTCAGTTGTCAT 1750
1AL_TaBradi2g14970      ----GTCCCAGTTTTAGGTAGATATGAAAGAAAAAACTTTATTCAAATTTCAGTTGTCAT 1741
1BL_TaBradi2g14970      ATGATTCCCAGTTTTAGATAGATAGGAATGAGGAAGCTTTATTTAAATTTCACTTGTCAT 1937
                             ************ ****** *** **  ** ******* ******** *******

1DL_TaBradi2g14970      CT----GCACATGTTAAATTATTTGGATAGGACCAGTTGAAGTACAGCTCATT---CAGT 1803
1AL_TaBradi2g14970      CT----GCACATGTTAAATTATTTGGATAGGACCAGTTGAAGTACAGCTCATTATTCAGT 1797
1BL_TaBradi2g14970      CTATCTGCACATGGCAATTGATTTGGATAGGACCAGTTGAAGTACAGCTCATT---CAGT 1994
                        **    *******  ** * *********************************   ****
                        casTaBradi2g14970_DR3
1DL_TaBradi2g14970      ACCAAGTTTTCTGCATTGTGTTGTGTTTAAATCATTATTAGAAGCAGTGGTTTCTGTAGC 1863
1AL_TaBradi2g14970      AGCAAGGTTTCTGCATTGTGTTGTGTTTAAATCATTATTAGCAGCAGTGGTTTATGTAGC 1857
1BL_TaBradi2g14970      AGCAAGTTTTCTGCATTGTGCTGTGTTCAAATCATTATTAGCAGCAGTGGTTTCTGTAGC 2054
                        * **** ************* ****** ************* *********** ******

1DL_TaBradi2g14970      CGGACCCGATGATGCCCCCCACTTTAACCGACATGATGTCAACCTCAAGGCTATCAGTGA 1923
1AL_TaBradi2g14970      CGGACCCGATGATGCCCCCCACTTTAACTGACATGATGTCAACCTCAAGGCTATCAGTGA 1917
1BL_TaBradi2g14970      CGGACCCGATGATGCCCCCCACTTTAACCGACATGATGTCAACCTCAAGGCTATCAGTGG 2114
                        **************************** ******************************

1DL_TaBradi2g14970      CCATGCATGTAGCCCGTCCAGTCATCTTCGGATCGCCAGCCTGAATCTTGTTCCTTTCCC 1983
1AL_TaBradi2g14970      CCATCCATGTAGCCCGTCCAGTCATCTTCGGATCGCCAGCCTGAATCTTGTTCCTTTCCC 1977
1BL_TaBradi2g14970      CCATCCATGTAGCCCGTCCAGTCATCTTCGGATCGCCAGCCTGAATCTTGTTCCTTTCCC 2174
                        **** *******************************************************

1DL_TaBradi2g14970      TTTGTTGCATTGCTCAGGTTCCTATTGGAGGATGTTACAGGCTCATCGATATTCCCATGA 2043
1AL_TaBradi2g14970      TTTGTTGCATTGCTCAGGTTCCTATTGGAGGATGTTACAGGCTCATCGACATTCCCATGA 2037
1BL_TaBradi2g14970      TTTGTTGCATTGCTCAGGTTCCTATTGGAGGATGTTACAGGCTCATCGACATTCCCATGA 2234
                        ************************************************* **********

                     casTaBradi2g14970_DF5
1DL_TaBradi2g14970      GCAACTGCTTCAATAGTGGCATCAACAAGATATTCGTCATGACGCAGTTCAACTCGGCCT 2103
1AL_TaBradi2g14970      GCAACTGCTTCAACAGTGGCATCAACAAGATATTCGTCATGACGCAGTTCAACTCGGCCT 2097
1BL_TaBradi2g14970      GCAACTGCTTCAACAGTGGCATCAACAAGATATTCGTCATGACCCAGTTCAACTCGGCCT 2294
                        ************* ***************************** ****************

                        casTaBradi2g14970_DR4
1DL_TaBradi2g14970      CTCTTAATCGTCACATTCACCGCACCTACCTCGGCGGGGGAATCAATTTCACTGATGGAT 2163
1AL_TaBradi2g14970      CCCTTAATCGTCACATTCATCGCACCTACCTCGGCGGGGGAATCAATTTCACTGATGGAT 2157
1BL_TaBradi2g14970      CGCTTAATCGCCACATTCACCGCACCTACCTCGGCGGGGGAATCAATTTCACTGATGGAT 2354
                        * ******** ******** ****************************************

1DL_TaBradi2g14970      CTGTTGAGGTAATTGACCTCAGCTTATTAGTTTG---TACTCAACTTTTTTTATGATCTT 2220
1AL_TaBradi2g14970      CTGTTGAGGTAGTTGACCTCAGATTATTAGTTTGTTGTACTCAACTTTTTTTATGATCTT 2217
1BL_TaBradi2g14970      CCGTTGAGGTAATTGATCTCAGCTTATTAATTTA---TACTTGATTTTT----------T 2401
                        * ********* **** ***** ****** ***    ****  * ****          *

1DL_TaBradi2g14970      CATCTCGATGTATTGGGCTTTTAGCTGACTACAGCACACGTTGACTGATACACCTTTTTG 2280
1AL_TaBradi2g14970      CATCTCGATGTCTTGGGCTTTTAGCTGACTACAGCACAGGTTGACTGATACACCTTTTTG 2277
1BL_TaBradi2g14970      CATCTTGACGTCTTGGGCTTTTAGCTGACTACAGCACACATTGACTGATACACCTTTTTG 2461
                        ***** ** ** **************************  ********************

1DL_TaBradi2g14970      CAACAAATAGGTATTGGCCGCGACGCAAATGCCCGGGGAGGCTGCTGGATGGTTCCGCGG 2340
1AL_TaBradi2g14970      CAACAAATAGGTATTGGCCGCGACGCAAATGCCTGGGGAGGCTGCTGGATGGTTCCGCGG 2337
1BL_TaBradi2g14970      CAACAAATAGGTATTGGCCGCGACGCAAATGCCCGGGGAGGCTGCTGGATGGTTCCGCGG 2521
                        ********************************* **************************

1DL_TaBradi2g14970      AACAGCGGATGCCGTCAGAAAATTTATCTGGGTGCTTGAGGTGAGAAGAGTA---TCTAG 2397
1AL_TaBradi2g14970      AACAGCGGACGCCGTCAGAAAATTTATCTGGGTGCTTGAGGTGAGAAGAGTACTATCTAG 2397
1BL_TaBradi2g14970      AACAGCGGACGCCGTCAGAAAATTTATCTGGGTGCTTGAGGTGAGAAGAGTACTATCTGG 2581
                        ********* ******************************************   *** *

1DL_TaBradi2g14970      GAGCACATGGCCCTCCTTGCACCTCATACTTGTAAATCTGGATCTGTTAAAGTAATGCTT 2457
1AL_TaBradi2g14970      GAGCACATGACCCTCCTTGCACCTCATACTTGTACATCTGGATCTGTTAAAGTAATGCTT 2457
1BL_TaBradi2g14970      -------------------------ATACTTGTACATCTGCATGTGTTAAAGTAATGCTA 2616
                                                 ********* ***** ** ***************

1DL_TaBradi2g14970      CTTGTGTTCTGTCTACCTCTCCAGGACTATTATAAGAATAAATCCATAGAGCACATTTTG 2517
1AL_TaBradi2g14970      ATTGTGTTCTGTCTACCTCTCCAGGACTATTATAAGAATAAATCCATAGAGCACATTTTG 2517
1BL_TaBradi2g14970      CTTGTGTTATGTGTACCTCTCCAGGACTATTATAAGAATAAATCCATAGAGCACATTTTG 2676
                         ******* *** ***********************************************
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1DL_TaBradi2g14970      ATCTTGTCGGGCGATCAGCTTTATCGCATGGATTACATGGAGCTTGTGCAGGTTTGTGAT 2577
1AL_TaBradi2g14970      ATCTTGTCGGGCGATCAGCTTTATCGCATGGATTACATGGAGCTTGTGCAGGTTTGTGAT 2577
1BL_TaBradi2g14970      ATCTTGTCGGGCGATCAGCTTTATCGCATGGATTACATGGAGCTTGTGCAGGTTTGTGAT 2736
                        ************************************************************
                                                            casTaBradi2g14970_DF6
1DL_TaBradi2g14970      GTTCTCTTTAACCAGCTCTAGTGTATGTTCTGTTTTGAACTGGCTGACCAAGCTTATTCA 2637
1AL_TaBradi2g14970      GTTCTCTTTAACCAGCTCTAGTGTATGTTCTGTTTTGAACTGGCTGACCAAGCTGTGGCA 2637
1BL_TaBradi2g14970      GTTCTCTTTAACCAGCTCCAGTGTATGTTCTGTTTTGAACTGGCTGACCAAGCTGTGGCA 2796
                        ***************** ************************************    **

1DL_TaBradi2g14970      TGCATCCTTTACAGAAACATGTGGATGACAATGCTGACATTACTTTATCATGTGCCCCTG 2697
1AL_TaBradi2g14970      TACATCCTTTACAGAAACATGTGGATGACAATGCTGACATTACTTTATCATGTGCCCCTG 2697
1BL_TaBradi2g14970      TACATCCTTTACAGAAACATGTGGATGACAATGCTGACATTACTTTATCATGTGCCCCTG 2856
                        * **********************************************************

1DL_TaBradi2g14970      TTGGAGAGAGGTATTAACTATTCTTGTACATCCCAGATCCTTGTTTATGAGTTGTATCTT 2757
1AL_TaBradi2g14970      TTGGAGAGAGGTATTAACTATTCTTGTACATCCCAGATCCTTATTTATGAGTTGTATCTT 2757
1BL_TaBradi2g14970      TTGGAGAGAGGTATTAACTATTGTTCTACATCCCAGATCCTTATTTATGAGT-GTATCTT 2915
                        ********************** ** **************** ********* *******

1DL_TaBradi2g14970      CCTTTTGTTGAAGTTGCACTGCATCCTGATTTGCTTTTCTTTGTTTTGGAAGCCGGGCAT 2817
1AL_TaBradi2g14970      CCTTTTGGTGAAGTTGCACTGCATCCTGATTTGCTTTTCTTTGTTTTGGAAGCCGGGCAT 2817
1BL_TaBradi2g14970      CCTTTTGTTGAAGTTGCACTGCATCCTGATTTGCTTTTCTTTGTTTTGGAAGCCGGGCAT 2975
                        ******* ****************************************************

1DL_TaBradi2g14970      CTGAGTACGGGCTAGTGAAGTTCGACAGTTCAGGCCGTGTGGTCCAATTTTCTGAGAAGC 2877
1AL_TaBradi2g14970      CTGAGTACGGGCTAGTGAAGTTCGACAGTTCAGGCCGTGTGGTCCAATTTTCTGAGAAGC 2877
1BL_TaBradi2g14970      CTGAGTACGGGCTAGTGAAGTTCGACAGTTCAGGCCGTGTGGTCCAGTTTTCTGAGAAGC 3035
                        ********************************************** *************
                                                          casTaBradi2g14970_DR6
1DL_TaBradi2g14970      CAAAGGGTGACGATCTGGAAGCGATGGTTAGCACTGGTCTTACCTCACTGTGTCAGATAT 2937
1AL_TaBradi2g14970      CAAAGGGTGCCGATCTGGAAGCGATGGTTAGCGCTCACCTTAGCTCACTGATTCAGATAT 2937
1BL_TaBradi2g14970      CAAAGGGTGACGATCTGGAAGCGATGGTTAGCACTCGTCTCAGCTCACTGTGTCAGATAT 3095
                        ********* ********************** **   ** * *******  ********

1DL_TaBradi2g14970      ATGCCTAAAGATATAACTGTCTTAAATAAGTTGCAGTATCTGAAATTTAATCCATTGATC 2997
1AL_TaBradi2g14970      ATCTCTACA----------TCTTGAATGAGGTCTAGTTTCTGAAATTTAACCCATTGATC 2987
1BL_TaBradi2g14970      ATGCCTAAAGATATGACTGTCTTAAATAAGTTGCAGTATCTGAAATTTAAGCCATCGATC 3155
                        **  *** *          **** *** ** *  *** ************ **** ****

1DL_TaBradi2g14970      AT-TGCAGAAAGTGGACACCAGTTTTCTCAATTTCGCCATCGACGACCCTGCTAAATATC 3056
1AL_TaBradi2g14970      AT-TGCAGAAAGTGGATACCAGTTTTCTCAATTTCGCCATAGACGACCCTGCTAAATATC 3046
1BL_TaBradi2g14970      ATGTGCAGAAAGTGGACACCAGTTTTCTCAATTTCGCCATAGACGATCCTGCTAAATATC 3215
                        ** ************* *********************** ***** *************

1DL_TaBradi2g14970      CATACATTGCTTCTATGGGAGTCTATGTCTTCAAAAGAGATGTTCTGCTCAACCTTCTAA 3116
1AL_TaBradi2g14970      CATATATTGCGTCGATGGGAGTTTATGTCTTCAAAAGAGATGTTCTGCTGAACCTTCTAA 3106
1BL_TaBradi2g14970      CATACATTGCTTCTATGGGAGTCTATGTCTTCAAAAGAGATGTTCTGCTCAACCTTCTAA 3275
                        **** ***** ** ******** ************************** **********

                  casTaBradi2g14970_DF7
1DL_TaBradi2g14970      AGTAAGAACCTGCTCTCGTGACGATGCCGTTGTCCTGTCGGTCTGAATTCTAATATCTGC 3176
1AL_TaBradi2g14970      AGTAAGAACCTGCTCTTGTGACGATGCGGTTCTCCTGTCAGCCTGAATTCTAATGTTGGC 3166
1BL_TaBradi2g14970      AGTAAGAACCTGCTCTTGTGGTGACGCCGTCGTCCTGTCGGTCTGAATTCTAATATCCGC 3335
                        **************** ***  ** ** **  ******* * ************ *  **

1DL_TaBradi2g14970      ATTCTCAGGTCAAGATACGCAGAACTACATGACTTTGGGTCTGAAATCCTCCCGAGAGCT 3236
1AL_TaBradi2g14970      ATTCTCAGGTCAAGATACGCAGAACTACATGACTTTGGGTCTGAAATCCTCCCGAGAGCT 3226
1BL_TaBradi2g14970      ATTCTCAGGTCAAGATATGCAGAACTACATGACTTTGGGTCTGAGATCCTCCCGAGAGCT 3395
                        ***************** ************************** ***************

1DL_TaBradi2g14970      CTGCATGACCACAATGTACAGGTAAACTAACAGTGTGAGCTTCATTCGTTGTTTCTGTTG 3296
1AL_TaBradi2g14970      CTGCATGATCACAATGTGCAGGTAAAATTACCATGTGAACTTTATTCATTGTTTCTGCTG 3286
1BL_TaBradi2g14970      CTGCATGACCACAATGTACAGGTAAACTAACAGTGTGAGCTTCATTCGTTGTTTCTGTTG 3455
                        ******** ******** ******** * **  ***** *** **** ********* **

1DL_TaBradi2g14970      GGGAGGTAGCAC-TGCATGAAATGCAGTCTGTAAAA-CTATTTCCTATGTGCTGCACGAA 3354
1AL_TaBradi2g14970      GGGAGGTAGCACCTGCATGAAATGCAGTCTGTAAAAACGATTTCCTCTGCATTGCACGA- 3345
1BL_TaBradi2g14970      GGGAGGTAGCTC-TGCGTGAAATGCAGTCTGTAAAA-CTATTTCCTATGTGTTGCACGAA 3513
                        ********** * *** ******************* * ******* **   ******* 

                                      casTaBradi2g14970_DR6
1DL_TaBradi2g14970      GTGGCCGTTCATTTGACTCTGTTTTTGTCAGGCTTATGTCTTCACTGACTACTGGGAGGA 3414
1AL_TaBradi2g14970      ----CCGTTCATTTGACACTATGTTTGTCAGGCATATGTCTTCACTGACTACTGGGAGGA 3401
1BL_TaBradi2g14970      GTGGCCGTTCATTTGACACTGTTTTTGTCAGGCTTATGTCTTCACTGACTACTGGGAGGA 3573
                            ************* ** * ********** **************************
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1DL_TaBradi2g14970        CATTGGAACAATCAGATCCTTCTTCGATGCGAACATGGCCCTCTGCGAGCAGGTGACATT 3474
1AL_TaBradi2g14970        CATTGGAACAATCAGATCCTTCTTCGATGCGAACATGGCCCTCTGCGAGCAGGTGACATT 3461
1BL_TaBradi2g14970        CATTGGAACAATCAGATCCTTCTTCGATGCAAACATGGCCCTCTGCGAGCAGGTGCCATT 3633
                          ****************************** ************************ ****

1DL_TaBradi2g14970        CTATTTTTGGGTGCTTCC-AAATTTGACTT----------------CAGTTGTGCTAATA 3517
1AL_TaBradi2g14970        CTAGTTTTGTTT-CTTCC-AAGTT-GACTTGATGTTATTGCAGAAGTAGTTAGGCTTAAA 3518
1BL_TaBradi2g14970        ATCTTTTTGGGTGCTTCCCAAATTTGACTT----------------CAGTAGTGCTAATA 3677
                           *  *****  * ***** ** ** *****                 ***   *** * *

1DL_TaBradi2g14970        TGATAATTGATAAATGATAAAGCTACATTAAGACTCTTCACTTAATACATTTTTCAGTAT 3577
1AL_TaBradi2g14970        TCAT--CTGATAAATGATAAAGTTGCACTGAGAGACTTCAAGTAACATAATTT-CAATCT 3575
1BL_TaBradi2g14970        TGATAATCGATAAATGATAAAGTTATATTAAGACTCTTCACTTAATACATTTTTCAGTAT 3737
                          * **    ************** *  * * ***  *****  *** * * *** ** * *

1DL_TaBradi2g14970        TTTCACACAGTTTCTTCATTGCAGCCCCCAAAGTTCGAGTTTTATGATCCCAAAACTCCC 3637
1AL_TaBradi2g14970        TCTCACACATTTTTTATTTTGCAGCCTCCAAAGTTTGAATTTTATGATCCAAAAACTCCC 3635
1BL_TaBradi2g14970        TTTCACACATTTTGTTCATTGCAGCCCCCAAAGTTCGAGTTTTATGATCCCAAAACTCCC 3797
                          * ******* *** *   ******** ******** ** *********** *********

1DL_TaBradi2g14970        TTCTTCACCTCGCCTCGATACTTGCCACCAACAAAGTCAGACAAGTGCAGGGTACGTGTT 3697
1AL_TaBradi2g14970        TTCTTCACTTCGCCTCGGTACTTACCACCAACAAAGTCAGACAAGTGCAGGGTACGTGTT 3695
1BL_TaBradi2g14970        TTCTTCACCTCGCCTCGATACCTGCCACCAACAAAGTCAGACAAGTGCAGGGTACGTGTT 3857
                          ******** ******** *** * ************************************
          casTaBradi2g14970_DF8
1DL_TaBradi2g14970        AGAACCAACCTGCCATTGAGACTATTCCATACAAGCATCGGTGGTAAGCATCTGATATGG 3757
1AL_TaBradi2g14970        AGAATGGACCTGCTATTCAGACTATTCCATACAAGCCTCGGTGGTAAGCATCTGATATGG 3755
1BL_TaBradi2g14970        AGAATCAACCTGCCATTCAGACTATTCCATACAAGCATTAGCTGTAAGCATCTGATATGG 3917
                          ****   ****** *** ****************** *  *  *****************

1DL_TaBradi2g14970        ATTCTTCTGTGTGCAGATCAAAGAAGCGATCATTTCGCACGGCTGCTTCTTGCGTGAATG 3817
1AL_TaBradi2g14970        ATTCTTCTGTGTGCAGATCAAAGAAGCGATCATTTCGCACGGCTGCTTCTTGCGTGAATG 3815
1BL_TaBradi2g14970        ATTCTTCTGTGTGCAGATCAAAGAAGCGATCATTTCGCACGGCTGCTTCTTGCGTGAATG 3977
                          ************************************************************

1DL_TaBradi2g14970        CAAAATCGAGCACTCCATCATCGGCGTTCGTTCACGCCTAAACTCCGGAAGCGAACTCAA 3877
1AL_TaBradi2g14970        CAAAATCGAGCACTCCATCATCGGCGTCCGTTCACGCCTAAACTCCGGAAGCGAGCTCAA 3875
1BL_TaBradi2g14970        CAAAATCGAGCACTCCATCATCGGCGTTCGCTCACGCCTAAACTCCGGAAGCGAGCTCAA 4037
                          *************************** ** *********************** *****

              casTaBradi2g14970_DR7                      ngs_F2
1DL_TaBradi2g14970        GGTATGCTTTTTCGCACCGAATTAATGCTTGTGGTGCATGTCAACTGTAAAA-TGATCCA 3936
1AL_TaBradi2g14970        GGTATGTTTTTTCGCACCGAATTAATGCATGTGGTGCATGTCAACTGTAAAAATCATCAT 3935
1BL_TaBradi2g14970        GGTATGCCTTTTCGCACCGAATAATGGCATGTGGTGCATGTCAACTGTAAAA-TCATCCT 4096
                          ******  ************** *  ** ********************** * ***

1DL_TaBradi2g14970        TTGTCTGAACGCTGTCATTCTTCTGAATGGTGTTTGTTTGCAGAACGCGATGATGATGGG 3996
1AL_TaBradi2g14970        GCGTCTGAACGCTGTCATTCTTCTGAATGGTGTTTGTTTGCAGAACGCGATGATGATGGG 3995
1BL_TaBradi2g14970        GTGTCTGAACGCTGTCGCTCTTCCAAATGGTGGTGGTTTGCAGAATGCGATGATGATGGG 4156
                            **************  *****  ******* * ********** **************

1DL_TaBradi2g14970        TGCGGATTCGTACGAGACCGAGGATGAGATCTCGAGGCTGATGTCCGAGGGCAAGGTCCC 4056
1AL_TaBradi2g14970        CGCGGACTCGTACGAGACCGAGGACGAGATCTCGAGGCTGATGTCGGAGGGCAAGGTCCC 4055
1BL_TaBradi2g14970        CGCGGACTCGTACGAGACCGAAGACGAGATCTCGAGGCTGATGTCGGAGGGCAAGGTCCC 4216
                           ***** ************** ** ******************** **************

1DL_TaBradi2g14970        CATCGGCGTCGGGGAGAACACAAAGATCAGGTGAGAGAGACTGATCTGTACCTCAGAAAC 4116
1AL_TaBradi2g14970        CATCGGCGTCGGGGAGAACACAAAGATCAGGTGAGAGAGACTGATCTGTACCTCAGAAAC 4115
1BL_TaBradi2g14970        CATCGGCGTCGGGGAGAACACAAAGATCAGGTGAGAGAGACTGATCTGTACCTCAGGAAC 4276
                          ******************************************************** ***
                                   casTaBradi2g14970_DF9
1DL_TaBradi2g14970        AACACGTATCGTTCGGCGCAAGTGAGACAGTATCTCT-AACACTTTTTGCATCGATACAT 4175
1AL_TaBradi2g14970        AACACGTGTCGTTCGGCGCAAGTGACACATTATCTTT-AACACTTTT-ACGTGGATACAT 4173
1BL_TaBradi2g14970        GACACGTACCGTTCGGCGCAAGTGCCACATTATCTCTTAACACGTTTTGCGTGGATACGT 4336
                           ******  ***************  *** ***** * ***** ***    * * ***** *

                               Exon15
1DL_TaBradi2g14970        TGCAGCAACTGCATCATCGACATGAACGCGAGGATAGGAAGGGACGTGGTCATCTCAAAC 4235
1AL_TaBradi2g14970        TGCAGCAACTGCATCATCGACATGAACGCGAGGATAGGAAGGGACGTGGTCATCTCAAAC 4233
1BL_TaBradi2g14970        TGCAGCAACTGCATCATCGACATGAACGCGAGGATAGGAAGGGACGTGGTCATCTCAAAC 4396
                          ************************************************************

                                       casTaBradi2g14970_DR8
1DL_TaBradi2g14970        AAGGAGGTAAGATGCCCTCCTTCAGAGTTC-AAACTGGCCCCAAAATTCTGAAGAAAAC 4294
1AL_TaBradi2g14970        AAGGAGGTAAGATACCCTCCTTCAGAGTTT-AAACTTGGTCCCAAAATTCTGAAGAAAAC 4292
1BL_TaBradi2g14970        AAGGAGGTAAGACACCCTCCTTCAGAGTTTTAAACCTGGTCCCAAAGTTCTGAAGAAAAC 4456
                          ************ ***************  **** *** ****** *************
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1DL_TaBradi2g14970      AACACTCGTCTCTGAAACCATGCCACTTTGTGCCATTTCTGACAGGGAGTGCAAGAAGCC 4354
1AL_TaBradi2g14970      AACACTTGTCTCTGAAACCATGCTGCTTTGTGCCATTTCTGACAGGGAGTGCAAGAAGCC 4352
1BL_TaBradi2g14970      AACACTNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN 4516
                        ******

1DL_TaBradi2g14970      GACAGGCCGGAGGAGGGGTACTACATCAGGTCCGGGATCGTGGTGATCCAGAAGAACGCG 4414
1AL_TaBradi2g14970      GACAGGCCGGAGGAAGGGTACTACATCAGGTCCGGGATCGTGGTGATCCAGAAGAACGCG 4412
1BL_TaBradi2g14970      NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN 4576


1DL_TaBradi2g14970      ACCATCAAGGACGGCACCGTCGTGTAGAGCACCGCCGGGTCGGCGTGACGGGTTCTGCGA 4474
1AL_TaBradi2g14970      ACCATCAAGGACGGCACCGTCGTGTAGAGCGCCGCCGGGTCGGCG------------CGA 4460
1BL_TaBradi2g14970      NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN---NNN 4633


1DL_TaBradi2g14970      CAACCTCTGCGCTGCGTTGATCGTCGTCGTCGTCTCGAGGCCCGGGAGGGACTGAAGAAG 4534
1AL_TaBradi2g14970      CAACCTCTGTGCTGCATTGATCGTCGTCGTTGTCTCGAGGCC-----GGGACTGAAGAAG 4515
1BL_TaBradi2g14970      NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNTCGGGGCC-----GGGACTGGAGGAG 4688
                                                          *** ****     ******* ** **

1DL_TaBradi2g14970      TGACCCGGGGACGGGAGGCGTTTGAAGCTT-GAATGACTGAGA----------AGGCGCG 4583
1AL_TaBradi2g14970      TGATCCCGGGACGGGAGACGTTTGAAGCTT-GAATGATCGAGACTGAAAGAGAAGGCGCG 4574
1BL_TaBradi2g14970      TGACCCGGGGACGGGGGCCGTTTGAAGCTTTGAATGGCTGAGACTGAAAGTGGAGGCGCG 4748
                        *** ** ******** * ************ *****   ****          *******

1DL_TaBradi2g14970      CGCGGGCAGCATTAGTAGTAA---GTA-GTAGTAAGGAGCAGTGGAACAAAGTAATAGTC 4639
1AL_TaBradi2g14970      CGCATGCAGCATTAGTGGTAAA--GTAAGTAGTAAGTAGCAGTGGAACAAAGTAATAGTC 4632
1BL_TaBradi2g14970      CGCAGGCAGCATCAGTAGTAAGTAGTAAGTAGTAAGTAGCAGTGGAACAAAGTAATAGTC 4808
                        ***  ******* *** ****   *** ******** ***********************

1DL_TaBradi2g14970      GTT------------------------------------CGTTT---------------- 4647
1AL_TaBradi2g14970      GTTTTTCCCCTGTACTCCCTCTGTAAACATATATAAGAGCGTTTAGATCACTACTTTAAT 4692
1BL_TaBradi2g14970      GTT------------------------------------CGTTT---------------- 4816
                        ***                                    *****

1DL_TaBradi2g14970      ------------------TTCCCCT---------GTAATAAATAAGA---GGCTGTGTGT 4677
1AL_TaBradi2g14970      AATCTAAATGCTCTTATATTTCTTTACGGAGGGAGTAATAAATAAGA---GGCTGTGTGT 4749
1BL_TaBradi2g14970      ------------------TGCCCCT---------GTAATAAATAAGAAGAGGCTGTGTGT 4849
                                          *  *  *         *************   **********

                                                   ngs_R2
1DL_TaBradi2g14970      TGAGGTAAAGAAGTGGCAGCGAGCAAACAAACTCCCGGGGGATGTTCGTGTAAATAAAAC 4737
1AL_TaBradi2g14970      TGAGGTAAAGAAGTGGCAGCGATCAAACAAACTCCCGGGGGATGTTCGTGTAAATAAAAC 4809
1BL_TaBradi2g14970      TGAGGTAAAGAAGTGGCCGCGAGCAAACAAACTCCCGGGGGATGTTCGTGTAAATAAAAC 4909
                        **************** **** *************************************

1DL_TaBradi2g14970      TCTATCTAG--ACCTGTGAAATTTTCAGGGGGTTTTCT---------TGTCGACTGACGT 4786
1AL_TaBradi2g14970      TCTATCTAG--ACTTGTGAAATTTTCAGGGGGTTTTCCCGTCGTCTCTGTCGGTCGACAT 4867
1BL_TaBradi2g14970      TCTATCGGGCGACTTGCGAAATTTC--GGGGGTTTTCC-GTCGCCTTTGTCGACCGACAT 4966
                        ******  *  ** ** *******   **********          *****   *** *

1DL_TaBradi2g14970      TGC------------------TTTCGAGTGGTGGTTGCTTTATCTATGAAGCGGAGCGAA 4828
1AL_TaBradi2g14970      TGCCACTTTCCTCTGACGGTCTTTCATGTGATGGTTGCTTTATCTATAAAGCCGGG---A 4924
1BL_TaBradi2g14970      TGC-----------GAAAAGCTTTCGCGTGGTGGTTGCTTTATCTATGAAGCGGAGCGAA 5015
                        ***                  ****  *** **************** **** * *   *

1DL_TaBradi2g14970      AGACCATTTCGAGACGCTGCCACTTTGGTAGC--TATCGGGCGGTTCCCAGAGTA-TCGG 4885
1AL_TaBradi2g14970      AACCTACTTTAAAATGTTGCCACCTTACCATC--CATCGGGCG----CCACCGCA-ACAA 4977
1BL_TaBradi2g14970      AGCCTATTTCGTGACGCCGCCACTTTGCTAGCGCTATCGGGCGGCTCCCGGAGTAATCGG 5075
                        *  * * **    * *  ***** **   * *   ********    **   * *  *

1DL_TaBradi2g14970      CGTCAGCTCTGATCGCCTCCACCGTTGCGACCGAAGGTGGAAATGACCGGATACAGTTAG 4945
1AL_TaBradi2g14970      CAATA------------------TGTTGCCACCTCAGGTGGAAACCAACAGATACGGTCAG 5020
1BL_TaBradi2g14970      CGTCAGCTCCGATTGCCGGCGCGGTTGCGACCGAGGGTGGAAATGACCGGATACAGTTAG 5135
                        *   *                  ***** ***   ********  * * ***** ** **

                                 castaBradi2g14970_DR9
1DL_TaBradi2g14970      GAACTTTGAAATTTAGAACTGTGAAGCCTCGGTAGCAAGAGCGCTGGTGGT--GAAGTCC 5003
1AL_TaBradi2g14970      GAACTTTGAATTCGAGAAT-----AACT-------CATGACCGTTCTTCCTTCGGAGCTC 5068
1BL_TaBradi2g14970      GAACTTTGAATTTTAGAACTGCGAAGCCTCGGTAGCAAGAGCGCTGGTGGT--GAAGTCC 5193
                        ********** *  ****      * *        ** ** ** *  *  *  * **  *
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Appendix 4.5 TaBradi2g14940

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urartu                        ---------------------AATATTATGAAAAATCGAGATTTTTAAGG 2533
1AL_casTaBradi2g14940        ---------------------AATATTATGAAAAATCGAGATTTTTAAGG 751
1BL_3_casTaBradi2g14940      ATCTTGGTGTTATCCTCTCTGAATATTATTAAGATTGGAGATTTTTAAGG 955
1DL_casTaBradi2g14940        ---TTGGTGTTATCCTCTCCGAATATTATGCAGATTAGAGATTTTTAAGG 945
1BL_1_casTaBradi2g14940      ---------------------AATATTATGAATAATCGAGATTTTTAAGG 1120
1BL_2_casTaBradi2g14940      ----------------------ACACGGATATGTCTCGCTGTTACTACGT 696
                                                   * *          * *   **  ** *

urartu                        TACACTCAAGACAGTAACAACCCAACATTACTGCACCAAATATGTCGGTG 2583
1AL_casTaBradi2g14940        TACACTCAAGACAGTAACAACCCAACATTACTGCACCAAATACGTCGGTG 801
1BL_3_casTaBradi2g14940      TACACTCAAGACAGTAACAACCCAACATTACTGCACCAAATATGTCGGTG 1005
1DL_casTaBradi2g14940        TACACTCAAGACAGTAACAACCCAACATTACTGCACCAAATATGTCGGTG 995
1BL_1_casTaBradi2g14940      TACACTCAAGACAGTAACAACCCAATATTACTGCACCAAATATGTCGATG 1170
1BL_2_casTaBradi2g14940      CA-ATCCCATCTAGCCACGTCTCAA-AT----------AACGTGTTAATG 734
                              * *  * *   **  **  * *** **          **    **    **
                               F1                         F2
urartu                        GTA---GAACCAAGATCATCACGCCTGCAAGAAGTTGGTTGAACCACAAG 2630
1AL_casTaBradi2g14940        GTA---GAACCAAGATCATCACGCCTGCAAGAAGTTGGTTGAACCACAAG 848
1BL_3_casTaBradi2g14940      GTA---GAACCAAGATTATCACGCCCGCAAGTAGTTGGTTGAACCACAAC 1052
1DL_casTaBradi2g14940        GTA---GAACCAAGACCATCACGCCCGCAAGAAGTTGGTCGAATCACAAC 1042
1BL_1_casTaBradi2g14940      GTA---GAA------TCATCACGCTCGCAAGAAGTTGGTTGAACCACAAC 1211
1BL_2_casTaBradi2g14940      GAATTCGAAGGAGTTATATTACGC----AAGAAGTTGGTTGAACCACAAC 780
                             * *   ***        ** ****    *** ******* *** *****
                                                       F3
urartu                        ACTAGTAAAAAGAATAGTTTTTTTTCGCTATTTTGTGGTGTAAACAAGAG 2680
1AL_casTaBradi2g14940        ACTAGTAAAAAGAATAGTTTTTTT-CGCTATTTTGTGGTGTAAACAAGAG 897
1BL_3_casTaBradi2g14940      ACTAGTAATAAGAATAGTTTTT---CGCTATTTTGCGGAGTAAATAAGAG 1099
1DL_casTaBradi2g14940        ACTAGTTATAAGAATAGGTTTT---CGCTATTTTGTGGTGCAAATAAGAG 1089
1BL_1_casTaBradi2g14940      ACTAGTAATAAGAATAGTTTTT---CGCTATTTTGTGGTGTAAATAAGAG 1258
1BL_2_casTaBradi2g14940      ACTAGTAGAAAGAATAGTTCTT---TGCTATTTTGTGGTGTTAATAAGAG 827
                             ******   ******** * **     ********* ** *  ** *****

urartu                        TCAACATGGATGTACATGCACACTTTAAAGCTAATAGAATTTGCTTAATT 2730
1AL_casTaBradi2g14940        TCAACATGGATGTACATGCACACTTTAAAGCTAATAGAATTTGCTTAATT 947
1BL_3_casTaBradi2g14940      TGAACATGGATGTACATGAACAGTTCAAAGCTAATAGAACTTGCTTAATT 1149
1DL_casTaBradi2g14940        TCAACATGGATGTACATGAACACTTCAAAGCTAATAGAACTTGTTTAATT 1139
1BL_1_casTaBradi2g14940      TCAACATGGATGTAGATGAACACTTTAAAGCTAATAGAACTTGCTTAATT 1308
1BL_2_casTaBradi2g14940      TCAACATCGCTGTACATGCACAATTCAAAGCTAATAGAACTTGCTTAATT 877
                             * ***** * **** *** *** ** ************* *** ******

urartu                        TGGTGTAACAAAATGCTTTGATTCACTAACCATGGACTATATTTTTCA-A 2779
1AL_casTaBradi2g14940        TGGTGTAACAAAATGCTTTGATTCACTAACCATGGACTATATTTTTCA-A 996
1BL_3_casTaBradi2g14940      TGGTGTAACAAAAAGCTTTGATTCACTAACCATGGATT---TTT------ 1190
1DL_casTaBradi2g14940        TGGTGTAACAAAAAACATTGATTCACTGACCAAGGATTACCTTTTTTTTA 1189
1BL_1_casTaBradi2g14940      TGGTGTAACAAAAAGCTTTGATTCACTAACCATGGATTACTTTTTTTT-A 1357
1BL_2_casTaBradi2g14940      TGGTGTAACAAAAAGCTTTCATTCACTAAGCATGGATTATATTTTTCA-A 926
                             *************  * ** ******* * ** *** *   ***

urartu                        AATGACAGAAGGGAAACCTCTTTCGGTATCTGCATATGAAGATGCATATG 2829
1AL_casTaBradi2g14940        AATGACAGAAGGGAAACCTCTTTCGGTATCTGCATATGAAGATGCATATG 1046
1BL_3_casTaBradi2g14940      -------------------------------------------------G 1191
1DL_casTaBradi2g14940        AATGACAGAAGGGAAACCTCTTTCGGCATCTGCATATGAAGATGCACATG 1239
1BL_1_casTaBradi2g14940      AATGATAGAAGGGAAACCTCTTTCAGTATCTGCATATGAAGATGCACATG 1407
1BL_2_casTaBradi2g14940      AATGATAGAAGAGAAACCTCATTCGGTATCTGCATAT------------G 964
                                                                              *

urartu                        TCTCAACTTTAACTA---GAGCATACATGTATATGGATG----TATGGAT 2872
1AL_casTaBradi2g14940        TCTCAACTTTAACTA---GAGCATACATGTATATGGATG----TATGGAT 1089
1BL_3_casTaBradi2g14940      TCTCAACTTCAACTACGAAAGCATACATGTATGTGCATG----TATGGAT 1237
1DL_casTaBradi2g14940        TCTCAACTTTAACTACGAAAGCATACATGTATG--CATG----TATGGAT 1283
1BL_1_casTaBradi2g14940      TCTCAACTTTAACTACGAAAGCATACATGTATATGCATG----TATGGAT 1453
1BL_2_casTaBradi2g14940      CCTCAACTTTAAATACGAGAGCATACATGTATATACATGAATGTATAGAT 1014
                              ******** ** **    *************    ***    *** ***

urartu                        GCATATATATT-TACATTTTTTTGCTTTGAATCT------TTGAGAGGGA 2915
1AL_casTaBradi2g14940        GCATATATATT-TACATTTTTTTGCTTTGAATCT------TTGAGAGGGA 1132
1BL_3_casTaBradi2g14940      GCATATATATT-TACGTTTTTTCTCTTTGAATCT------TTGAGAGGGA 1280
1DL_casTaBradi2g14940        GCATATATATT-TACGTTTT-CTCTTTGAATCT------TTGAGAGGGA 1325
1BL_1_casTaBradi2g14940      GCATATATATTATATGTTTT-CTCTTTGAATCTCAATCTTTGAGAGGGA 1502
1BL_2_casTaBradi2g14940      GCACATGTATT-TGCATTTT--CTCTTTGAATCT------TTGAGCGGGA 1055
                             *** ** **** *   ****    **********      ***** ****
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```
                                                                F4
urartu                        GGAGGTGAGGAAGGATGCCGAGGCGATTCACGACGCAAAAGGGACGAAAA 2965
1AL_casTaBradi2g14940        GGAGGTGAGGAAGGATGCCGAGGCGATTCACGACGCAAAAGGGACGAAAA 1182
1BL_3_casTaBradi2g14940      GGAGGTGAGGAAGGATGCCGAGGCGATTCGCGACGCAAAAGGGCCGAAAA 1330
1DL_casTaBradi2g14940        GGAGGTGAGGAAGGATGCTGAAGCGATTCGCGACGCAAAAGGGACGGAAA 1375
1BL_1_casTaBradi2g14940      GGAGGTGAGGAAGGAGGCTGAGGCGATTCACGATGCAAAAGGGCTGAAAA 1552
1BL_2_casTaBradi2g14940      GAAGGTGATGAAGGATGCCAAGGCGATTCACGACGCAAAAGGGCCGAAAA 1105
                             * ****** ****** **  * ******* *** *********  * ***
                                                     R1
urartu                        GATAGAAAGGTAGATCCCCCACTTCCAGGGGACAGAAATGTTTGTTCCTT 3015
1AL_casTaBradi2g14940        GATAGAAAGGTAGATCCCCCACTTCCAGGGGACAGAAATGTTTGTTCCTT 1232
1BL_3_casTaBradi2g14940      GATAGAAAGGTTGGTCCCCCACTTCCAGGGGACAAAAATGTTTGTTCCTT 1380
1DL_casTaBradi2g14940        GATAGAAAGGTAGATCCCCCATTTCCAGGGGACAAAAATGTTTGTTCCTT 1425
1BL_1_casTaBradi2g14940      GATAGAAAGGTAGATCCCCCACTTCCAGGGGACAAAAATGTTTGTTCCTT 1602
1BL_2_casTaBradi2g14940      GATAGAAAGATAGATCCCCCACTTCCAGGGGACAGAAATGTTTATTCCTT 1155
                             ********* * * ******* ************ ******** ******

urartu                        TCTCCAATCGACCCCCC---TCCTCAGTCCTCTCGTGCTGGCCTGCTGCT 3062
1AL_casTaBradi2g14940        TCTCCAATCGACCCCCC---TCCTCAGTCCTCTCGTGCTGGCCTGCTGCT 1279
1BL_3_casTaBradi2g14940      TCTCCAATCGTCCCCC----TCCTCACTCCTCTCGTGCTGGCCTGCCGCT 1426
1DL_casTaBradi2g14940        TCTCCAATCGTCCCCCC---TCCTCACTCCTCTCGTGCTGGCCTTCTGTT 1472
1BL_1_casTaBradi2g14940      TCTCCNNNNNNNNNNNNNNNNCTCACTCCTCTCGTGCTGGCCTGTTGCT 1652
1BL_2_casTaBradi2g14940      TCTCCAATGGACCCCC----TCCTCA---CTCTCGTGCT----------- 1187
                             *****                 ****   **********

urartu                        TCAAAATTCCTCTAGTTTTTCGCCCTCCACTCGTATGCACATCATCGATC 3112
1AL_casTaBradi2g14940        TCAAAATTCCTCTAGTTTTTCGCCCTCCACTCGTATGCACATCATCGATC 1329
1BL_3_casTaBradi2g14940      TGAAAATTCCTCTAGTTTTCTCC--TCCACTCGTATGCACATCAT----C 1470
1DL_casTaBradi2g14940        TCAAAATTCCTCTAGTTTTTTCCCCTCCACTCGTATGCACATTAT----C 1518
1BL_1_casTaBradi2g14940      TCAAAATTCCTCTAGTTTTCCCA--TCCACTCGTACGCACATTAT----C 1696
1BL_2_casTaBradi2g14940      TCAAAATTCCTCTAGTTTTTTCCCCTCCACTCGTATGCACATTAT----C 1233
                             * *****************      ********** ****** **    *
                                         F5
urartu                        GTCCATCTTCTTCCACCCCCACACAAAGCTGAATCCTCCTCGACTGCTAT 3162
1AL_casTaBradi2g14940        GTCCATCTTCTTCCACCCCCCCACAAAGCTGAACCCTCCTCGACTGCTAT 1379
1BL_3_casTaBradi2g14940      GTCCATCTTCT-CCGCGCCCACACAAAGCTGAATCCTCCTCGACTGCTAT 1519
1DL_casTaBradi2g14940        GTCCATCTTCT-CCGCCCCCACACAAAGTTGAATCCTCCTCGAGTGCTAT 1567
1BL_1_casTaBradi2g14940      ATCCATCTTCGCCGTCCCCCACACAAAGCTGAATCCTCCTCGAGTGCTAT 1746
1BL_2_casTaBradi2g14940      ATCCTCCTTC--CCGCTCCCACACAAAGCTAAATCCTCCTCGACTGCTAT 1281
                              ***  ****  *  * *** ******* * ** ********* ******

urartu                        AAGTAGCACCTCTTCTCACAGCTTCTTCCCCATCCATCTCACCAGCAGCC 3212
1AL_casTaBradi2g14940        AAGTAGCACCTCTTCTCACAGCTTCTTCCCCATCCATCTCACCAGCAGCC 1429
1BL_3_casTaBradi2g14940      AAGTAGCACCTCTTCTCACACCTTCTTCCTCATCCATCTCACCAGGTCCA 1569
1DL_casTaBradi2g14940        AAGTAGCACCTCTTCTCACACCTTCTTCCCCATCCATCTCACCAGCAGCC 1617
1BL_1_casTaBradi2g14940      AAGTAGCACCTCTTCTCACACCTTCTTCCCTATCCATCTTACC------- 1789
1BL_2_casTaBradi2g14940      AAGTAGCACCTGTTCTCACACCTTCTTCCTCATCTATCTCACCAGCAGCC 1331
                             *********** ******** ********  *** **** ***
                                                                   R2
urartu                        AACATCCAAGCGTAGTTCAGGTCATAAGTTAAGGTATATAGCAGCTTAAT 3262
1AL_casTaBradi2g14940        AACATCCAAGCGTAGTTCAGGTCATAAGTTAAGGTATATAGCAGCTTAAT 1479
1BL_3_casTaBradi2g14940      AGCATCCAAGCATAGTTCAGGTCATAACTTAAGGTATATAATAGC--AGC 1617
1DL_casTaBradi2g14940        AACATCCAAGCGTAGTTCAGGTCATAAGTTAAGGTGTATAGAAGT--AAT 1665
1BL_1_casTaBradi2g14940      --------------------------------------------------
1BL_2_casTaBradi2g14940      AAGATCCTAGTGT------------------------------------- 1344


urartu                        TA-TCGTTCGAGAAACCAATCGTCGAGCGAGATCAATGGCTTCCCTGTCA 3311
1AL_casTaBradi2g14940        TA-TCGTTCGAGAAACCAATCGTCGAGCGAGATCAATGGCTTCCCTGTCA 1528
1BL_3_casTaBradi2g14940      TGATTGATCAAGGAACCAATAGTCGAGTGACATCCATGGCTTCTCTGTCG 1667
1DL_casTaBradi2g14940        TG-TCGATCGAGGAACCAATCGTCGAGTGACATCAATGGCTTCCCTGTCG 1714
1BL_1_casTaBradi2g14940      -----GATCGAAGAACCAATCGTCGAGCGACATCAATGGCTTCTCTGTCG 1834
1BL_2_casTaBradi2g14940      ------------------ATCGTCGAGCGACATCAATGGCCTCTCTGTCG 1376
                                               ** ****** ** *** ***** ** *****

                        Start!                                            ngs_F1
urartu                        ATGAGCGCGGTGTGGACGCCGATGCAGAACAAGCTGTTCGAGCAGGCGTT 3361
1AL_casTaBradi2g14940        ATGAGCGCGGTGTGGACGCCGATGCAGAACAAGCTGTTCGAGCAGGCGTT 1578
1BL_3_casTaBradi2g14940      ATGAGTGCGGGGTGGACGCCGAAGCAGAACAAGCTGTTCGAGCAGGCGTT 1717
1DL_casTaBradi2g14940        ATGAGCGCGGGGTGGACACCGAAGCAGAACAAGCTGTTCGAGCAGGCGTT 1764
1BL_1_casTaBradi2g14940      ATGAGCGCGGGGTGGACGCCGAAGCAGAACAAGCTGTTTGAGAAGGCGTT 1884
1BL_2_casTaBradi2g14940      ATGAGCGCGGGGTGGACACCGAAGCAGAACAAGCTGTTCGAGCAGGCGTT 1426
                             ***** **** ****** **** *************** *** *******
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urartu                          GGCGGTGCACGACAGGGACACGCCCGACCGCTGGCACAACATCGCCCGGG 3411
1AL_casTaBradi2g14940          GGCGGTGCACGACAGGGACACGCCCGACCGCTGGCACAACATCGCCCGGG 1628
1BL_3_casTaBradi2g14940        GGCGGTGCACGACAGGGACACACCCGACCGCTGGCACAACATCGCCCGTG 1767
1DL_casTaBradi2g14940          GGCGGTGCACGACAGGGACACGCCCGACCGCTGGCACAACATCGCCCGCG 1814
1BL_1_casTaBradi2g14940        GGCGGTGCACGACAGGGACACACCCGACCGCTGGCACAACATCGCCCGTG 1934
1BL_2_casTaBradi2g14940        GGCGGTGCACGACAGGGACACGCCCGACCGCTGGCACAACATCGCCCGGG 1476
                               ********************* ************************** *
                                                       R3
urartu                          CTGTCGGCGGCGGAAAGTCGGCGGACGATGTCAGGCGCTACTACGAGCTG 3461
1AL_casTaBradi2g14940          CTGTCGGCGGCGGAAAGTCGGCGGACGATGTCAGGCGCTACTACGAGCTG 1678
1BL_3_casTaBradi2g14940        CTGTCGGGGGCGGCAAGTCGGCGGACGATGTCAGGCGCTACTACGAGCTG 1817
1DL_casTaBradi2g14940          CTGTCGGCGGCGGCAAGTCCGCGGACGACGTCAGGCGCTACTACGAGCTG 1864
1BL_1_casTaBradi2g14940        CTGTCGGGGGCGGCAAGTCAGCGGACGATGTCAGGCGCTACTACGAGCTG 1984
1BL_2_casTaBradi2g14940        CTGTCGGCGGCGGAAAGTCGGCGGACGATGTCAGGCGCTACTATGAGCTG 1526
                               ******* ***** ***** ******** ************** ******

urartu                          CTCGTCCACGACATCGCCCGTATCGAGGCCGGCAAGGTGCCCTTCCCCGC 3511
1AL_casTaBradi2g14940          CTCGTCCACGACATCGCCCGTATCGAGGCCGGCAAGGTGCCCTTCCCCGC 1728
1BL_3_casTaBradi2g14940        CTCGTCCACGACATCGCCCGGATCGAGGCCGGCAAGGTGTCTTTCCCCGC 1867
1DL_casTaBradi2g14940          CTCGTCCACGACATCGCCCGGATCGAGGCCGGCAAGGTGCCTTTCCCCGC 1914
1BL_1_casTaBradi2g14940        CTCGTCCACGACATCGCCCGGATCGAGGCCAGCAAGGTGCCTTTCCCCGC 2034
1BL_2_casTaBradi2g14940        CTCGTCCATGACATCGCCCGTATCGAGGCCGGCAAGGTGCCTTTCCCCGC 1576
                               ******** *********** ********* ******** * ********

urartu                          CTACCGTCCCCCATGTCCTGGCCCCGGCCACAACGCCAGCTACGAGGCTG 3561
1AL_casTaBradi2g14940          GTACCGTCCCCCATGCCCCGGCCCCGGCCACAACGGTAGCTACGAGGCCG 1778
1BL_3_casTaBradi2g14940        CTACCGTCCACCATGCCCCGGCCCCGGCCACAACGCCAGCTACGAGGCCG 1917
1DL_casTaBradi2g14940          CTACCGTCCACCGTGCCCCGGCCCGGCCACAACGCCAGCTACGAGGCCG 1964
1BL_1_casTaBradi2g14940        CTACCGTCCACCATGCCCCGGCTCCGGCCACAACGGCAGCTACGAGGCCG 2084
1BL_2_casTaBradi2g14940        CTACCGTCCACCATGCCCCGGCACCGGCCACAACGCCAGCTACGAGGCCG 1626
                                ******** ** ** ** *** * **********  *********** *
                                          R4  F6
urartu                          ACAGGTACGACCTCCATCGCTGTGTTTCTTAT-AGTTATGCATGGGCTTA 3610
1AL_casTaBradi2g14940          ACAGGTAAGACCGCCATCACTGTGTTTCTTATCAGTTATGCATGGGCTTA 1828
1BL_3_casTaBradi2g14940        ACAGGTACGACCGCCATCACTGTGTTTATTATCAGTTATTCATGGGCTTA 1967
1DL_casTaBradi2g14940          ACAGGTACGATCGCCATGGCTGTGCTTCTTATCAGTTATGCATGGGCTTA 2014
1BL_1_casTaBradi2g14940        ACAGGTACGACCGCCATCACTGTGTTTATTTTCAGTTATGCATGGGCTTA 2134
1BL_2_casTaBradi2g14940        ACAGGTACGACCGCCATCGCTGTGTTTCTTATCAGTTATGCATGGGCTTA 1676
                               ******* ** * **** ***** ** ** * ****** **********
                                                      ngs_F2
urartu                          AGATGGAGTTAAGCAGGTAACTTGTGTGATCAGGTTGAAGCACTTGAAGA 3660
1AL_casTaBradi2g14940          AGCTGGAGTTAAGCGGCTAATTTGTGTGATCAGGTTGAAGCACTTGAAGA 1878
1BL_3_casTaBradi2g14940        AGCTGGAGTTAAGCAGCTATTTTGTGTGATCAGGTTGAAGCACTTGAAGA 2017
1DL_casTaBradi2g14940          AGCTGGAGTTAAGCTGGTAATTTGTGTGATCAGGTTGAAGCACTTGAAGA 2064
1BL_1_casTaBradi2g14940        AGCTGGAGTTAAGCAGGTAATTTGTGTGATCAGGTTGAAGCACTTGAAGA 2184
1BL_2_casTaBradi2g14940        AGCTGGAGTTAAGCAGGTAATTTGTGTGATCAGGTTGAAGCATTTAAAGA 1726
                               ** *********** * **  ********************* ** ****

urartu                          TCTAGCTAGGAGGTAATCGGGTAATGGGCAAGGGATGATACACACTACAC 3710
1AL_casTaBradi2g14940          TCTAGCTAGGCGGTAATCGGGTAATGGGCAAGGGATGATACACACTACAC 1928
1BL_3_casTaBradi2g14940        TCTAGCTAGGCGGTAATCTGGTAATGGCCAAGGGATGATACACAATACAC 2067
1DL_casTaBradi2g14940          TCTAGCTAGGCGGTAATCGGGTAATGGGCAAGGGATGATACACACTACAC 2114
1BL_1_casTaBradi2g14940        TCTAGCTAGGCGGTAATCTGGTAATGGGCAAGGGATGATACACACTACAC 2234
1BL_2_casTaBradi2g14940        TCTAGCTAGGCGGTAATCGGGTAATGGGCAAGGGATGATACACACTACAC 1776
                               ********** ******* ******** **************** *****

urartu                          AGATGGACTGAACGAAGAAGCATGTGCGTGCATGGGGGTACCTTGTACAG 3760
1AL_casTaBradi2g14940          AGATGGACTGAACGAAGAAGCATGTGCGTGCATGGG-------------- 1964
1BL_3_casTaBradi2g14940        AGATGGACTGAATGAAGAAGCATGTGCGTGCATGGGGGTACCTTTTA--- 2114
1DL_casTaBradi2g14940          AGATGGACTGAACGAAGAAGCATGTGCGTGCATGGG-------------- 2150
1BL_1_casTaBradi2g14940        AGATGGACTGAACGAAGAAGCATGTGCGTGCATGGGGGTACCTTGTA--- 2281
1BL_2_casTaBradi2g14940        AGATGGACTGAACGAAGAAGCATGTGCGTGCATGAGGGTACCTTGTA--- 1823
                               ************ ********************* *

                                                     ngs_R1
urartu                          TAATACTCATAAGCGTGTGCATGGTGTCCATGACTCCATGTCA------- 3803
1AL_casTaBradi2g14940          -----CTCATAAGCGCGTGCATGGTGTCCATGACTCCATGTCA------- 2002
1BL_3_casTaBradi2g14940        --ATACTCATAAGCGTGTGCATGGTGTCCATGACTCCATGTCA------- 2155
1DL_casTaBradi2g14940          -----CTCATAAGCGTGTGCATGGTGTCCATGACTCCATGTCA------- 2188
1BL_1_casTaBradi2g14940        --ATACTCATAAGAGTGTGGATGGTGTCCATGACTCCATGTCA------- 2322
1BL_2_casTaBradi2g14940        --ATACTTATAAGCGTGTGCATGGTGTCCATGACTCCATGTCATATGTCA 1871
                                    ** ***** * *** **********************
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                                            R5
urartu                       ATGTATACATGCACGACTAGTGGGCAGAAAAGTCGGCCGATTATGCAGAT 3853
1AL_casTaBradi2g14940        ATGTATACATG-----------GGCAGAAAAGTCGGCCGATTATGCAGAT 2041
1BL_3_casTaBradi2g14940      ATGTATACATGCACTACTAGCCGGCAGAAAAGTTGGCCGATTATGCAGAT 2205
1DL_casTaBradi2g14940        ATGTATACATGCATGACTAGCGGGCAGAAAAGTCGGCCGATTATGCAGAT 2238
1BL_1_casTaBradi2g14940      ATGTATACATGCACGACTAGCGGGCAGAAAAGTCGGCCGGTTATGCAGAT 2372
1BL_2_casTaBradi2g14940      ATGTATACATGCACGACTAGCGGGCAGAAAAGTCTGCCGATTATGCAGAT 1921
                             ***********           ***********  **** **********

urartu                       GCATGCATGTTCATAATACT---------AGTGGTCTATAAGTATGTA-- 3892
1AL_casTaBradi2g14940        GCATGCATGTTGATAATA-------------------------------- 2059
1BL_3_casTaBradi2g14940      GCATGCATGTTCATAATACTCTAGTGGCTAGTGGTCTATAAGTATGTA-- 2253
1DL_casTaBradi2g14940        GCATGCATGTTCATAATACTCTAGTGGCTAGTGGTCTATAAGTATGTA-- 2286
1BL_1_casTaBradi2g14940      GCATGCATGTTCATAATACTCTAGTGGATAGTGGTCTATAAGTATGTA-- 2420
1BL_2_casTaBradi2g14940      GCATGCATGTTCATAATACTCTAGTGGCTAGTGGTCTATAAGTATGTATA 1971
                             *********** ******

urartu                       CGTGAGATCGACTTGTCTCCTTACTCACATGGGTTTAACTTATCTCGTAT 3942
1AL_casTaBradi2g14940        --------------------------------------------------
1BL_3_casTaBradi2g14940      CGTGAGAT------------TTACTCACATGGGTTTAACTTATCTCCTAT 2291
1DL_casTaBradi2g14940        CCTGAGATCGACTTGTCTCCTTACTCACATGGGTTTAACTTATCTCGTAT 2336
1BL_1_casTaBradi2g14940      CGTGAGATCGACTTGTCTCCTTACTCACATGGGTTTAACTTATCTCGTAT 2470
1BL_2_casTaBradi2g14940      CGTGAGATCGACTTGTCTCCTTACTCACATGGGTTTAAGTTATCTCCTAT 2021

urartu                       GTATTCTAATGTACAATATTAAT--------------------------- 3965
1AL_casTaBradi2g14940        --------------------------------------------------
1BL_3_casTaBradi2g14940      GTAT-CTAATGTACAATATTAATATTATCCTTTATATTATTGTCTGCACG 2340
1DL_casTaBradi2g14940        GTATTCTAATGTACAATATTAATATTATCCTT-ATATTATTGTCTGCACA 2385
1BL_1_casTaBradi2g14940      GTATTCTAATGTACAATATTAATATTATCCTT-ATATTATTGTCTGCACA 2519
1BL_2_casTaBradi2g14940      ATATTCTAATGTACAATATTAATATTATCCTT-ATATTATTGTCTGCACA 2070

                                           ngs_R2
urartu                       ------------GTCCATATCAATGGAGAGACAAAT--ATGTTAATGCC- 4000
1AL_casTaBradi2g14940        --------------------------------------------------
1BL_3_casTaBradi2g14940      TTGTAACCATATGTCCATATCAATGGAGAGATAAATTGATGTTAATGGCT 2390
1DL_casTaBradi2g14940        T-GTAACCATATGTCCATATCAATGGAGAGATAAATTGATGTTAATGTCA 2434
1BL_1_casTaBradi2g14940      T-GTAACCATATGTCCATATCAATGGAGAGATAAATTGATGTTAATGCC- 2567
1BL_2_casTaBradi2g14940      T-GTAACCATATGTCCATATCAATGGAGAGATAAATTGATGTTAATGTCA 2119

urartu                       --------------AAATATGTTAC-----------------ACACACAC 4019
1AL_casTaBradi2g14940        --------------------------------------------------
1BL_3_casTaBradi2g14940      TA------ATGC-CAAATATGTTAT-----------------ACTCACAC 2416
1DL_casTaBradi2g14940        AATATGTTATGCACACACATACTACTTT-TTTTTGCGAGGGACACACAC 2483
1BL_1_casTaBradi2g14940      --------------AAATATGTTAT-----------------ACACACAC 2586
1BL_2_casTaBradi2g14940      AATATGTTATGCACACACATAGTACTTTCTTTTTTGCGAGGGACACACAC 2169

urartu                       ATACTACTAATACAAAGACAAAACAACTGCGGTGTGTTTCACGCTTTAAT 4069
1AL_casTaBradi2g14940        --------------------------------------------------
1BL_3_casTaBradi2g14940      ATACTACTAATACAAAGACAAAACAACTGCGGTGTGTTTCACGCTT---- 2462
1DL_casTaBradi2g14940        ATACTACTAATTCAAAGACAAAACAACTGCGGTGTGTTTCACACTTTAAT 2533
1BL_1_casTaBradi2g14940      ATACTACTAATACAAAGACAAAACATCTGCGGTGTGTTTCACGCTTTAAT 2636
1BL_2_casTaBradi2g14940      ATACTACTAATACAAAGACAAAACAACTGCGGTGTGTTTCACGCTTTAAT 2219

urartu                       CACATATT------------------------------------------ 4077
1AL_casTaBradi2g14940        --------------------------------------------------
1BL_3_casTaBradi2g14940      --------------------------------------------------
1DL_casTaBradi2g14940        CACATATT------------------------------------------ 2541
1BL_1_casTaBradi2g14940      CAC----T------------------------------------------ 2640
1BL_2_casTaBradi2g14940      CACATACTCCCTCCGTCCCAAAATTCTTGTCTTAGATTTGTCTAAATACG 2269

urartu                       --------------------------------------------------
1AL_casTaBradi2g14940        --------------------------------------------------
1BL_3_casTaBradi2g14940      --------------------------------------------------
1DL_casTaBradi2g14940        --------------------------------------------------
1BL_1_casTaBradi2g14940      --------------------------------------------------
1BL_2_casTaBradi2g14940      GATGTATTAAGTCACGTTTTAATATTAGATACATCCGTATCTAGACAAAT 2319

urartu                       --------------------------------TTTTG-AGGGAGCACTTA 4094
1AL_casTaBradi2g14940        --------------------------------------------------
1BL_3_casTaBradi2g14940      --------------------------------------------------
1DL_casTaBradi2g14940        --------------------------------TTTTTTGGGGAGCATTTA 2559
1BL_1_casTaBradi2g14940      --------------------------------TTTTTTTGGGAGCATTTA 2658
1BL_2_casTaBradi2g14940      GTAAGACATGAATTTTGGGACGGAGGGAGTACTTTTTTGGGGAGCATTTA 2369
```

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                                                                  R6
urartu                         CAGCTTAGCATCTCGTTGAGGTGCCACAATAGAGGCAGTGGGGATCATGA 4144
1AL_casTaBradi2g14940         --------------------------------------------------
1BL_3_casTaBradi2g14940       --------------------------------------------------
1DL_casTaBradi2g14940         CGACTAAGCATCTCGTTGAGGTGCCACAGTAGAGGCATTAGAGATCATGA 2609
1BL_1_casTaBradi2g14940       CAACTTAGCATCTCGTTGAGGTGCCACAATAGAGGCAGTAGAGATCATGA 2708
1BL_2_casTaBradi2g14940       CGGCTTAGCATCTCGTTGAGGTGCCACA---GAGGCAGTGGAGATCATGA 2416

urartu                         GTATATATGTTAAAATAGTATTATGTGAGCAAGGACGGAGAACACGCACC 4194
1AL_casTaBradi2g14940         --------------------------------------------------
1BL_3_casTaBradi2g14940       --------------------------------------------------
1DL_casTaBradi2g14940         GTATATATGTTAAAATAATATTATGTGACCAAGGATGGAGAACACGCACC 2659
1BL_1_casTaBradi2g14940       GTATATATGTTCAAATAATATTATGTAACCAAGGACGGAGAACACGCACC 2758
1BL_2_casTaBradi2g14940       GTATATATGTTAAGATAATATTATGTGACCAAGGACAGAGAACACGCACC 2466
```

Appendix 4.6 TaBradi2g14830

```
1BL_casTaBradi2g14830      GCGTTTCTATATGAATGCTAGCACTATTGCCTAGAGACGTGCATAGAAGT 932
1DL_casTaBradi2g14830      ACGTTTCTATATGAATGCTAGCACTATTGCCTAGAGACGTGCATACAAC- 989
1AL_casTaBradi2g14830      ACGTTTCTATATGAATGCTAGCACTATTGTCTAGAGACGTGCATAGAAC- 134
                            **************************** *************** **

1BL_casTaBradi2g14830      AGAATTGCTGCTAGGGAGGGA----TACCGCTGCTAGAGCGAGTGGTGGA 978
1DL_casTaBradi2g14830      --AATTGCTGCTAGGGAGGGAGGGATGCTACTGCTAGAGCGAGTGGTGGA 1037
1AL_casTaBradi2g14830      --AATTGCT-CTAGGGA-----------------------------TGGA 152
                             ******* *******                             ****
                              F1
1BL_casTaBradi2g14830      CACAACTGTTACTTTCCTGTTCTGTCCACTCGCCGATGCTAGAACGGTAC 1028
1DL_casTaBradi2g14830      CACTGCTATTACTTTCCTATTATGTCCACTCACCGATGCTAGAACGGTAG 1087
1AL_casTaBradi2g14830      CACTACTATTACTTTCCCATTCTGTCCACTCACCGATGCTNNNNNNNNNN 202
                           ***  ** *********  ** ********* ********

1BL_casTaBradi2g14830      GCGCACTGCTTTTACCACAAAGAGAATCATACTGTATA-----TATCTGG 1073
1DL_casTaBradi2g14830      GCTAGCTGCTTTTACCACAAAAAGAATCATACTGTATACTGTATATCTGA 1137
1AL_casTaBradi2g14830      NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN---------TGG 243
                                                                          **

1BL_casTaBradi2g14830      GAGG------------GGTATGA----AAAATGCCAATGATGCTGCTGTG 1107
1DL_casTaBradi2g14830      GAGGCTTCTGCTCTGTGCTATCA----AAAATGCCAAAGATGTTGCTGTG 1183
1AL_casTaBradi2g14830      GAGGGTTCTGCTTCTTCTTCTCTTGTCAAATTGTCAATGGCGTTG-TG-G 291
                           ****              * *      *** ** *** *  * ** ** *

1BL_casTaBradi2g14830      CTGTTCCTTTTCTACCCCCTCCGTCCGGAAATACTTGTCGAAGAACTGGA 1157
1DL_casTaBradi2g14830      CTGTTCCTTTTCT------------------------------------- 1196
1AL_casTaBradi2g14830      CTGTTTCTTTTCT------------------------------------- 304
                           ***** *******

1BL_casTaBradi2g14830      TAAAAATGAATGTATTTAGAACTAAGATATGTCTAGATACATCCATTCTT 1207
1DL_casTaBradi2g14830      --------------------------------------------------
1AL_casTaBradi2g14830      --------------------------------------------------


1BL_casTaBradi2g14830      CCGACAAGTATTTCATACTATGAAGGGGCATGCTTCTCAGTTTGTATCGC 1257
1DL_casTaBradi2g14830      -----------TTTATG----GAAGGGGCCTGTTTCTTAGTTTGCATCGC 1231
1AL_casTaBradi2g14830      --------------------------------CTTAGTAGTTTGTATCGC 322
                                                            **   ****** *****

1BL_casTaBradi2g14830      CAAATTTTGCGA---GAAT--TCGTACCATATCCGGGACGGTTTTTGATT 1302
1DL_casTaBradi2g14830      CAAATTTTGCGA---GAATCATGCTACTGTATCCGGGAGGGGTTTTAATC 1278
1AL_casTaBradi2g14830      CAGATGCTGCTTCCTGAATC-AGCCAGCGT-----GGAGGATTTTATATT 366
                           ** **  ***     ****      *   *     *** *  ***  **

1BL_casTaBradi2g14830      TCTCGCTGTTATGAGA-----------------------AATGCCGATGG 1329
1DL_casTaBradi2g14830      CCTCTCTGCTGTGAGA-----------------------AATGCCGATGA 1305
1AL_casTaBradi2g14830      TTCCTCTGTTATGAAATAGCCATGAAAAGTTCCTGCAAAAATGCCGATGA 416
                              * *** * *** *                       **********

1BL_casTaBradi2g14830      GGGAGCGCTGTTTCTATCTTTGATTGATTGCTGAAGGGGACTGTTTCCTA 1379
1DL_casTaBradi2g14830      CGGTGCGCTGTTTCTATCTTTGATTGATTGCTGAAGGGGACTGTTTCCTA 1355
1AL_casTaBradi2g14830      CGGTGTGCTGTTTCTTTCTCTTATTGATTACTGAAGGGGACGGTTTCCAA 466
                            ** * ********* *** * ******* *********** ****** *

1BL_casTaBradi2g14830      GTTTCTGTTGGAAGATTATGCGTTGTGGATT----AGCTGTAGCAAGACT 1425
1DL_casTaBradi2g14830      GTTTCTGTTGGAAGATTTTGCGTTGTGGATCTATCAGTTGTAGCAAGACT 1405
1AL_casTaBradi2g14830      GATTATCCGGGAGG-----GCATT-TAGTTC------CTAGCACAATGCC 504
                           * ** *   *** *     ** ** * * *        *    ***  *

1BL_casTaBradi2g14830      -GT-CAGCAGAGCTAAGCTAAGC-----GGTCGGATTGCCTGGCGTCTCA 1468
1DL_casTaBradi2g14830      -GT-AATCAGA-CTATGCCTGGC-----G-----------TGGCGTTTCC 1436
1AL_casTaBradi2g14830      AGTGAAGCGGAGTTAAGCTAGGCAACCTGCTTGGCTGGCGTGGCGTCTTA 554
                            **  * * **  ** **   **     *           ****** *
```

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1BL_casTaBradi2g14830      TGTCAGTATATGCTTTAGCTTTGCTACATAGATTGTCTTTATGTTGCAAT 1518
1DL_casTaBradi2g14830      TGTCAGTATATGCTTTAGCTTTGC----TAGATTGTCTTTATGTTGCAAT 1482
1AL_casTaBradi2g14830      TGTCAGTATATGCTTTAGCTTTGCTACATAGATTGTCTTTATGTTGCAAT 604
                           ************************    **********************

                                                       F2
1BL_casTaBradi2g14830      CCTTGGGTTTGTTAGTGGTATCTCTGCTGCAAAAGGCGAGCATCGATGCC 1568
1DL_casTaBradi2g14830      CCTTGGGTTTGTTAGTGGTATCTATGCTGCAAAAGGTGAGGATCAATGCC 1532
1AL_casTaBradi2g14830      CCTTGGGTTTGTTAGTGGTATCTCTGCTGCAAAAGGCGGGCATCGATGCC 654
                           *********************** ************ * * *** *****

1BL_casTaBradi2g14830      CCTCCCTTTGCTCGGATTCAGATTTGGTATTT----TCATTAGTAAACGC 1614
1DL_casTaBradi2g14830      CCTCCCTTTGCTGGGATTCTGATCTGGTATTT----TCATTAGTAAACGC 1578
1AL_casTaBradi2g14830      CCTCCCTTTGCTGGGATTCTGATCTGCTATTTCATTTCATTAGTAAACGC 704
                           ************ ****** *** ** *****    **************

1BL_casTaBradi2g14830      TCCGTCAGAAAGTGAAATCTCAGGCTTGTCGATGTTTCCACAGATGGCAT 1664
1DL_casTaBradi2g14830      TGCGTGGGAAAGTGAAATCTCAGGCTTGTCGATGTTTCCACAGATGGCAT 1628
1AL_casTaBradi2g14830      TGCGTCGGAAAGTAAAATCTCAGGCTTGTCGATGTTTCCACACATGGCAT 754
                           * ***  ****** **************************** *******

                               R1
1BL_casTaBradi2g14830      GCAAAGTGGCCATGGTTTTCCATGGTTTTGTTAGTCAGTGTTCTTTGGTA 1714
1DL_casTaBradi2g14830      GCAGAGTGGCCATGGTTTTCCATGGTTTTGTTAGTCAGCTTTCTTTGGTA 1678
1AL_casTaBradi2g14830      GCAAAGTGGCCATGGTTTTCCATGGT--TGCTAGTCAGCTTTCTTTGGTA 802
                           *** **********************  ** *******  **********

1BL_casTaBradi2g14830      GCTGTACTGTGGGGAATACCATTGTTCTGTTTTTTTCAT----------G 1754
1DL_casTaBradi2g14830      GGTATACTGTGGGGAATACCATTGTTCTGTTTTTTTTCTTGGTCTACCGG 1728
1AL_casTaBradi2g14830      GGTATACTGTGGGGAATACTGGTGTTCTGGTTTATC-------------- 838
                           * * ***************   ******* *** *

1BL_casTaBradi2g14830      GTCGGTCACTTTTCGTATCCGGTTATTTTATTTTGTCAGAGTGGATTCGT 1804
1DL_casTaBradi2g14830      GTCGGTCACTTTTCGTATCCGGTTATTTTATTTTGTCAGAGTTGATTCGT 1778
1AL_casTaBradi2g14830      -TCGGTC----TCCCCGGCCGACCACTTT---TCGT--------ATCCGC 872
                            ******    * *    ***   * ***   * **        ** **

1BL_casTaBradi2g14830      CGTTCGTACGTGCAATCTTATGTTGTTTGTTGGAAGA---TTACTGTGTT 1851
1DL_casTaBradi2g14830      CGTTCGTACGTGCAATCTTATGTTGTTTGTTGGAAGA---TTACTGCATT 1825
1AL_casTaBradi2g14830      CATTCGTGCGTGCAATCTTGTGGTGTTCGTTGGAAGAAGATTACTGCGTT 922
                           * ***** *********** ** **** *********   ******  **

1BL_casTaBradi2g14830      TCTGGTCGGATATTCATATTCTGTCGGTGATAAAGTTTGAAGTTCATCAA 1901
1DL_casTaBradi2g14830      T-TAGTCGGATATTCATATTCTGTCGGTGATAAAGTTTGAAGTTGTTCAA 1874
1AL_casTaBradi2g14830      T-TAGTCGGATATTCACATTCTGTCGGTGATAAAGTTTGAAGTTCTTCAA 971
                           * * ************ ***************************  ****

1BL_casTaBradi2g14830      GAATGTCTTAACATTCTGATGCCTTGCCTCTCTCTTTAGACTGCACTGTC 1951
1DL_casTaBradi2g14830      GAATGTCTTAACATTCTGATG-----CCTCTCTCTTTAGACTGCACTGTC 1919
1AL_casTaBradi2g14830      GAATGTCTTAACATTCTGATG-----CCTCTCTCTTTAGACTGCACTGTC 1016
                           *********************     ************************

                            F3
1BL_casTaBradi2g14830      GGTTCTTTGGTTTCCAGCTCAGTTTGTGGTTACA---GTCTGCAAAATCT 1998
1DL_casTaBradi2g14830      GGTTCTTTGGTGTCCACTTCAGTTCGTGGTTAGACAAAACCGCGAAATCT 1969
1AL_casTaBradi2g14830      GGTTCTT-GGTTTCCAGCTCAGTCAGTGGTTACA---GACTGCAAAATCT 1062
                           ******* *** ****  *****  ******* *     * ** ******

                                                                        R2
1BL_casTaBradi2g14830      TTTGACTCGCCGTTCTCTTTGAATTCACTGCCACTTGATTTGAATTTGCA 2048
1DL_casTaBradi2g14830      TTTGACTCGCCGTTCTCTTTGAATTCACTGCCACTTGATTTGAATTGGCA 2019
1AL_casTaBradi2g14830      TTTGAC--GCCGTTCTCTTTGAATTCACTGCCACTTAATTTGAATTTGCA 1110
                           ******  **************************** ********* ***

                                                               ngs_F1
1BL_casTaBradi2g14830      ACACGGCAATGCCTTCAGCTCTTCTCTTATAACTGGCCTCACAGATTTGG 2098
1DL_casTaBradi2g14830      ACACCGCAATGCCTTCAGCTCTTCTCCTATAACTGGCCTCACAGATTTGC 2069
1AL_casTaBradi2g14830      ATGCAGCAATGCCTTCAGCTCTTCTCCTATAACTGGCCTCACAGATTTGC 1160
                           *  * ********************* **********************
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1BL_casTaBradi2g14830      TTGCTCACTCACAGACATTTCCTCTGTTTTATCCTGCAGAACAGGTGATA 2148
1DL_casTaBradi2g14830      TTGCTCACTCACACACATTTCCTCTGTTTTATCCTGCAGAACAGGTGATA 2119
1AL_casTaBradi2g14830      TTGCTCACTCACACACATTTCCTCTGTTTTGTCCTTCAGAACAGGTGATA 1210
                           ************* **************** **** **************

                                                 Start
1BL_casTaBradi2g14830      GAGCCAGGATTCTGCCAGCACGAATGACGATCTGTAGCTGCGAGGAGACC 2198
1DL_casTaBradi2g14830      GAGCCAGGATTCTGCCAGCACAAATGACGATCTGTAGCTGCGAGGAGACT 2169
1AL_casTaBradi2g14830      GAGCCAGGATTCTGCCAGCACAAATGACGATCTGTAGCTGCGAGGAGACC 1260
                           ********************* *************************** 

1BL_casTaBradi2g14830      ATCAATGAGTTCGAGATGTTGACGCGCGATGCTGCGCGTGTGCAGCTGGA 2248
1DL_casTaBradi2g14830      ATCAATGAGTTCGAGATGTTGACGCGCGATGCTGCGCGCGTGCAGCTGGA 2219
1AL_casTaBradi2g14830      ATCAATGAGTTCGAGATGTTGACGCGCGATGCTGGGCGCGTGCAGCAGGA 1310
                           ********************************** *** ******* ***

1BL_casTaBradi2g14830      TACGCTGAAGAAGATCCTTGAGGCGAATGCTGGTGCTGAATACCTGAGGC 2298
1DL_casTaBradi2g14830      TACGCTGAAAAGGATCCTTGAGGCGAATGCCGGTGCTGAATACCTGAGGC 2269
1AL_casTaBradi2g14830      TACGCTGAAAAGGATCCTTGAGGCGAATGCCGATGCTGAATACCTGAGGC 1360
                           ********* * ****************** * *****************

                                      F4
1BL_casTaBradi2g14830      AGTTTGGCCTCGACGGGAGGACCGATGCCGCTAGCTACAAATCTTGCATC 2348
1DL_casTaBradi2g14830      AGTTTGGCCTCGATGGGAGGACCGATGCCGCTAGCTACAAATCTTGCATC 2319
1AL_casTaBradi2g14830      AGTTTGGCCTCGACGGGAGGACTGATGCCCAGAGCTACAAATCTTGCATC 1410
                           ************* ******** ******   ******************

1BL_casTaBradi2g14830      CCGTTGTGTGTGCACAGCGACGTTGAACCGTTCATCCAGAGGGTTGCTGA 2398
1DL_casTaBradi2g14830      CCGTTGTGTGTGCACAGCGACGTTGAACCGTTCATCCAGAGGGTTGCTGA 2369
1AL_casTaBradi2g14830      CCGCTGTGCGTGCACAGCGACGTTGAACCTTTCATCCAGAGGGTTGTTGA 1460
                           *** **** ******************** **************** ***

                                                         ngs_R1
1BL_casTaBradi2g14830      TGGTGATAGCGCACCAGTGGTGACCGGGAAGCCCATCACCTCCCTCTCCC 2448
1DL_casTaBradi2g14830      TGGTGATAGCGCACCAGTGGTGACCGGGAAGCCCATCACCTCCCTCTCCC 2419
1AL_casTaBradi2g14830      TGGTGATAGCGCACCAGTGCTCACCGGGAAGCCCATCACCTCCCTCTCCC 1510
                           ******************* * ****************************

                                               R3
1BL_casTaBradi2g14830      TCAGGTACTCATCGCCTTCGAATGT-GTTGTCTTGTTGTCCTATGGAAGT 2497
1DL_casTaBradi2g14830      TCAGGTACTCATCGCCTTCGGATGT-GTTATCTTGTTGTCCTATGGAAGT 2468
1AL_casTaBradi2g14830      TCAGGTACTCATTGCCTTCGAATGTAGTTGTCTTGCTGTTCTGTGGAAGT 1560
                           ************ ******* **** *** ***** *** ** *******

1BL_casTaBradi2g14830      AGATTTCCGTAACCTGTTTTCCTAT-TTTTATGCAGTTCTGGTACGACGC 2546
1DL_casTaBradi2g14830      AGATTTCCGTAACCTGTTTTCCTAT-TTTTATGCAGTTCTGGTACGACGC 2517
1AL_casTaBradi2g14830      AGATGTTTATAACCTGTTTGCTGTTGTTTTATGCAGTTCTGGTACGACGC 1610
                           **** *   ********** *   * ************************

1BL_casTaBradi2g14830      AGGGGAAGCCTAAGTTCCTGCCATTTAATGATGAATTGCTTGAGAACACA 2596
1DL_casTaBradi2g14830      AGGGAAAGCCTAAGTTCCTGCCATTTAATGATGAATTGCTTGAGAACACA 2567
1AL_casTaBradi2g14830      AGGGGAAGCCTAAGTTCCTGCCATTTAATGATGAATTGCTTGAGAACACA 1660
                           **** *********************************************

1BL_casTaBradi2g14830      CTTCAAATATTCCGTACTTCGTACGCATTCAGGAACCGGTAAGGATCTCC 2646
1DL_casTaBradi2g14830      CTTCAAATATTCCGTACTTCGTACGCATTCAGGAACCGGTAAGGATCTCC 2617
1AL_casTaBradi2g14830      CTTCAAATATTCCGTACTTCATACGCATTCAGAAACCGGTAAGGATCTCC 1710
                           ******************** *********** *****************

1BL_casTaBradi2g14830      GTTTTGTTATTGCGCTCAAGAACAACTGCAGCTTCTGAGTTTCAAACTAA 2696
1DL_casTaBradi2g14830      ATTTTGTTATTGCGCTCAAGAACAACTGCAGCTTCTGATTTTCAAACTAA 2667
1AL_casTaBradi2g14830      ATTTTGTTACCATGCTCAAGTACAACTGCTGCTTTTG------------- 1747
                            ********    ******* ******** **** **

1BL_casTaBradi2g14830      TCTTGCTGGTCAAGTTCGGCAGGAACTTTTGCTGTTTATACATTATTACT 2746
1DL_casTaBradi2g14830      TCTTGCTGGTCAAGTCCGGCAGAAACTTTTGTTGTTTATACATTA---CT 2714
1AL_casTaBradi2g14830      -CTT---------------CATAAACTTGTGTTGTTTATACATTA---CT 1778
                            ***               ** ***** ** *************   **
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1BL_casTaBradi2g14830      GTGACGCGTGTGATTAA---GT-GTAGCTTGGGTTCTGAATTTCTTCCAT 2792
1DL_casTaBradi2g14830      GTGACGCGTGTGATTAA---GT-GTAGCTTGGGTTCTGAATTTCTTCCAT 2760
1AL_casTaBradi2g14830      TTAACTCGTGTGATTAGAATGTAGTAGCCTGGGTTCTTAATTTCTTCAAT 1828
                            * ** **********    ** ***** ******** ********* **

1BL_casTaBradi2g14830      GCATCCGAAAATTTTAGAATAATATTGTGTTTTGTTATTACAGTGAATAC 2842
1DL_casTaBradi2g14830      GCATCTGAAAATTTTAGAATAATATTGTGTTTTGTTATTACAGTGAATAC 2810
1AL_casTaBradi2g14830      GCATCACAAAGTTTTGGAATGATATTATTTTTTGTCATTACAGTGAATAC 1878
                           *****  *** **** **** ***** * ****** **************

1BL_casTaBradi2g14830      CCTATCAGCGAAGGAAAAGCCTTGCAGTTTGTTTATGGTAGCAAGCAAGC 2892
1DL_casTaBradi2g14830      CCTATCAGCGAAGGAAAAGCCTTGCAGTTTGTTTATGGTAGCAAGCAAGT 2860
1AL_casTaBradi2g14830      CCTATCGGCGAAGGAAAGGCCTTGCAATTTGTTTATGGTAGCAAGCAATC 1928
                           ****** ********** ******** *********************

1BL_casTaBradi2g14830      CTTGACGCCTGGTGGCATCCTTGCTACAACTGCAACAACAAACCTGTACC 2942
1DL_casTaBradi2g14830      CTTGACGCCTGGTGGCATCCTTGCTACAACTGCAACAACAAACCTGTACC 2910
1AL_casTaBradi2g14830      CTTGACGCCTGGTGGCATCCTTGCTACAACTGCAACAACAAACCTGTACC 1978
                           **************************************************

1BL_casTaBradi2g14830      GGAGTCAGCGCTACAAGGAAGGGATGAAGGATATCCAGTCTCAGGGCTGC 2992
1DL_casTaBradi2g14830      GGAGTCAACGCTACAAGGAAGGGATGAAGGATATCCAGTCTCAGGGCTGC 2960
1AL_casTaBradi2g14830      GGAGTCAGCGCTACAAGGAAGGGATGAAGGATATCCAGTCTCAGGGCTGC 2028
                           ******* ******************************************

1BL_casTaBradi2g14830      AGCCCCGACGAAGTCATCTTTGGCCCTGACTTCAACCAATCCTTGTACTG 3042
1DL_casTaBradi2g14830      AGCCCCGACGAAGTCATCTTTGGCCCTGACTTCAACCAATCCTTGTACTG 3010
1AL_casTaBradi2g14830      AGCCCCGACGAAGTCATCTTTGGCCCTGACTTCAACCAATCCTTGTACTG 2078
                           **************************************************
                                           F5
1BL_casTaBradi2g14830      TCACTTGCTCTGTGGGTTGATATACTCGGACGAGGTCCATTCCGTGTTCT 3092
1DL_casTaBradi2g14830      TCACTTGCTCTGTGGGTTGATATACTCAGATGAGGTCCATTCCGTGTTCT 3060
1AL_casTaBradi2g14830      TCACTTGCTCTGTGGGTTGATATATTCGGACGAGGTCCATTTTGTGTTCT 2128
                           ************************ ** ** **********  *******

1BL_casTaBradi2g14830      CGACGTTTGCTCACAGCCTAGTGCATGCATTTCAAACATTGGAGGAGGTC 3142
1DL_casTaBradi2g14830      CGACGTTTGCTCACAGCCTAGTGCATGCATTTCAAACATTGGAGGAGGTT 3110
1AL_casTaBradi2g14830      CGACGTTTGCTCACAGCCTAGTGCATGCATTTCAAACATTGGAGGAGATC 2178
                           *********************************************** * 

                                       R4
1BL_casTaBradi2g14830      TGGGAGGACCTCTGTGCTGATATAAGAGATGGCGTCCTTTCAGAAAAAAT 3192
1DL_casTaBradi2g14830      TGGGAGGAGCTATGTGCTGATATAAGAGATGGTGTTGTTTCAGAGAAAAT 3160
1AL_casTaBradi2g14830      TGGGAAGACCTCTGTGCTGATATAAGAGACGGTGTTCTTTCAGAAAGAAT 2228
                           ***** ** ** ***************** ** **  ******* * ***

1BL_casTaBradi2g14830      CACAGTGCCATCAATTCGCGAGGCTGTTTCAAAGATTCTGAAGCCCAACC 3242
1DL_casTaBradi2g14830      CACAGTACCATCAATTCGCGAGGCTGTTTCAAAGATTCTGAAGCCCAACC 3210
1AL_casTaBradi2g14830      CACAGTACCATCAATTCGCGGGGCTGTTTCAAAGATTCTGAAGCCCAACC 2278
                           ****** ************* *****************************

1BL_casTaBradi2g14830      CCGAGCTTGCCGACTCGATCCACAAGAAGTGTGCGGGCTTGAGCAACTGG 3292
1DL_casTaBradi2g14830      CTGAGCTTGCTGACTCGATCCACAAGAAGTGTGCGGGCTTGAGCAACTGG 3260
1AL_casTaBradi2g14830      CCGAGCTTGCTGACTCGATCCACAACAAGTGTGCGGGCTTGAGCAACTGG 2328
                           * ******** ************** ************************

1BL_casTaBradi2g14830      TACGGTGTGATCCCGGCACTGTGGCCCAAGGCAAAGTACGTGTATGGCAT 3342
1DL_casTaBradi2g14830      TATGGTGTGATCCCGGCACTGTGGCCCAAGGCAAAGTACGTGTATGGCAT 3310
1AL_casTaBradi2g14830      TATGGTGTGATCCCGGCACTGTGGCCCAAGGCAAAGTACGTGTATGGCAT 2378
                           ** ***********************************************

1BL_casTaBradi2g14830      CATGACAGGGTCCATGGAGCCGTATCTGAAGAAGCTGCGGCATTATGCTG 3392
1DL_casTaBradi2g14830      CATGACAGGGTCCATGGAGCCGTATCTGAAGAAGCTGCGGCATTATGCTG 3360
1AL_casTaBradi2g14830      CATGACAGGGTCCATGGAGCCGTATCTGAAGAAGCTGCGGCATTATGCTG 2428
                           **************************************************
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                                          F6
1BL_casTaBradi2g14830      GGCACTTGCCGCTGATCAGTGCCGACTACGGCGCGTCTGAAGGATGGGTT 3442
1DL_casTaBradi2g14830      GGCACTTGCCACTGATCAGTGCCGACTATGGCGCCTCTGAAGGATGGGTT 3410
1AL_casTaBradi2g14830      GGCATTTGCCGCTGATCGGTGCTGACTACGGCGCGTCCGAAGGATGGGTT 2478
                           **** ***** ****** **** ***** ***** ** ************

1BL_casTaBradi2g14830      GGCTCTAACATCGACCCCACGGTGCCGCCTGAGCAGGTGACGTATGCCGT 3492
1DL_casTaBradi2g14830      GGTTCTAACATCGACCCCACGGTGCCGCCTGAGCAGGTGACTTATGCTGT 3460
1AL_casTaBradi2g14830      GGCTCTAACATTGACCCCACGGTACCGCCTGAGCAGGTGACGTATGCTGT 2528
                           ** ******** *********** ***************** ***** **

1BL_casTaBradi2g14830      TCTACCGCAGACTGGTTATTTTGAGTTCATTCCCTTGGAGAAACCAACAG 3542
1DL_casTaBradi2g14830      TCTGCCGCAGACTGGTTATTTTGAGTTCATTCCTTTGGAGAAACCAACAG 3510
1AL_casTaBradi2g14830      TCTGCCGCAGACTGGTTATTTTGAGTTCATTCCTTTGGAGAAGCCAACAG 2578
                           *** ***************************** ******** *******

1BL_casTaBradi2g14830      GGGAGGAGACGGAGAACAGTGCAGCTATTCATTACATCGAGTCGGAGCCG 3592
1DL_casTaBradi2g14830      GGGAGGAGACGGAGAACAGTGCAGCTATTCATTACATCGAGTCGGAGCCG 3560
1AL_casTaBradi2g14830      GGGAGGAGACGGAGAACAGTGCAGCTATTCATTACATCGAGTCCGAGCCG 2628
                           ******************************************* ******

1BL_casTaBradi2g14830      GTTGGGTTAACTGAAGTTGAGGTTGGCAAAATCTATGAAGTTGTGCTCAC 3642
1DL_casTaBradi2g14830      GTTGGGTTAACTGAAGTTGAGGTTGGCAAAATCTATGAAGTTGTGCTGAC 3610
1AL_casTaBradi2g14830      GTTGGCTTAACTGAAGTTGAGGTTGGCAAAATCTATGAAGTTGTGCTCAC 2678
                           ***** ***************************************** **

1BL_casTaBradi2g14830      TACCTTTGCAGGTACATTCTTTCTCTTGGCTATTTGTTCTGAAACTTAGA 3692
1DL_casTaBradi2g14830      TACCTTTGCAGGTACATTCCTTCTCTTGGCTATTTGTTCTGACACTTAGA 3660
1AL_casTaBradi2g14830      TACCTTTGCAGGTACATTCCTTCTCTTGGCTATTTGTTCGGAAACTTATA 2728
                           ******************* ******************* ** ***** *
                                         R5
1BL_casTaBradi2g14830      TTGATGTTC------------------------------TGAATTTCCAT 3712
1DL_casTaBradi2g14830      TTAATGGTGGGGTAAATATAGCTATTAAGGACAACAATATAAATTTTCAT 3710
1AL_casTaBradi2g14830      TTAATGTTC------------------------------TGGATTTTCAT 2748
                           ** *** *                               *  **** ***

1BL_casTaBradi2g14830      CACGTGT------------------------------------------- 3719
1DL_casTaBradi2g14830      CATGTGTTCTCCTTTTGCGCTTGTCACCTGAGTCAGATATCTTATCTCGT 3760
1AL_casTaBradi2g14830      CATGTGTTCTCCTTTTGCGCTTGTCACCTGAGTCAGATATCTTATCTTCT 2798
                           ** ****

1BL_casTaBradi2g14830      -------------------------------------GGTGTGTAGTTTT 3732
1DL_casTaBradi2g14830      AACGATTATTAGAAGCACCTAATCTAGTGGTTCTTGTGGTGTGTAGTTTT 3810
1AL_casTaBradi2g14830      AACGATTATTAGAAGCACCGAATCTAGTGGTTCTTGTGGTGCGTAGTTTT 2848
                                                                **** ********
                                  F7
1BL_casTaBradi2g14830      CAGTGTAAATTCAGACTTCTTAGCCATGTCCCCTGCAAATTTGGAACACA 3782
1DL_casTaBradi2g14830      CAGTGTAAATTCAGACTTATTAGCCATGTCCC-TACAAATTTGAAACACA 3859
1AL_casTaBradi2g14830      CAGTGTAAATTCAGACTTGTTAGCCATGTCCC-TACAAATTTCAAACACA 2897
                           ****************** ************* * *******  ******

1BL_casTaBradi2g14830      GTTGCTCTGTATGCATCAAGGTTGTGGATTAAGCACGTGGGCAAGTAATT 3832
1DL_casTaBradi2g14830      GTTGCTCTGTATGCATCAAGGTTGTGGATTAAGCACGTGGGCAAGTAATT 3909
1AL_casTaBradi2g14830      GTTGCTCTGTATGCATCAAGGTTGTGTATTAAGCACGTGGGCAAGTAACT 2947
                           ************************** ********************* *

1BL_casTaBradi2g14830      ATCGCTAACGTTTCTTGTCCACTCATTGCTGCATTCATTAGGGGTAGCAT 3882
1DL_casTaBradi2g14830      ATCGCTAACGTTTCTTGTCCACTCATTGCTGCATTCATTAGGGGTAGCAT 3959
1AL_casTaBradi2g14830      ATCACAAACGTTTCTTGTCCACTCATTGCTGCATTCATTAGGGGTAGCAT 2997
                           *** * ********************************************

1BL_casTaBradi2g14830      CAAACAGCATGAGCCAGCAAGTGCGTCCTAATCTTGGTCTATATTAGCTT 3932
1DL_casTaBradi2g14830      CAAACAGCATAAGCCAGCCAGTGCGTCCTAATCTTGGTCTATATCAGCTT 4009
1AL_casTaBradi2g14830      CAAACAGCATAAGCCAGCCAGTGCGTCCTAATCTTGGTCTATATCAGCTT 3047
                           ********** ******* ************************* *****
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1BL_casTaBradi2g14830      TA--CCGGACTCAACAATCACATCGCGGCATTAATTAATTCAGCTAGTAC 3980
1DL_casTaBradi2g14830      TA--CCAGACTCAACAATCACATCGCGTCATTAATTAATTCAGCTAGTAC 4057
1AL_casTaBradi2g14830      TATACCAGACTCAACAATCACATCGCGTCATTAATTAATTCAGCTAGTAC 3097
                           **  ** ******************* ***********************

1BL_casTaBradi2g14830      ATATCTGTCAAGAGCAACTTTCGACGTGCCTAGCTCAGGAAATACTGAAC 4030
1DL_casTaBradi2g14830      ATATCTGTCAAGAGCAACTTTGGACATTCCTTGCTCAGGAAATAGTGAAC 4107
1AL_casTaBradi2g14830      ATATCTGTCAAGAGCAACTTTGGACATTCCTTGCTCAGGAAATAGTGAAG 3147
                           ********************* *** * *** ************ ****

1BL_casTaBradi2g14830      ACTACATATG--ATTTTAATTGTT----------GCAGAAAAC------- 4061
1DL_casTaBradi2g14830      TTTAGGTGTAGAATTTTGATCCTTCTCTTTTAAAGCATATGATTTT---- 4153
1AL_casTaBradi2g14830      TTTAGGTGTAAAATTTTGATCCTCTTCTCTTACAGCAGATGATTTAATTG 3197
                             **  * *   ***** **  *           *** *  *
                                              R6
1BL_casTaBradi2g14830      ------------AACCGTGATCTCGGAATGCTA---TTAGCCTATTTACA 4096
1DL_casTaBradi2g14830      ------------AATTTTGATCTCTGAATACTACTATTAGTCTATTTACA 4191
1AL_casTaBradi2g14830      TTGCAGAAAGCAAACCATGATCTCTGAGTACTAT--TTAGTCTATTTACA 3245
                                       **   ******* ** * ***   **** *********

1BL_casTaBradi2g14830      GTCCCTTTTCTGCTCTGTTGCTGCAGGCCTATATCGCTACAGACTAGGAG 4146
1DL_casTaBradi2g14830      ATCCCTTCTCTGCTCTGTTGCTGCAGGCCTATATCGCTACAGACTAGGAG 4241
1AL_casTaBradi2g14830      GTCCCTTCTCTGCTCTGTTGCTGTAGGCCTATATCGCTACAGACTAGGAG 3295
                            ****** *************** **************************
                                              ngs_F2
1BL_casTaBradi2g14830      ACGTGGTGAAGATAGCGCGCTTCCACAACTCGACGCCGGAGCTCCAGTTC 4196
1DL_casTaBradi2g14830      ATGTGGTGAAGATAGCGCGCTTCCACAACTCGACGCCGGAGCTCCAGTTC 4291
1AL_casTaBradi2g14830      ACGTGGTGAAGATAGCGCGCTTCCACAACTCGACGCCGGAGCTCCAGTTC 3345
                           * ************************************************

1BL_casTaBradi2g14830      ATCTGCCGCAGGAGCCTGGTGCTGAGCATCAACATCGACAAGAACACCGA 4246
1DL_casTaBradi2g14830      ATCTGCCGCAGGAGCCTGGTGCTGAGCATCAACATCGACAAGAACACCGA 4341
1AL_casTaBradi2g14830      ATCTGCCGCAGGAGCCTGGTGCTGAGCATCAACATCGACAAGAACACCGA 3395
                           **************************************************

                                  F8
1BL_casTaBradi2g14830      GAAGGACCTGCAGCTGGCCGTCGAGGAGGCGGCGAAGCTGCTGGAGGGGG 4296
1DL_casTaBradi2g14830      GAAGGACCTGCAGCTGGCTGTCGAGGAGGCGGCCAAGCTGCTGGAAGGGG 4391
1AL_casTaBradi2g14830      GAAGGACCTGCAGCTGGCCGTCGAGGAGGCGGCGAAGCTTCTGGAAGGGG 3445
                           ****************** ************** ***** ***** ****

1BL_casTaBradi2g14830      AGAAGCTGGAGATCGTGGACTTCACGAGCTACGTGGAGAAGTCGAGCGAC 4346
1DL_casTaBradi2g14830      AGAAGCTGGAGCTCGTGGACTTCACGAGCTACGTGGAGAAGTCGAGTGAC 4441
1AL_casTaBradi2g14830      AGAAGCTGGAGATCGTGGACTTCACGAGCTACGTGGAGAAGTCGAGCGAC 3495
                           *********** ********************************** ***
                               F9              R7
1BL_casTaBradi2g14830      CCGGGCCGGTACGTGATCTTCTGGGAGCTGAGCTCCGAGGCCACAGACGA 4396
1DL_casTaBradi2g14830      CCGGGCCGCTATGTGATTTTCTGGGAGCTGAGCTCTGAGGCCACAGACGA 4491
1AL_casTaBradi2g14830      CCGGGCCGGTACGTGATCTTCTGGGAGCTGAGCTCTGAGGCCACAGACGA 3545
                           ******** ** ***** ***************** **************

1BL_casTaBradi2g14830      TGTCCTGAGCGGGTGCGCCAACGCCCTGGACCTGGCATTCCTCGACGCGG 4446
1DL_casTaBradi2g14830      TGTTCTGAGCGGGTGCGCTAACGCCCTGGACCTGGCATTCCTCGACGCGG 4541
1AL_casTaBradi2g14830      TGTTCTGAGCGGGTGCGCCAACGCGCTGGACCTGGCATTCCTCGACGCGG 3595
                           *** ************** ***** *************************

1BL_casTaBradi2g14830      GCTACATGGGGTCGAGGAAGATCAAGACCATCGGGCCGCTCGAGCTCCGG 4496
1DL_casTaBradi2g14830      GCTACATGGGGTCGAGGAAGATCAAGACCATCGGGCCGCTCGAGCTCCGG 4591
1AL_casTaBradi2g14830      GCTACATGGGGTCGAGGAAGATCAAGACCATTGGCCCGCTCGAGCTCCGG 3645
                           ******************************* ** ***************

1BL_casTaBradi2g14830      GTCCTGAGGAAGGGCACATTCAGGGAGATCCTGCTCCACTTCCTGACCCT 4546
1DL_casTaBradi2g14830      GTCCTGCGGAAGGGCACATTCAGGGAGATCCTGCTCCACTTCCTGACCCT 4641
1AL_casTaBradi2g14830      GTCCTGAGGAAGGGCACATTCAGGGAGATCCTACTCCATTTCCTGACCCT 3695
                           ****** ************************* ***** ***********
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1BL_casTaBradi2g14830      AGGAGGCGCGGTGAGCCAGTTCAAGACGCCCCGGTTCGTGAGCCCGGCCA 4596
1DL_casTaBradi2g14830      AGGAGGCGCGGTGAGCCAGTTCAAGACGCCCCGGTTCGTGAGCCCGGCCA 4691
1AL_casTaBradi2g14830      AGGAGGCGCGGTGAGCCAGTTCAAGACGCCCCGGTTCGTGAGCCCGGGCA 3745
                           ************************************************ **

                                        F10                 R8
1BL_casTaBradi2g14830      ACGGCAAGGTCCTGCAGATCCTGAACCGGAACGTCGCCAAGAGCTACTTC 4646
1DL_casTaBradi2g14830      ACGGCAAGGTGCTGCAGATACTGAACCGGAATGTCGCCAAGAGCTACTTC 4741
1AL_casTaBradi2g14830      ACGGCAAGGTGCTGCAGATCCTGAACCGGAACGTGACCAAGAGCTACTTC 3795
                           ********** ******** *********** **  **************

                                 ngsR2     Stop!
1BL_casTaBradi2g14830      AGCACGGCGTATGGGCTATGACAGAAGCAAGAATAATTGCCTGCTGCTAG 4696
1DL_casTaBradi2g14830      AGCACCGCGTATGGGCTATGACAGAAGCAAGAATAATTGCCTGCTGCTAG 4791
1AL_casTaBradi2g14830      AGCACCGCGTATGGGCTATGACAGAAGCAAGAATAATTGCCTGCTGCTAG 3845
                           ***** ********************************************

1BL_casTaBradi2g14830      ATTTAGCAGGGGCGTGTAATTACCTTTCTTTTTCTGTTCTTTTTCTTTTT 4746
1DL_casTaBradi2g14830      ATTTAGCAGGGGCGTGTAATTACCTTTCTTTTTCTGTTCTTTTCCTTTTT 4841
1AL_casTaBradi2g14830      ATTTAGCAGGGGCGTGTAATTACCTTTCTTTTTCT-----------TTTT 3884
                           ***********************************           ****

1BL_casTaBradi2g14830      TT-GCTGGTACCTTTCAGTAGTCTCCTCAAGAAGGAACCGTTTGTTTTAG 4795
1DL_casTaBradi2g14830      TTTGCTGGTACCTTTTAGTAGTCTCCTCAAGAAGGAACCGTTTGTTTTAG 4891
1AL_casTaBradi2g14830      TT-GCTGGTACCTTTTAGTAGTCTCCTCAAGAAGGAACCGTTTGTTTTAG 3933
                           ** ************ **********************************

1BL_casTaBradi2g14830      TCTGTTGGAATAATGTTTTCTTTCTT---------ATGATCAATCTGGTG 4836
1DL_casTaBradi2g14830      TCTGTTGGAATAATGTTTTCTTTCTT---------ATGATCAATCTGGTG 4932
1AL_casTaBradi2g14830      TCTGTTGGAATAATGTTTTCTTCTTTCTTTCTTATATGATCAATCTGGTG 3983
                           **********************   **         ***************

1BL_casTaBradi2g14830      CCAGAGCTACTGAGCTAGAATCTATGTAAATTGCC---------GCAGTT 4877
1DL_casTaBradi2g14830      CCAAGGCTACTGAGCTAGAATCTATGTAAATTGCC---------GCAGTT 4973
1AL_casTaBradi2g14830      CTG--------GGGCTAGAATCCTTGTAAATTGTCAGTCTGCATGCAGTT 4025
                           *          * *********  ********* *         ******


1BL_casTaBradi2g14830      GTAGCGAAAGGTATGAAATGAGGAAAAAGAAAGAAATCTAG--------- 4918
1DL_casTaBradi2g14830      GTAGCGAAAGGTATGAAATGAGGAAAAAGAAAGAAAACTGG--------- 5014
1AL_casTaBradi2g14830      GTAGCGAAATGTATGAAATGAGGAGAAAGAAAGAAAGAAAGAAAGAAAGA 4075
                           ********* ************** ***********    *


1BL_casTaBradi2g14830      ------------TGTTGTTAATTTGCCTGACTTGTGATGCTGTGCACAGA 4956
1DL_casTaBradi2g14830      ------------TGTTGTTAATTTGCCTGACTTGTGATGCTGTGCACAGA 5052
1AL_casTaBradi2g14830      AAGAAAGAAAGCTAGTGTTAATTTGCATGACTTGTAATGCTGTGAACAGA 4125
                                       *  *********** ******** ******** *****

1BL_casTaBradi2g14830      AGTGCATTGCAACACTCCAAAGTAAATTCAGCAATA-TATGTTTCCAGAG 5005
1DL_casTaBradi2g14830      -GTGCATTACA-CACTCCAAAGTAAATTCAGCAATA-TATGTTTCCAGAG 5099
1AL_casTaBradi2g14830      AGTGCGT-ACA-CAC-CCAAAGTGAATCCAGCAATAATATGTTTCCAGAT 4172
                            **** *   ** *** ******* *** ******** ************
                                               R
1BL_casTaBradi2g14830      CTGGTCATCAAGTGTTTGTGAACAGCCTC---------TCAGTCCAGTTC 5046
1DL_casTaBradi2g14830      CTGGTCATCAAGTGTTTGAGAACAGCATC---------TCAGTTTAATTC 5140
1AL_casTaBradi2g14830      CTAGTCATATACTGTTTGTGAACATCCTCCTGAAACACTCAGTCTAGTTC 4222
                           ** *****  * ****** ***** * **         *****  * ***
                                  R9
1BL_casTaBradi2g14830      CTCTGTTTTCTGCCCCAGATATGTAATCCTCCAGAAACCATTTCATTCAC 5096
1DL_casTaBradi2g14830      TTCTCTTTTCAGCCCCAGGCATGTAATCCTGCAGAAACCATTTCATTCAC 5190
1AL_casTaBradi2g14830      TTCTCTTGTCTGCCCCAGACATGTAATCCTACAGGAACCATCTCATTCAA 4272
                            *** ** ** *******  **********  *** ****** *******
                                   R10
1BL_casTaBradi2g14830      CATTGAACTGTCTGTAGGCTTTGTATCCAAATTTATATGCAGAAGTGGTT 5146
1DL_casTaBradi2g14830      CATTGAACTATATGTATGCTTTGTA-----ATTTACATGCAGAAGTGGTT 5235
1AL_casTaBradi2g14830      CATTGAACTGTACAAGAG-----------GGCTAACCTGGAGAAACCATT 4311
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Appendix 4.7a TaBradi2g14790

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1AL_casTaBradi2g14790        TGCCCAGTCGGTTCAGTCTTCAGTGTTTTGCACATTCTGTCCGTGTTTGT 850
1BL_casTaBradi2g14790        G-----------TCCGTCTTCAGTGCTCTGCACATTCTGCTTGTGTTTGT 51
1DL_1_casTaBradi2g14790      -----------TAATGTCTTCAGTGTTTTACACATTCTGTTTGTGTTTGT 133
                                        :. ********** * *.*********    ********
                    Red highlights same as in the "Spark ins"  F2
1AL_casTaBradi2g14790        CAGAGATGGAAATGCTGAAATGTT--TGTATTAATTTTATCGTGCAGGAG 898
1BL_casTaBradi2g14790        CAGAGACAGAAATGCTGGCATGTTGTACTATAAATTTTATCGCGCAGGAG 101
1DL_1_casTaBradi2g14790      CAGAGATAGAAATGCTGAACTGTT---GTATTACTTTTATCGTCCAGGAG 180
                             ****** .*********...****    ***:*.********  ******
                               F3  Spark insertion btwn G/A!   ngs_F1
1AL_casTaBradi2g14790        AGACAGGAGATCAACATGGCGAGGGAGGAGCTGTCGTTCGAGCTCGGGAG 948
1BL_casTaBradi2g14790        AGGCAGGAGATCAACAGGGCGAGGGAGGAGCTGTCGTTCGAGCTCGGGAG 151
1DL_1_casTaBradi2g14790      AGACAAGAGATCAACAGGGCTCGGGAGGAGCTGTCGTTCGAGCTCGGGAG 230
                             **.**.********** ***  .***************************

1AL_casTaBradi2g14790        GACGCCGACGGACGAGGAGACGATGAAGAAAGTGGGGCTGTCGCCGGCGA 998
1BL_casTaBradi2g14790        GGCGCCGACGGACGAGGAGACGATGAAGAAAGTGGGGCTGTCGCCGGCGA 201
1DL_1_casTaBradi2g14790      GGCGCCGACGGACGAGGAGACGATGAAGAAAGTGGGGCTGTCGCCGGCGA 280
                             *.************************************************

1AL_casTaBradi2g14790        GGTACCGCGACGTGGTGCGGATGACGAGGCCGACCTACTCGCTCCACTCG 1048
1BL_casTaBradi2g14790        GGTACCGCGACGTGGTGCGGATGACGAGGCCCACCTACTCGCTGCACTCG 251
1DL_1_casTaBradi2g14790      GGTACCGCGACGTGGTGCGGATGACGAGGCCGACCTACTCGCTCCACTCG 330
                             ******************************* *********** ******

1AL_casTaBradi2g14790        CGGAACCGTGTCACGCAGGAGGAGCTCATCAAAGAGGTCACCGACGTGGA 1098
1BL_casTaBradi2g14790        CGGAACCGTGTCACGCAGGAGGAGCTCATCAAGGAGGTCACCGACGTGGA 301
1DL_1_casTaBradi2g14790      CGGAACCGTGTCACGCAGGAGGAGCTCATCAAAGAGGTCACCGACGTCGA 380
                             ********************************.************** **

1AL_casTaBradi2g14790        CGCCATCGGGGTCGACACCCACAAGCACAACCGGCTCCTCCGCCTCGCCA 1148
1BL_casTaBradi2g14790        CGCCATCGGGGTCGACACCCACAAGCACAACCGCCTCCTCCGCCTCGCCA 351
1DL_1_casTaBradi2g14790      CGCCATCGGGGTCGACACCCACAAGCACAACCGCCTCCTCCGCCTCGCCA 430
                             ********************************* ****************
                                                                         R1
1AL_casTaBradi2g14790        TTGACGACCTCGTAATCATAAACAACATCATCAGTT------GATTCATG 1192
1BL_casTaBradi2g14790        TTGACGACCTCGTAAGCACATACAACAACATCAACATCAAGAGATTCATC 401
1DL_1_casTaBradi2g14790      TCGACGACCTCGTAAGCACAAACAACAACATCAACAT------ATGCATG 474
                             * ************* ** *:******:*****. :      ** ***
                                            F4
1AL_casTaBradi2g14790        TGTTTGCTTTCTGAATGTTGATTGATGATCATGTGATGGATGGTGCAGCT 1242
1BL_casTaBradi2g14790        TGTTTGGTTTCTTGATTTTGATTGATGATCATGTGGTGGATGGTGCAGCT 451
1DL_1_casTaBradi2g14790      TCTTTGGTTTCTCGTTGTTGACAGATGATCATGTGATGGATGGTGCAGCT 524
                             * **** *****  .:* ****  :***********.**************

1AL_casTaBradi2g14790        GGATTCGCTGAAGCCCAAGGAGAGCGTGGTGATCAGGCAGAGGTTCGGGC 1292
1BL_casTaBradi2g14790        GGATTCGCTGAAGCCCAAGGAGAGCGTGGTGATCAGGCAGAGGTTCGGGC 501
1DL_1_casTaBradi2g14790      GGATTCGCTGAAGCCCAAGGAGAGCGTGGTGATCAGGCAGAGGTTCGGGC 574
                             **************************************************

1AL_casTaBradi2g14790        TGGACGGCAGAGGGAGGCGCACGCTGAGCGAAATCGCCGGCAACCTGAGG 1342
1BL_casTaBradi2g14790        TAGACGGCAGGGGGAGGCGCACGCTGAGCGAGATCGCCGGCAACCTGAGG 551
1DL_1_casTaBradi2g14790      TGGACGGCAGGGGGAGGCGCACGCTGAGCGAGATCGCCGGCAACCTGAGG 624
                             *.********.********************.******************
                                         ngs_R1
1AL_casTaBradi2g14790        ATCTCGAGGGAGATGGTGCGCAAGTACGAGCTCAAGGCGCTCATGAAGCT 1392
1BL_casTaBradi2g14790        ATCTCGAGGGAGATGGTGCGCAAGTACGAGCTCAAGGCGCTGATGAAGCT 601
1DL_1_casTaBradi2g14790      ATCTCGAGGGAGATGGTGCGCAAGTACGAGCTCAAGGCGCTCATGAAGCT 674
                             ***************************************** ********
                                                                R2  stop!
1AL_casTaBradi2g14790        CAAGCACCCCACCCGGGTCGACTACCTACGAAGATACATGTGAAATCATA 1442
1BL_casTaBradi2g14790        CAAGCACCCCACCCGGGTCGACTACCTGCGAAGATACATGTGAAATTATC 651
1DL_1_casTaBradi2g14790      CAAGCACCCCACCCGGGTCGACTACCTACGAAGATATATGTGAAATTATC 724
                             ***************************.******** ********* **.
                                              F5
1AL_casTaBradi2g14790        TG----CATCTCGGTCACGCACATACATACCAGTTCTCTAATTTGATTAT 1488
1BL_casTaBradi2g14790        TGTATATATCTCGGTCGCGCACATACATACCGGTTCTCTAATTTGATTAT 701
1DL_1_casTaBradi2g14790      TTTATATATCTCGGTCGCGCACGTGCATATAG------------------ 756
                             *      *********.*****.*.****  ..
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                                                       ngs_F2
1AL_casTaBradi2g14790        GCTGCATATAC----ATTGCAAGATGGCATAGACTCATCATTGATTCCGT 1534
1BL_casTaBradi2g14790        GCTGCATATACTTACATTGCAAGATGGCATAGACTCATCATTGATTCCGT 751
1DL_1_casTaBradi2g14790      --------TAC----ATTGCAAGATGGCATAGACTCATCATTGATTCCGT 794
                                     ***    ***********************************

1AL_casTaBradi2g14790        ATTTCGGACATGTATATAAGTCTGTATATACGAGTGAGGTTGTATATATA 1584
1BL_casTaBradi2g14790        ATTTCGGACATGTATATAAGTCTGTATATACGAGTGAGATTGTATATATA 801
1DL_1_casTaBradi2g14790      ATTTCGGACATGTATATAAGTCTGTATATACGAGTGAGGTTGTATATATA 844
                             **************************************.***********

1AL_casTaBradi2g14790        ATATTTGATTTAGACCTCGGGCTGATGTAGAGTAATTCATAGCATACAGA 1634
1BL_casTaBradi2g14790        ATATTTGATTTAGACCTCGCGCTGAT-----GTAATTCATAGCACGCAGA 846
1DL_1_casTaBradi2g14790      ATATTTGATTTAGACCTCGCGCTGAT-----GTAATTCGTAGCACGCAGA 889
                             ******************* ******     *******.***** .****

1AL_casTaBradi2g14790        AAAGAAAACGGTCTCTGGTATTATTAAAAG--ATAATAAATTATGCATTG 1682
1BL_casTaBradi2g14790        AAAGAAAATGGTCTCTGGTTTATTAGAAG-----AATATATAATGCATTA 891
1DL_1_casTaBradi2g14790      AAAGAAAATGGTCTCTGGTATTATTTAAACTAATAAATCATTTTGCATTA 939
                             ******** **********:*::*: **.     **:: **::******.
                                       R3
1AL_casTaBradi2g14790        CCATTTTGCAGTATGGGTTAAGTTTAAAGTTTAGAATACCACTTGAATAC 1732
1BL_casTaBradi2g14790        CCTATTTGCAGGATGGGCTGAGTTTAAAGTTCAGAATAGGACTTGAATAC 941
1DL_1_casTaBradi2g14790      CCTATTTACAGTATGGGGTGGATTTAAAGTTTGTAATACCACTTGAATAC 989
                             **::***.*** ***** *...********* . ****  **********

1AL_casTaBradi2g14790        ACCTTCTCAACTTATAAAACCATTTTCAATGAAGCTAT------------ 1770
1BL_casTaBradi2g14790        ACCTCCTCAACTTAT-AAACCATTTTCAATGAAGCTAT------------ 978
1DL_1_casTaBradi2g14790      ACCTTCTCAACTTATAAAACCATTTTCAATTAACCTACGCAAATCGTTGC 1039
                             **** ********** ************** ** ***

1AL_casTaBradi2g14790        -------------------GCAAAACCAGTTGATTCAGCCTCCTCTCAAT 1801
1BL_casTaBradi2g14790        -------------------GCAAAACCAGTTGAT---------------- 993
1DL_1_casTaBradi2g14790      AAAAAACAAATTAACCTACGCAAAACCAGTTGATTCAGCCTGCTCTCAAT 1089
                                                ***************

1AL_casTaBradi2g14790        ATCACTTCATGACTCGATTTCCCTATCATCCGCTATGCAGACAACACTGT 1851
1BL_casTaBradi2g14790        -----------------------------------------AAACACTGT 1002
1DL_1_casTaBradi2g14790      ATCACTTCATGCCTCG-ATTCCGTATCATCCACTATGCAGATGACACTGT 1138
                                                                       .*******
                                   F6
1AL_casTaBradi2g14790        CATGATCCTTCATGCATGG-AAAGACAATGGCAGCACATAAAGAACCCAC 1900
1BL_casTaBradi2g14790        CATGATCCTTCATGCATGGGAAAGACAATGGCAGCACATAAAGAACCCAC 1052
1DL_1_casTaBradi2g14790      CATGACCGTTCCTGCATGTGAAAGACAATGGCAGCACATAAAGAACCCAC 1188
                             ***** * ***.******  ******************************

1AL_casTaBradi2g14790        TCCTCCATCTTGCATCCTACACTGGTTTGAAAGTGAACTTTAACAAGTCT 1950
1BL_casTaBradi2g14790        TCCTCCATTTTGCATCCTACACTGGTTTGAAAGTGAAATCTAACAAGTCT 1102
1DL_1_casTaBradi2g14790      TCCTCCATTTTGCATCCTACACTGGTTTGAAAGTGAACTCTA--AAGTCT 1236
                             ******** ****************************.* **  ******
                                  R4
1AL_casTaBradi2g14790        ATTGTGGTGCGAATTAATG-TCTTTAATCCA---CACAACAATT-AATG- 1994
1BL_casTaBradi2g14790        ATTGTGGTGCTAATTAAAAGTCTTTAGTCCTTTTCACAAAAAAA-ATTGT 1151
1DL_1_casTaBradi2g14790      ATTATGGTGCCAATTAAATGACTTTAGTCCTTTTCGCAAAAAAAAAAATGT 1286
                             ***.****** ******:  :*****.***:   *.***.**:: *:**

1AL_casTaBradi2g14790        ----------------------------------------ACTTTGATCA 2004
1BL_casTaBradi2g14790        CTTTAATCCGCAAAAAAA-------------------AAGTCTTTGATCA 1182
1DL_1_casTaBradi2g14790      CTTTAATCTGCAAAAAAATTAATGTCCAAAAAAAAATAATGTCTTTGATCA 1336
                                                                     :*********

1AL_casTaBradi2g14790        CGGAATGCAAACCCTTGCTCAATCTTTTGGATGTATGTTGGGCTCCTTCC 2054
1BL_casTaBradi2g14790        CGGAATGCAAACCCTTGCTTAATCTTTTGGATGTATGTTGGGCTCCTTCC 1232
1DL_1_casTaBradi2g14790      CGTAATGCAAACCCTTGCTCAATCTTCTGGATGTATGTTGGGCTCCGTCC 1386
                             ** **************** ****** ******************* ***

1AL_casTaBradi2g14790        CTTTTACTGGTATCTAGGACTTCCCCACTCAACATTGTAAAGCCAAAGAC 2104
1BL_casTaBradi2g14790        CTTTTACC--TATCTAGGACTTCCCCACTCAACAATGTAAAGCCAAAGAC 1280
1DL_1_casTaBradi2g14790      CTTTTACC--TATCTTGGACTTCCCCACTCAACATTGTAAAGCTAAAGAC 1434
                             *******   *****:******************:******** ******
                                                                ngs_R2
1AL_casTaBradi2g14790        ATAAGAATTTGTCCCT-GTCCCTCTTGGCTAATTTCACCCCATAAAGATT 2153
1BL_casTaBradi2g14790        ATAAGAATTTGTCCTTTGTCCTGCTTGGCTAATTTCACCCCATAAAGACT 1330
1DL_1_casTaBradi2g14790      ATAAGAATTTGTCCAT-GTCCCGCTTGGCTAATTTCACCCCATAAAGACT 1483
                             ************** * ****  ************************* *
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                                                          R6
1AL_casTaBradi2g14790          T-ACTGGATGATCAACCTTCTTATCATCTGGGGTGAAATTATAGCTTGTG 2202
1BL_casTaBradi2g14790          T-ACTGGATGATCAACCTTCTTATCATGTGGGGTGAAATTACAGCTTGTG 1379
1DL_1_casTaBradi2g14790        TAACTGGATGATCGAACTTCTTATCATGTGGGGTGAAATTACAGCTTGTG 1533
                               * ***********.*.*********** ************* ********

1AL_casTaBradi2g14790          AAACCAGTGCTATGCAGTTTACCCATTTTCTTCATGTGCCCTCTGTCCCT 2252
1BL_casTaBradi2g14790          AAATCAGTGTTATGCAGTTTACCCATTTACTACACGTACACTCTGTCCCT 1429
1DL_1_casTaBradi2g14790        AAATCAGTGCTATGCAGTTTACCCATTTACTACATGTGCACTCTGTCCCT 1583
                               *** ***** ******************:**:** **.*.**********

1AL_casTaBradi2g14790          ACCACTTTCAGTTTCTTAGAAGATTAATAAATACTCCCTCAGTTTCTTTT 2302
1BL_casTaBradi2g14790          ACCACTTTCAGTTTCTTAGAAGATTAATAAATACT--------------- 1464
1DL_1_casTaBradi2g14790        ACCACTTTTAGTTTCTTAGAAGATTAATAAATACT--------------- 1618
                               ******** **************************

1AL_casTaBradi2g14790          TTACTTTGCATATAAAATTTGATCAAAGTCAAACTAAACAAAGTTTGACC 2352
1BL_casTaBradi2g14790          --------------------------------------------------
1DL_1_casTaBradi2g14790        --------------------------------------------------


1AL_casTaBradi2g14790          AAATTTATATTAAAAAATATCAACATCTACAATACCAAAGTTATATGGTA 2402
1BL_casTaBradi2g14790          --------------------------------------------------
1DL_1_casTaBradi2g14790        --------------------------------------------------


1AL_casTaBradi2g14790          TGGAAGTTAATTTCGTGATGCATCTAATAATATTGATTTCATATGGTGAA 2452
1BL_casTaBradi2g14790          --------------------------------------------------
1DL_1_casTaBradi2g14790        --------------------------------------------------


1AL_casTaBradi2g14790          TATTGATATTTTTCCTATAAAGTTAGTCAAACATTACAAAGTTTGACTTT 2502
1BL_casTaBradi2g14790          --------------------------------------------------
1DL_1_casTaBradi2g14790        --------------------------------------------------


1AL_casTaBradi2g14790          GACTCAATTTTATATGCAAATTAAAAAGAAACGGAGGGAGTACTTAAGGC 2552
1BL_casTaBradi2g14790          --------------------------------------------TAAGGC 1470
1DL_1_casTaBradi2g14790        --------------------------------------------TAAGGC 1624
                                                                           ******

1AL_casTaBradi2g14790          ACTGCTTTTGAAGAAAATATGACATGGAGGATTGAGGGACAACTCTCTTC 2602
1BL_casTaBradi2g14790          ACTGCTTTTGAAGAAAATATGACATGGAGGATAGAGGGACTGTTCTCTTC 1520
1DL_1_casTaBradi2g14790        ACTGCTTTTGAAGAAAATATGACATGGAGGATAGAGGGACTGCTCTCTTC 1674
                               ********************************:*******:. *******

1AL_casTaBradi2g14790          TCTTGGGACAAAGTGTGCAGCCTACAAGGTCAAGGTGGTCTTGCAGTTCC 2652
1BL_casTaBradi2g14790          TCTTGGGACAAG-TGTGCAACCCAAAAGGTCAAGGTGGTCTTGCAGTTCC 1569
1DL_1_casTaBradi2g14790        TCTTGGGACAAAGTGTGCAACCCAAAAGGTCAAGGTGGTCTTGCAGTTCC 1724
                               ***********. ******.** *.*************************

1AL_casTaBradi2g14790          TCACATTACACTTCAGAGCAAAATTGTTGTGATCAAGCACCTTTACAAAT 2702
1BL_casTaBradi2g14790          TCACATTGCACTTCATAGCAAAACT-------------------ACAAAT 1600
1DL_1_casTaBradi2g14790        TCACATTGCACTTCATAGCAAAACTCTTGTGATCAAGCACCTTTACAAAT 1774
                               *******.******* ******* *                   ******

1AL_casTaBradi2g14790          TCTTTAATAGATATATGAGTTACATTGGGTCAACCTCATTTGGGAATCAT 2752
1BL_casTaBradi2g14790          TATTTAATAGATATATGTGCTGCCTTGGGTCAAGCTCATTTGGATATCAT 1650
1DL_1_casTaBradi2g14790        TCTTTAATAGATATATGAGCTGCC-------------------------- 1798
                               *.***************:* *.*.

1AL_casTaBradi2g14790          ATTATAT 2759
1BL_casTaBradi2g14790          ATTATAT 1657
1DL_1_casTaBradi2g14790        -------
```

Appendix 4.7b The insertion in Spark for the gene TaBradi2g14790

Spark_F1_R1_comb_TaBradi2g14790 yellow is the Spark insertion that is between GA green is overlap of F1 and R1 Common region between Spark and Rialto

TGAACTGTTGTATTACTTTTATCGTCCAGGAGAGACAAGAGATCAACAGGGCTCG
GGAGCCAGGGACGGAGACAAGGGGGACGAGGGGGGCTAGACCCCCCCAAC
GAAGTGGTTCTCCTCAATAGCGATTAGTTAGATCCGTTTATTAGCAGGCCTTTTG
ACTTGATTCGCCCCCCCTGTCCACTTGTCTCGTGTAACACCGTGAAACCCCTCGG
GCAGCCCATGTACAAGAAACAACAGATCACAACCCAGCAAAAAAAAGGCCCAC
CATCGAGGTCAAAGAAAACAGAGCCCACCGGTCAAGGGCTTGCGACCAGGAGC
ACCAACGCAGTCTGCTACAATCCTGGCGATCGACACGATTTTATATCGCTCCAAC
AGAACGCACGCAGATTGCGGCTCGTGCGATCTTTCCATCTGTCGTCGCCTCCAAT
CTCCGCCTACCCGCAAGATTAGCTTCAGTCTCCAAGCGAAGATCATAGGGGGTT
GATCGAGATCCGCCACGGCTGATTACCTGCACGGTTAGTCCCTTACTTCATCTCC
TGATCTTTAATCTGCTCTAATTTGTGTGGTTGTTCCATAAAAAACCTACGAACATG
AGAAGTTAATTACAGTAGGAAATATTGGCTGTTGTGTGTAGATACGAAGAGGAA
GAGAAGAATGGAAAACGTTTCCTAGGGCACTTGCTTCCAACCGTTCAAGCCTAG
CAATCCCAATTGATCATTTCCTCAGCAACCATAAAGGAGATTAGGAGAAACACC
ACCACCATGAGCGACCACGGAGGAGATGATGCACGGAATCTGACATCCTCTTTG
CGTGTATGGTACGTCCACTCTCATAATTAATATCAGCTTCAAATATCTGATTTTTG
TGGGTTAAAACGAATGATTGTTAATTGATCGACATGAAAACTGAATTTGGAATCA
ATAGATAGATATTGTATTGTCTACCAAATTCGTAATGCAATCAATTTGGAAACTA
AATTTGTCTTGCCAAAAATGCACATTTTAATAGTTTTTTGTAGTGTTCACACTAAT
GAAAACACTAGTTCAGGCTTAGGTTTTTGCAAGGAATTTTTTTTATGGTTAACCG
ATGCCCAACTGCCTATAAGAGCTCAAGTCTGCAACTCGCCCCCCCTATACAAAAT
TCCTGGCTCCGTCCCTGTCGGGAGGAGCTGTCGTTCGAGCTCGGGAGGGCGCCGA
CGGACGAGGAGACGATGAAGAAAGTGGGGCTGTCGCCGGCGAGGTACCGCGAC
GTGGTGCGGATGACGAGGCCGACCTACTCGCTCCACTCGCGGAACCGTGTCACG
CAGGAGGAGCTCATCAAAGAGGTCACCGACGTCGACGCCATCGGGGTCGACACC
CACAAGCACAACCGCCTCCTCCGCCTCGCCATCGACGACCTCGTAAGCACAA

>Ria_F1_TaBradi2g14790 common region between Rialto and Spark

TATCATTTCTGATGTGTTGTCAGAGATAGAATGCTGAACTGTTGTATTACTTTTAT
CGTCCAGGAGAGACAAGAGATCAACAGGGCTCGGGAGGAGCTGTCGTTCGAGCT
CGGGAGGGCGCCGACGGACGAGGAGACGATGAAGAAAGTGGGGCTGTCGCCGG
CGAGGTACCGCGACGTGGTGCGGATGACGAGGCCGACCTACTCGCTCCACTCGC
GGAACCGTGTCACGCAGGAGGAGCTCATCAAAGAGGTCACCGACGTCGACGCCA
TCGGGGTCGACACCCACAAGCACAACCGCCTCCTCCGCCTCGCCATCGACGACCT
CGTAAGCACAAACAACAACATCAACATATGCATGTCTTTGG

Appendix 4.8 TaBradi2g14730

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                                                                             DDF1
1ALcasTaBradi2g14730      GATTTTGAACGGTGCTGAACAGTAGCAGCGGTTTCACCCGGCACCAGCCAACCTTTTGTT 60
1DLcasTaBradi2g14730      --------------CTGAACAGTAGCAGCGGCTTCACCCGGCACCAGCCAACCTTTTATT 46
1BLcasTaBradi2g14730      ----------------GAACAGTAGCAGCGGCTTCACCCGGCACCGGCCAACCTTTTATT 44
                                          *************** ************* *********** **
                                            Intron1
1ALcasTaBradi2g14730      TCGCATGCCCGTGATTTGTCCATGGATCATAT--TGATGTCAATCTGGAAA-GGATCAAG 117
1DLcasTaBradi2g14730      TCGCCTGTCCGTGATTTGTCCATGGATCATAT--TGATGTGAATCAGGAAA-GGATCAAG 103
1BLcasTaBradi2g14730      TCGCATGCCCGTGATTTGTCCATGGATCATATATTGACATGAATCAGGAAAAGGATCAAG 104
                          **** ** ************************  ***  * **** ***** ********

1ALcasTaBradi2g14730      AATTAGCTGGGTTTGGTCCTCAGTGCTGTTGTATCTAA-------TCTAAATGGTACAAG 170
1DLcasTaBradi2g14730      AATTAGCCGGGTTTGGTCCTCAGTGCTGTTGTATCCAA-------TCTAAATGGTACAAG 156
1BLcasTaBradi2g14730      AATTAGCCGGGCCTGGTCATCAGTGCTGCTGTATCTGAAGCTCCATCTGAAGGGTGCAAG 164
                          ******* ***  ***** ********* ******  *       *** ** *** ****

1ALcasTaBradi2g14730      GTGGCCAGGATAAGTTTAAAGAACCACCACTAGGTTTATCCCTCCATTTCTTGTTTCTGT 230
1DLcasTaBradi2g14730      GTGGCCAGGATAAGTTTAAAGAACCACCACTAGGTTTATCCCTCCATTTCTTGTTTCTGT 216
1BLcasTaBradi2g14730      GTGGCCAGGATAAGTTTAAAGAACCACCACTAGGTTTATCCCTCCATTTCTTGTTTCTGT 224
                          ************************************************************

1ALcasTaBradi2g14730      GCTGGAGGCCTTGTGTGTTCCGGAGGGATTCTCGATGCGTTGTCGCGGCGCCACGCAGGC 290
1DLcasTaBradi2g14730      GCTGGAGGCCTCGTGTGTTCCGGAGGGATTCTCGATGCGTTGTCGCCGCGCCACGGAGGC 276
1BLcasTaBradi2g14730      GC--------------GTTCCGGAGGGATTCTCGATGCGTTGTCGCAGCGCCACGGAGGC 270
                          **              ****************************** ******** ****

1ALcasTaBradi2g14730      CCGGTTTAGATTTCTACCATTCC----AGCATCCAACCATTGGCGATACACGTAGGGTAC 346
1DLcasTaBradi2g14730      CCGGTTTAGATTTCTACCATTCC----AGCATCCAACCATCGGCGATACACGTAGGGTAC 332
1BLcasTaBradi2g14730      CCGGTTTAGATTTCTACCATTCCTTCCAGCATCCAACCATCGGCGATACACGGAGGGTAC 330
                          ***********************    ************* *********** *******

1ALcasTaBradi2g14730      ACGTTGGATAAACTCGGATTAGTTTGTTTATGCTATTCATCGTTTGATAGTTATTGGTTT 406
1DLcasTaBradi2g14730      ACGTTGGATAAACTCGGATTAGTTTGTTTATGCTACTCATCGTTTGATAGTTATTGGTTT 392
1BLcasTaBradi2g14730      ACGTTGGATAAACTCGGATTAGTTTGTTTATGCTATTCATCGTTTGATAGTTATTGGTTT 390
                          *********************************** ************************

1ALcasTaBradi2g14730      CTAGTTAACTACACCCTTCTTTCTCTTGGCTCGTTGTGGCTAT----TTGTTTATGTTAT 462
1DLcasTaBradi2g14730      CTAGTTAACTACACCCTTCTTTCTCTTGGCTCCTTGTGGCTAT----TTGTTTATGTTAT 448
1BLcasTaBradi2g14730      CTAGTTAACTACACCCTTCTTTCTCTTGGCTCCTTGTGGCTATATTATTGTTTATATTAT 450
                          ******************************** **********    ******** ****

1ALcasTaBradi2g14730      TGCCAGGAA---TCATCATTTCGAGTAATTTTTGTGTTGTAGCGTTGGGGCAATGCTGGC 519
1DLcasTaBradi2g14730      TGCCAGGAAGAATCATCATTTCGAGTAATTTTTGTGTTGTAGCGTTGGGGCAATGCTGGC 508
1BLcasTaBradi2g14730      TGCCAGGAAGAATCATCATTTCGAGTAATTTTTGTGTTGTAGCGTTGGGGCAATGCTACC 510
                          *********   *********************************************  *

1ALcasTaBradi2g14730      TATTGCCTGGCCGGATGCTTTGACTGATTACTTCTGTTCTTGCAA--------------- 564
1DLcasTaBradi2g14730      TATTGCCTGGCCGGATGCTTTGACTGATTACTTCTGTTCTTGCAA--------------- 553
1BLcasTaBradi2g14730      TATTGCCTGCCCAGATGCTTTGACTGATTACTTCTGTTCTTGCAAAAAAAACTTCTGTTC 570
                          ********* ** ********************************
                                                          Exon2 start!
1ALcasTaBradi2g14730      ------GGTTGGCATCTTCTGATTGTATCATTCAAATGTGCAGATCCTTACCTTAACACT 618
1DLcasTaBradi2g14730      ------GGTTGGCATTTTCTGATTGTATCACTCAAATGTGCAGATCCTTACCTTAACACT 607
1BLcasTaBradi2g14730      TTGCAAGGCTGGCATTTTCTGATTGTGTCACTCAAATGTGCAGATCCTTACCTTAACACT 630
                                ** ****** ********** *** *****************************

1ALcasTaBradi2g14730      GATGCTGGAACCATGTCTCCTTTTGAACATGGCGAAGTGTTTGTTCTAGATGATGGTGGC 678
1DLcasTaBradi2g14730      GATGCTGGAACCATGTCTCCTTTTGAACATGGCGAAGTGTTTGTTCTAGATGATGGTGGC 667
1BLcasTaBradi2g14730      GATGCTGGAACCATGTCTCCTTTTGAACATGGCGAAGTGTTTGTTCTAGATGATGGTGGC 690
                          ************************************************************

                                DDF2
1ALcasTaBradi2g14730      GAGGTATTAGAATCTGCTATATGACTAAGTCATTGATGTTTTAATGCTCGCACAGATCTG 738
1DLcasTaBradi2g14730      GAGGTATTGGGATTTGCTATATGACTAAGTCATTGATGTTTTAATGCTGGCACAGATCTG 727
1BLcasTaBradi2g14730      GAGGTATTGGAATCTGCTACATGACTAAGTCATCGATGTTTTAATGCTGGCACAGATCTG 750
                          ******** * ** ***** ************* ************** ***********

                                         DDR1 ex3 start!
1ALcasTaBradi2g14730      TTCATTTGATATGGC-TTAAATCATTGCAGGTGGACTTGGATCTTGGAAACTATGAGAGG 797
1DLcasTaBradi2g14730      TTCAGTTGATATAGCCTTATATTGTTGCAGGTGGATTTGGATCTCGGAAACTATGAGAGG 787
1BLcasTaBradi2g14730      TTCATTTGATATAGCCTTAAATCGTTGCAGGTGGACTTGGATCTCGGGAACTATGAGAGG 810
                          **** ******* ** *** ** *  *********** ******** ** ************

1ALcasTaBradi2g14730      TTTCTAGACATTAAGCTGACACGGGACAATAACATAACTACTGGAAAGATCTACCAGGTG 857
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1DLcasTaBradi2g14730      TTTCTAGACATTAAGCTGACACGTGACAACAACATAACTACTGGAAAGATCTACCAGGTG 847
1BLcasTaBradi2g14730      TTTCTAGACATTAAGCTGACACGCGACAACAACATAACTACTGGAAAGATCTACCAGGTG 870
                          *********************** ***** ******************************

1ALcasTaBradi2g14730      TGCAACTACAACCTACCACC----TCTTGCTTAATGGCAATGTCAAACTATAGCTGGGTC 913
1DLcasTaBradi2g14730      TGCAACTACAACCTACCACCACC-TCCTGCTTAATGGCAATGTCAAACTATAGCTGGTTC 906
1BLcasTaBradi2g14730      TGCAACTACAACCTACCACCCCCCCCCTGCTTAATGGCAATGTCAAACTATAGCTGGGTC 930
                          ********************     * ****************************** **
                           DDF3
1ALcasTaBradi2g14730      GGATAATGGACATGCTGAATCATTGGCTGTATTTCAACATCACTGCAATTTATTAATCTC 973
1DLcasTaBradi2g14730      GGATAATGTTCATGCTGAATCGTTGGCTGTATTTCAACATCACTGCAATTTATTAATCTT 966
1BLcasTaBradi2g14730      GGATAATGTTCATGCTGAATCATTGGCTGTATTTCAACATCATTGCAATGTCTTAATCTT 990
                          ********  *********** ******************** ****** * ******* 

1ALcasTaBradi2g14730      AACAGTATGACTTGGTC-ATACAAGGTCATTAGCTTCTTATCCACTTTCCTTGTTACATA 1032
1DLcasTaBradi2g14730      AACTGTATGACTTGGTCCATACAAGGTCATTAGCTTCTTATCCACTTTCTTTGTTACATA 1026
1BLcasTaBradi2g14730      AACAGTATGACTTGGTC-ATACAAGGTCATTAGCTTCTCATCCACTTTCTTTGTTACATA 1049
                          *** ************* ******************** ********** **********

1ALcasTaBradi2g14730      GCCATCAAACATAATTTAATTTAATAAAGCTTCGTACATTTTGATGTTGACATCTTGTAA 1092
1DLcasTaBradi2g14730      GCCATCAAACATAATTTAATTTAATAAAGCTTCGTACATTTTGATGTTGACATCTTGTAA 1086
1BLcasTaBradi2g14730      GCTATCAAACACTATTTAATTT---TAAGCTTTCTACATTTTGATGTTGACATCTTGTAA 1106
                          ** ********  *********    ******  **************************

1ALcasTaBradi2g14730      CAGCTTA--GGATATAAAAAAA-CTTGTTTTCTCATCCACCTTTATATTGAATGTGCAAT 1149
1DLcasTaBradi2g14730      CAGCTTA--GGATATAAAAAAAACTTGTTTTCTCATCCACCTGTATATTGAATGTGCAAT 1144
1BLcasTaBradi2g14730      CAGCTTACAGGATATAAAAGA--CTTGTTTTCTCATCCACCTGTATATTGAATGCGCAGC 1164
                          *******  ********** *  ******************* *********** ***  

1ALcasTaBradi2g14730      ATAACTTATACTTAAGCATATGAGTAA-GTGAGAAACTCAGAATAGTGGCATGTAAAACA 1208
1DLcasTaBradi2g14730      ATAACTTATACTTAAGCATATGAGTAAAGTGAGAAACTCAGAATAGTGGCATGTAAAACA 1204
1BLcasTaBradi2g14730      ATAACTTATACTTAAGCATATGAGTAT-GTGAGAAACTGAGAATAGCGGCATGTACAACA 1223
                          **************************  ********** ******* ******** ****

1ALcasTaBradi2g14730      TGTGCATTTGTAAATATGTGTTGTAAAAGTTGCAAAATAGTCTGATCTTGCTTGTTTATT 1268
1DLcasTaBradi2g14730      TGTGCATTTGTAAATATGTGTTGTAGAAGTTGCAAAATAGTCTGATCTTGCTTGTTTATT 1264
1BLcasTaBradi2g14730      TGTGCATTTGTAAATATGT-TTGTAAAAATTGCAAAATAGTCTGATCTTGCTTGTTTGTT 1282
                          ******************* ***** ** **************************** **
                                         DDR2
1ALcasTaBradi2g14730      TAACTT------AATATATTTTTATGGCAGTCTGTTATTAATAAAGAAAGAGAGGGAGAA 1322
1DLcasTaBradi2g14730      TAACTTAATATTAATATATTTTTATTGCAGTCTGTTATTAATAAAGAAAGAGAGGGAGAA 1324
1BLcasTaBradi2g14730      TAACTT------GATATTTTTTTATGGCAGTCTGTTATAAATAAAGAAAGAGAGGGAGAA 1336
                          ******       **** ******* ************ *********************

1ALcasTaBradi2g14730      TACCTGGGAAAGACTGTGCAGGTGCAAGCCACTTCCTCCAGACTCATCTTTT-TTTTTCT 1381
1DLcasTaBradi2g14730      TACCTGGGAAAGACTGTGCAGGTGCAAGCCACTTCCTCCAGACCCATCTTTT-TTTT-CT 1382
1BLcasTaBradi2g14730      TACCTGGGAAAGACTGTGCAGGTGCAAGCCACTTCCTCCAGACTCATCTTTTCTTTTTCT 1396
                          ******************************************* ******** **** **

1ALcasTaBradi2g14730      TACTTGAAATT-GGCAACTAACATTGAACATTTCTTGGGAATCTAATATGATCAATCATG 1440
1DLcasTaBradi2g14730      TACTTGAAATTTGGCAACTTACATTGAACATTTCTTGGGAATCTAATATGATCA-TGTTT 1441
1BLcasTaBradi2g14730      TACTTGAAATT-GGCAACTTACATTGAACATTTCTTGGGAATCTAATATGATCAATCATG 1455
                          *********** ******* ********************************** *  * 

1ALcasTaBradi2g14730      TTTTCCTTTTAATTAAGGTTGTCCCACACATTACAAATGCCATACAAGATTGGATTGAGC 1500
1DLcasTaBradi2g14730      TTTTTCCTTTAATTAAGGTTGTCCCACACATTACAAATGCTATACAAGATTGGATTGAGC 1501
1BLcasTaBradi2g14730      TTTTTCCTTTAATTAAGGTTGTTCCACACATTACAAATGCAATACAAGATTGGATTGAGC 1515
                          **** * *************** ***************** *******************

1ALcasTaBradi2g14730      GCGTTGCAATGGTTCCTGTTGATGGCCAGGAGGGACCTGCCGATGTCTGTGTTATAGAAC 1560
1DLcasTaBradi2g14730      GTGTTGCAATGGTTCCTGTTGATGGCCAGGAGGGACCTGCCGATGTCTGTGTTATAGAAC 1561
1BLcasTaBradi2g14730      GTGTTGCAATGGTCCCTGTTGATGGCCAGGAGGGACCTGCCGATGTCTGTGTTATAGAAC 1575
                          * *********** **********************************************

1ALcasTaBradi2g14730      TGGGTGGCACTATAGGTGCAAGAGATAACTTTTAACATTTTGTTCATTTTTAAGACTCTT 1620
1DLcasTaBradi2g14730      TGGGTGGCACTATAGGTGCAAGAGATAACTTTTAACATTCTGTTCATTTTTAAGACTCT- 1620
1BLcasTaBradi2g14730      TGGGTGGCACTATAGGTGCAAGAGATAACTTTTAACATTTTGTTCATTTCTAAGACTCTT 1635
                          *************************************** ********* ********* 

1ALcasTaBradi2g14730      TCTTTGCTTACAATTCATTTTGGAGTTCTAATCTTCTGT----AACTTAATGATGTGCTG 1676
1DLcasTaBradi2g14730      -CTTTGCTTACAATTCATTTTGGGGTTCTAATCTTCTGT----AACTTAATGATGTGCTG 1675
1BLcasTaBradi2g14730      TCTTTGCTTACAATTCATTTTGGAGTTCTAATCTTCTGTCTGTAACTTAATGATGTGCTG 1695
                           ********************** ***************    *****************
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1ALcasTaBradi2g14730      CAGGGGATATTGAATCCATGCCATTTATTGAAGCTCTAGGTCAATTCTCCTATCGTGTTG 1736
1DLcasTaBradi2g14730      CAGGGGATATTGAATCCATGCCATTTATTGAAGCTCTAGGTCAATTCTCCTATCGTGTTG 1735
1BLcasTaBradi2g14730      CAGGGGATATTGAATCCATGCCATTTATTGAAGCTCTAGGTCAATTCTCCTATCGTGTTG 1755
                          ************************************************************

1ALcasTaBradi2g14730      GTAAGGAACTTGCATGTTACATTAAAAAGATAAACTTCTACATGGTGGTACTAATATCAT 1796
1DLcasTaBradi2g14730      GTAAGGAACTTGCATGTTACATTTTTT---TAATCTTCTACATGGTGGTACTAATATCAT 1792
1BLcasTaBradi2g14730      GTAAGGAACTTGCATCTTACATTAAAAAA--AATCTTCTACATGGTGGTATGAATATCAT 1813
                          *************** *******        ** ****************  ********

1ALcasTaBradi2g14730      TATTTCCATGTTCTTTATTTATTTGCCAGGTGCTGGTAATTTCTGTTTGGTACATGTCAG 1856
1DLcasTaBradi2g14730      TATTTCCATGTTCTTTATTTATTTGCCAGGTGCTGGTAATTTCTGTTTGGTACATGTCAG 1852
1BLcasTaBradi2g14730      TATTTCCATGTTCTTTATTTATTTGCCAGGTGCTGGTAATTTCTGTTTGGTACATGTCAG 1873
                          ************************************************************
                                                      DDF4
1ALcasTaBradi2g14730      TCTGGTTCCGGTATTGAATGTTGTCGGTGAGCAGGTAAGTAAACTTCTCACTTCTCAGTC 1916
1DLcasTaBradi2g14730      TCTGGTTCCGGTATTGAATGTTGTCGGTGAGCAGGTAAGTAAACTTCTCATTTCTCAGTC 1912
1BLcasTaBradi2g14730      TCTGGTTCCGGTATTGAATGTTGTCGGTGAGCAGGTAAGTAAACTTCTTACTTCTCAGTC 1933
                          ************************************************ * *********

1ALcasTaBradi2g14730      AGTTCATAATGCCAGTCTTCGCTTTGCTAGTTGTGGCTTGGTGTTGTGACTAAGGCACTA 1976
1DLcasTaBradi2g14730      AGTTCATAATGCCAGTCTTCGCTTTGCTGATTGTGGCTTGGTGTTGTGACTAAGGCACTA 1972
1BLcasTaBradi2g14730      AATTCATAATGCCAGTCTTCCCTTTGCTGATTGTGGCTTGGTGTTGTGACTAAGGCACTA 1993
                          * ****************** *******  ******************************

1ALcasTaBradi2g14730      AGCATAACTAACATCATATTTAATATACTATGTTACGTATGGCTTGTTGTTATTGTAGAA 2036
1DLcasTaBradi2g14730      AGCATAACTAACATCATATTTAATATACTTTGTTACGTATGGCTTGCTGTTATTGTAGAA 2032
1BLcasTaBradi2g14730      AGCATAACTAACATCATATTTAATATACTTTGTTACGTATGGCTTGCTGTTATTGTAGAA 2053
                          ***************************** **************** *************

1ALcasTaBradi2g14730      AACTAAGCCAACTCAACACAGTGTACGTGGTCTGAGAGGACTTGGTCTCACGCCAAATAT 2096
1DLcasTaBradi2g14730      AACTAAGCCAACTCAACACAGTGTACGTGGTCTGAGAGGACTTGGTCTCACGCCAAATAT 2092
1BLcasTaBradi2g14730      AACCAAGCCAACTCAACACAGTGTACGTGGTCTGAGAGGACTTGGTCTCACGCCAAATAT 2113
                          *** ********************************************************

                                                                         DDR3
1ALcasTaBradi2g14730      GTTAGCTTGTCGCAGTACTAAGGTTAGTCAACGGACCTGTCCAACTTACCATGTGTTCTG 2156
1DLcasTaBradi2g14730      GCTAGCTTGTCGCAGTACTAAGGTTAGTCAATGGACCCGTCCAACTTACCATGT-CTCTG 2151
1BLcasTaBradi2g14730      GTTAGCTTGTCGCAGTACTAAGGTTAGTCAATGGACCTGTCCAACTTACCATGTGTTCTG 2173
                          * ***************************** ***** ****************  ****

1ALcasTaBradi2g14730      ACCCGTATTGATTTATTAACTTCGCATGCTTTATTGGTGACAGGAGCTAGAGGAAAATGT 2216
1DLcasTaBradi2g14730      ACCCGTATTGATTTGTTAACTTCTCATGCTTTATTGGTGACAGGAGCTAGAGGAAAATGT 2211
1BLcasTaBradi2g14730      ACCCGTATTGATTTATTAACTTCTCATGCTTTATTGGTGACAGGAGCTAGAGGAAAATGT 2233
                          ************** ******** ************************************

1ALcasTaBradi2g14730      GAAAGAAAAACTCTCCCAGTTTTGTCATGTGCCGGTATTGAAATTGTCCTTTTCTA-AAC 2275
1DLcasTaBradi2g14730      GAAAGAAAAACTCTCCCAGTTTTGTCATGTGCCGGTATTGAAATTGTCCTTTTCTACAAC 2271
1BLcasTaBradi2g14730      GAAGGAAAAACTCTCCCAGTTTTGTCATGTGCCGGTATTGAAATTGTCCTTTTCTACAAC 2293
                          *** **************************************************** ***

1ALcasTaBradi2g14730      GGATAATGTATATGTGCAGCTGATCGCTCTTGTTGATAATGAATTCTTTTGGTTGCAGGC 2335
1DLcasTaBradi2g14730      GGATAATGTGTATGTGCAGCTGATCGCTCTTGTTGATAATGAATTCTTTTGGTTGCAGGC 2331
1BLcasTaBradi2g14730      GGATAATATGTATGTGCAGCTGATCACTCTTGTTGATAATGGATTCTTTTGGTTGCAGGC 2353
                          ******* * * *************** *************** ******************

1ALcasTaBradi2g14730      CGCTAATATTTTCACCCTATATGATGTTTCGAACATTTGGCACATTCCTTTGCTGTTACG 2395
1DLcasTaBradi2g14730      TGCTAATATTTTCACTCTATATGATGTTTCGAACATTTGGCATATTCCTTTGCTGTTACG 2391
1BLcasTaBradi2g14730      CGCTAATATTTTCACCCTATATGATGTTTCGAACATTTGGCACATCCCTTTGCTGTTACG 2413
                           ************** ************************** ** **************

1ALcasTaBradi2g14730      GGTATAGCACATCTCATTATTTATGTATAAATGTATGTTTTCCCC--------ATGCACT 2447
1DLcasTaBradi2g14730      GGTATAGCGCATCTCATTATTTATGTATAAATGTACATCTTTCCC--------ATGCACT 2443
1BLcasTaBradi2g14730      GGTATAGCACATCTCATTATTTATGTATAAATGTATGTTTTTCCCCATGCACGATGTACT 2473
                          ******** **************************  * ** ***        *** ***

1ALcasTaBradi2g14730      ATATGATATTTTCATTTTCC------ATTTCAGGACCAGAAAGCACACAATGCTATCCTT 2501
1DLcasTaBradi2g14730      ATATGATATTTTCATTTTCCATTTCCATTTCAGGACCAGAAAGCACACAATGCTATTCTT 2503
1BLcasTaBradi2g14730      ATATGATATTTTCGTTTTCC------ATTTCAGGACCAGAAAGCACACAATGCTATTCTT 2527
                          ************* ******      ****************************** ***
                                                                        DDF5
1ALcasTaBradi2g14730      AAAGTTCTGAATCTTGAAAGGTTTGTTTTCATGTACCTTATTGTGATTTTCTTCCAAAGA 2561
1DLcasTaBradi2g14730      AAAGTTCTGAATCTTGAAAGGTTTGTTTTCATGTACCTTATTGAGGTTTTCTTCCAAAGA 2563
1BLcasTaBradi2g14730      AAAGTTCTGAATCTTGAAAGGTTTGTTTTCATGTACCTTATTGAGATTTTCTTCCAAAGA 2587
                          ******************************************* * **************
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1ALcasTaBradi2g14730      TGGCATGCTGACATGGTAT-CTGAATCCTCTTTCCCATGTTTGCAGTGTTGCCCAGGAGC 2620
1DLcasTaBradi2g14730      TGCCATGCTGACATGGTGTTCTGAATCTTCTTTCCCATGTTTGCAGCGTTGCCCAGGAGC 2623
1BLcasTaBradi2g14730      TGGCATGCTGACATGCTAT-CTGAATCTTCTTTCCCATGTTTGCAGCGTTGCTCAGGAGC 2646
                          ** ************ * * ******* ****************** ***** *******

1ALcasTaBradi2g14730      CGAAGTTGGATGAATGGGTGGCAAGGGCCACTTTATATGACACCCTACAGGATGAAGTTG 2680
1DLcasTaBradi2g14730      CGAAGTTGGATGAATGGGTGGCAAGGGCTACTTTATATGACACCCTACAGGATGAAGTTG 2683
1BLcasTaBradi2g14730      CGAAGTTGGAGGAATGGGTGGCAAGGGCTACTTTATATGACACCCTACAGGATGAAGTTG 2706
                          ********** ***************** *******************************

                                     DDR4
1ALcasTaBradi2g14730      GTTTCTGTTTGACCTTTGCAATTGTTTTATCTGTCTGGAAACCTTTACTTAGGGCCGCTT 2740
1DLcasTaBradi2g14730      GTTTCTGTTCGTCCTTTTCAATTGTTTTATCTGTCTGGAAACCTTTACTTAGGCCCAATT 2743
1BLcasTaBradi2g14730      GTTTCTGTTTGTCCTTTACAATTGTTTTATCTGTCTGGAAACCTTTACTTAGGCCCAATT 2766
                          ********* * ***** *********************************** **  **

1ALcasTaBradi2g14730      GTACTGTACTGTTGTTTCAGGTGAGGATTGCCATGGTTGGAAAGTACACTGGTCTGTCTG 2800
1DLcasTaBradi2g14730      ATACTGCACTGTTGTTTCAGGTGAGGATTGCCATGGTTGGAAAGTACACTGGTCTGTCTG 2803
1BLcasTaBradi2g14730      GTACCGCACTGTTGTTTCAGGTGAGGATTGCCATGGTTGGAAAGTACACTGGTCTGTCTG 2826
                           *** * *****************************************************

1ALcasTaBradi2g14730      ATTCGTACCTTTCTGTGTTAAAGGTGAGATGATCATTGTGGTCATTGGTTCAGTCTTGTT 2860
1DLcasTaBradi2g14730      ATTCGTACCTTTCTGTGTTAAAGGTGAGATGATCATTGTGGCCATTGTTTCAGTCTTGTT 2863
1BLcasTaBradi2g14730      ATTCGTACCTTTCTGTGTTAAAGGTGAGATGATCATTGTGGTAATTGTTTCAGTCTTGTT 2886
                          *****************************************  **** ************

1ALcasTaBradi2g14730      GTTAAATCTGTTTATTGTTGTCCAACATTTTTTTCTGCATTCTTTTGTAGGCACTTTTGC 2920
1DLcasTaBradi2g14730      GTTAAATCTGTTTATTGTTGTCCAACATTTTTTTCTGCATTCTTTTGTAGGCACTTTTGC 2923
1BLcasTaBradi2g14730      GTTAAATCTCGTTATTACTGTCCAACATTTTTTTCTGCATTTTTTTGCAGGCTCTTTTGC 2946
                          *********  *****  ********************** ***** **** *******

1ALcasTaBradi2g14730      ATGCTTCTGTCTCTTGCCACAAAAAACTTGTTGTAGATTGGGTTGCTTCCACTGATCTTG 2980
1DLcasTaBradi2g14730      ATGCTTCTGTCTCTTGCCACAAAAAACTTGTTGTAGATTGGGTTGCTTCCACTGATCTTG 2983
1BLcasTaBradi2g14730      ATGCTTCTGTCTCTTGCCGCAAAAAACTTGTTGTAGATTGGGTTGCTTCCACTGATCTTG 3006
                          ****************** *****************************************

1ALcasTaBradi2g14730      AGGATTCAACTGCTTCTGAGGTTTGAACTACACATAGTATGCAGTTACTTTAGTCTTT-- 3038
1DLcasTaBradi2g14730      AGGATTCAACTGCTTCTGAGGTTTGAACTACACATAGTATGCAGTTACTTTAGTCTTT-- 3041
1BLcasTaBradi2g14730      AGGATTCAACTGCCTCTGAGGTTTGAACTACTCGTAGTATGTAGTTTCCTTAGTCTTTAA 3066
                          ************* ***************** * ******* **** * *********

1ALcasTaBradi2g14730      TCTTTACTGCATTTCCTCACCTGTCCGTGGTTAAATTTTATAGGCGCCTGATGCTTACAA 3098
1DLcasTaBradi2g14730      TCTTTACTGCATTTCCTCACCTGTCCGTGGTTAAATTTTATAGGCGCCTGATGCTTACAA 3101
1BLcasTaBradi2g14730      CCTGTACTGCATTTCCTTACCTGTCCGTGGTTAAATTTTATAGGCACCTGATGCTTACAA 3126
                           ** ************* *************************** **************

1ALcasTaBradi2g14730      AGCAGCATGGACTTTATTGAAGGT-AGGAGTTTATGCCCTTAAATACTGTCAAATTTACA 3157
1DLcasTaBradi2g14730      AGCAGCATGGACTTTATTGAAGGTGAGGAGTTTATGCCCTTAAATACTGTCAAATTTACA 3161
1BLcasTaBradi2g14730      TGCAGCGTGGAGTTTATTGAAGGTGACGAGTATATGCCCTTAAATGTTGCTGAATTTACA 3186
                           ***** **** ************ * **** *************  **   ********

                            DDF6
1ALcasTaBradi2g14730      ATTT-GTACGTGTCTGACAAATTTTCATCCCAGGGCGCTGATGGCGTTTTAGTGCCCGGT 3216
1DLcasTaBradi2g14730      ATTT-GTACCTGTCTGACAGATTTTCATTCCAGGGCGCTGATGGCGTTTTAGTGCCCGGT 3220
1BLcasTaBradi2g14730      ATTTTGTACTTGTCTGACAATTTCTTACTCCAGGGTGCTGATGGCATTTTAGTGCCTGGT 3246
                          **** **** *********  ** * *  ****** ********* ********** ***

1ALcasTaBradi2g14730      GGCTTTGGAGACAGAGGTGTTAAAGGGAAAATGATGGCTGCTAAGTATGCCCGTGAAAAC 3276
1DLcasTaBradi2g14730      GGCTTTGGAGACAGAGGTGTTAAAGGGAAAATGATGGCTGCTAAGTATGCCCGTGAAAAC 3280
1BLcasTaBradi2g14730      GGCTTTGGGGACAGAGGTGTTAAAGGGAAAATGATGGCTGCTAAGTATGCCCGTGAAAAC 3306
                          ******** ***************************************************

                                             DDR5
1ALcasTaBradi2g14730      AATGTCCCCTATCTTGGCATATGCCTTGGCATGCAGCTTGCTGTTGTAGAGTTTGCACGC 3336
1DLcasTaBradi2g14730      AATGTCCCCTATCTTGGTATATGCCTTGGCATGCAGCTTGCTGTTGTAGAGTTTGCGCGC 3340
1BLcasTaBradi2g14730      AATGTCCCCTATCTTGGCATATGCCTTGGGATGCAGCTTGCTGTTGTAGAGTTTGCGCGC 3366
                          ***************** *********** ************************** ***

1ALcasTaBradi2g14730      CATGTTATGAAATTCCCTGATGCGGACAGCACAGAATTTAATCCCAATACGAAGACCCCA 3396
1DLcasTaBradi2g14730      CATGTTATGAAATTCCCTGATGCGGACAGCACAGAATTTAATCCCAATACGAAGACCCCA 3400
1BLcasTaBradi2g14730      CATGTCATGAAATTCCCTGATGCGGACAGCACAGAATTTAATCCCAATACGAAGACCCCA 3426
                          ***** ******************************************************

1ALcasTaBradi2g14730      TGTGTTATTTTTATGCCAGAGGTAATCTTCAAGCACACACACACAACACACAACCTCCAC 3456
1DLcasTaBradi2g14730      TGTGTTATTTTTATGCCAGAGGTAATCTTCAAGCACACACACACAACACACAACCTCCAC 3460
1BLcasTaBradi2g14730      TGTGTTATTTTTATGCCAGAGGTAATCTTCAAGCGCACACACA--ACACACCACCTCCAC 3484
                          ********************************** ********  ****** ********
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1ALcasTaBradi2g14730        CCATAACTTCAACAACTTGCAGGGGAAATTATTTATCTGCAGACCTGTGGCATTTTTTCT 3516
1DLcasTaBradi2g14730        CCATAACTTTAACAACTTGCAGGGGAAATTATTTATCTGCAGACCTGTGGCATTTTTTCT 3520
1BLcasTaBradi2g14730        CCATAACCTTA----CTTGCAGGGGAAACTATTTATCTGCGGACCTGTGGCATTTTTTCT 3540
                            ******* * *    ************* *********** *******************

1ALcasTaBradi2g14730        GTATACAACGTATTGCATTTAGTTTTATTTGAAACTGGAAACCGCCTT-GAGCTCACAT 3575
1DLcasTaBradi2g14730        GTATACAACGTATTGCATTTAGTTTTATTTGAAACTGGAAACTGCCTT-GAGCTCACAT 3579
1BLcasTaBradi2g14730        GTATCGAACATATTGCATTTAGTTTTATTTGAAAGTGGAAACCGCCTTCAAGCTCACAT 3600
                            ****  *** ************************ ******* *****  *********

1ALcasTaBradi2g14730        ATGGTTCCTTACAATTTAATAATATTT---TTTTAGGGTTCAAAAACACATATGGGTGGG 3632
1DLcasTaBradi2g14730        ATGGTTCCTTACAATTTATTAATATTT---TTTTAGGGTTCAAAAACACATATGGGTGGG 3636
1BLcasTaBradi2g14730        ATGGTTTCTTACAATTTAATAATATTTCTTTTTTAGGGTTCAAAAACACATATGGGTGGG 3660
                            ****** *********** ********   ******************************

1ALcasTaBradi2g14730        ACCATGCGCCTTGGATCAAGGAGAACATTTTTCAAGGTTACTGACTGCAAATCTGCCAAG 3692
1DLcasTaBradi2g14730        ACCATGCGCCTTGGATCAAGGAGAACATTTTTCAAGGTTACTGACTGCAAATCCGCCAAG 3696
1BLcasTaBradi2g14730        ACCATGCGCCTTGGATCAAGGAGAACATTTTTCAAGGTTACTGACTGCAAATCTGCCAAG 3720
                            ***************************************************** ******

1ALcasTaBradi2g14730        CTGTGAGTGCAGTGCATGTTCTCTGTTATAGTTGTCTGGGTTGACACTACT--CC---TT 3747
1DLcasTaBradi2g14730        CTGTGAGTGCAGTGCATGTTCTCTGTTATAGTTGTCTGGGTTGACACTACT--CC---TT 3751
1BLcasTaBradi2g14730        CTGTGAGTGCAGTGCATGTTCTCTGTCATAGTTATCTGTGTTGGCGCTACTGACCATGTT 3780
                            ************************** ****** **** **** * *****  **   **

1ALcasTaBradi2g14730        GCCCACTCATGAGTTTTGTTTTGATCACTCAGCTATGGTGATGTCAACTATGTAGATGAG 3807
1DLcasTaBradi2g14730        GCCCACTCATGAGTTTTGTTTTGATCACTCAGCTATGGTGATGTCAACTACGTAGATGAG 3811
1BLcasTaBradi2g14730        GCCTACTCATTAGTTTTGTTTTGTTCACTTAGCTATGGTGGTGTCAACTTCGTAGATGAG 3840
                            *** ****** ************ ***** ********** ********  *********

1ALcasTaBradi2g14730        AGGCATCGGCACAGATATGAGGTCTGTAATAATCTTTGCTCAGTCATATCGATGTCTAAA 3867
1DLcasTaBradi2g14730        AGGCATCGGCACAGATATGAGGTCTGTAATAATCTTTGCTCAGTCATATCGATGTATAAA 3871
1BLcasTaBradi2g14730        AGGCATCGTCACAGATATGAGGTCTGTA-TAATATTTGCTCAGCCACATCGATGCATAAA 3899
                            ******** ******************* **** ********* ** *******  ****

1ALcasTaBradi2g14730        TGCTTTGGATGCGTTTAACATGGTCTTTGTTCCCTTTTTGACCAC-TTCATTGTTTTGTT 3926
1DLcasTaBradi2g14730        TGCTTTGGATGCGTTTAACATGGTCTTTGTTCCCTTTTTGACCACATTCATTGTTTTGTT 3931
1BLcasTaBradi2g14730        TGCTTTGGATGCTTTTGA-----------TCCCTTTTCTGACCGCATTCATTGTTTTGTT 3948
                            ************ *** *           * ** *** ***** * **************

1ALcasTaBradi2g14730        TTAAAATGGGTGTCTGCAGGTAAATCCTGATATGGTGCCAGCATTTGAAAATGCTGGACT 3986
1DLcasTaBradi2g14730        TTAAAATGGGTGTCTGCAGGTAAATCCTGATATGGTGCCAGCATTTGAAAATGCTGGACT 3991
1BLcasTaBradi2g14730        TTAAAAATGATGTCTGCAGGTAAATCCTGATATGGTGCCAGCATTTGAAAATGCCGGACT 4008
                            ******  * ******************************************** *****

1ALcasTaBradi2g14730        TCAGTTTGTTGGCAAGGACGAGACTGGACAGAGAATGGAGGTATGTATAATAACAGAACC 4046
1DLcasTaBradi2g14730        TCAGTTTGTTGGCAAGGACGAGACTGGACAGAGAATGGAGGTATGTATAATAACAGAACC 4051
1BLcasTaBradi2g14730        TCAGTTTGTTGGCAAGGACGAGACTGGACAGAGAATGGAGGTATGTATAATAACAAAACC 4068
                            ******************************************************* ****

1ALcasTaBradi2g14730        AAGAATCTTACTTGTGCTTCACCATGCTAGTTGATTCACCATTATAACTACCATTTTTCT 4106
1DLcasTaBradi2g14730        AAGAATCTTACTTGTGCTTCACCATGCTAGTTGATTCACCATTATAACTACTATTTTTCT 4111
1BLcasTaBradi2g14730        AATAACCTTGCCTGTGCTTCACCATGCTAGTTGATTCACCATTATAACTACTATTTTTCT 4128
                            ** ** *** * *************************************** ********

                                                                 Common BS00009377
1ALcasTaBradi2g14730        AGATCATTGAAATACCTGATCACCGGTTCTTTGTCGGCGTCCAATTCCATCCGGAGTTCA 4166
1DLcasTaBradi2g14730        AGATCATTGAAATACCTGATCACCGGTTCTTCGTCGGCGTCCAATTCCATCCAGAGTTCA 4171
1BLcasTaBradi2g14730        AGATCATTGAAATACCTGATCACCGGTTCTTCGTCGGTGTCCAATTCCATCCGGAGTTCA 4188
                            ******************************* ***** ************** *******
                            Fam BS00009377
1ALcasTaBradi2g14730        AGTCAACGCCTTCAAAACCTTCACCTCCATTTGTCGGTAAGCTACTCGACACTTACTGGA 4226
1DLcasTaBradi2g14730        AGTCAACGCCTTCAAAACCTTCACCTCCATTTGTCGGTAAGCTACTTGACACTTACTGGA 4231
1BLcasTaBradi2g14730        AGTCGACGCCTTCAAAACCTTCACCTCCATTTGTCGGTAAGCTACTCGACTCTTACTGGA 4248
                            **** ***************************************** *** *********

1ALcasTaBradi2g14730        AACTATCTCGGTCCGGTGGGGAAGCTACAGCAAACACTGACAATCTGCTCAAACATCCAC 4286
1DLcasTaBradi2g14730        AACTATCTTGGTCCAGTGGG-AAGCTACAGCAAACACTGACAATCTGCTCAAACATCCAC 4290
1BLcasTaBradi2g14730        AATTATCTTGGTTCGGTGTG-AAGCTACAGCAAACACTGACAATCTGCTCAACCATCCAC 4307
                            ** ***** *** * *** * ******************************* *******

                                                                          DDF7
1ALcasTaBradi2g14730        ACAT-GCCTG--CAGGACTAATCGCTGCAGCATGCGGACAACTGGACCAGGTGCTGCAGG 4343
1DLcasTaBradi2g14730        ACGTTGCCTA--CAGGACTAATCGCCGCAGCGTGTGGGCAGCTGGATCAGGTGCTGCAGG 4348
1BLcasTaBradi2g14730        ACTTTGCCTATACAGGACTAATCGCCGCAGCATGCGGGCAACTGGACCAGGTGCTGCAGG 4367
                            ** * ****    ************* ***** ** ** ** ***** *************
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1ALcasTaBradi2g14730      ACAGCTGCAATGGCCATGTGGTTGCGGCTAAACACAAGCTCGGCGACAGCTTCTCGACAC 4403
1DLcasTaBradi2g14730      ACAGCTGCAATGGCCATGTGGTTGCGGCTAAACACAAGCTCGGTGACAGCTCCTCAACAC 4408
1BLcasTaBradi2g14730      ACAGCTGCAACGGCCATGTGGTTGCGGCTAAACACAAGCTCGGCGACAGCTCCTCGACGC 4427
                          ********** ******************************** ******* *** ** *

                                                      Exon21
1ALcasTaBradi2g14730      CCCTAGTACACCAGAACGGGCACGCGCAGAAGCAAGCCAATGGTGGTGTAGCAAATGGAA 4463
1DLcasTaBradi2g14730      CCCTAGTACACCAGAACGGGCACGCGCAGAAGCAAGCCAATGGTGGTGTAGCAAATGGAA 4468
1BLcasTaBradi2g14730      CCCTAGTACACCAGAACGGGCACGCGCAGAAGCAAGCCAACGGTGGTGTAGCAAATGGAA 4487
                          ***************************************** ******************
                                                                         DDR6
1ALcasTaBradi2g14730      CCTGCCATGCCAACGGCAATGGCAGTACCCATGGTTAGCACGCC--GCGGGTTTCGCCAA 4521
1DLcasTaBradi2g14730      CCTGCCATGCCAACGGCAATGGCAGTACCCATGGTTAGCGTACC--GTCGGTTTCGCCAA 4526
1BLcasTaBradi2g14730      CCTGCCATGCCAACGGCAACGGCAGTACCCATGGTTAGCGCACCCCGTCGGTTTCGCCAA 4547
                          ******************* *******************    **   *  ***********

1ALcasTaBradi2g14730      GGGGATCATCTCGCCTGTCTTCTGTGGTCCTCATCGTCCCGTCGACTGCGACAA-CGGCT 4580
1DLcasTaBradi2g14730      GGGGATCATCTCGCCTGTCTTCTGTGGTCCTCATCGTCCCGTCGACTGCGACAAACGGCT 4586
1BLcasTaBradi2g14730      GGGGATCATCTCGCCTGTCTTCTGTGGTCCTCATCGTCCCGTCGACTGCGACAA-CGGCT 4606
                          ****************************************************** *****

1ALcasTaBradi2g14730      GAGCAACTTATCAGCAGGGCCGGCGGCCCTACAAGAAGGGCGACGGTCAGAGCCTAGGAA 4640
1DLcasTaBradi2g14730      GAGCAACTTATCAGCAGGGCCGGCGGCCCTACAAGAAGGGCGACGGTCAGAGCCTAGGAA 4646
1BLcasTaBradi2g14730      GAGCAACTTATCAGCAGGGCCGGCGGCCCTACAAGAAGGGCGACGGTCAGAGCCTAGGAA 4666
                          ************************************************************

1ALcasTaBradi2g14730      AAAAAATAGAGGACTAGCATTTTATACA-TGAGCACCTTTGTATAGTATTAGGTTCTGTG 4699
1DLcasTaBradi2g14730      AAAAA-TAGAGGACTAGCATTTTATACA-TGAGCACCTT-GTATAGTATTAGGTTCTGTG 4703
1BLcasTaBradi2g14730      AAAAAATAGAGGACTAGCATTTCATACAATGAGCACCTT-GTATAGTATTAGGTTCTGTG 4725
                          ***** **************** ***** ********** ********************

1ALcasTaBradi2g14730      CTGATATGCAGCCGAATGTTTTTGATCCTTGCGTGTGGACTAAATAATAAGCTAGAC-AT 4758
1DLcasTaBradi2g14730      CTGATATGCAGCCGAATGTTTTTGATCCTTGCGTCTGGACTAAATAATAAGGTAGACCAT 4763
1BLcasTaBradi2g14730      CTGATATGCAGCCGAATGTTTTTGATCCTTGCGTATGGACTAAATAATAAGCTAGAC-AT 4784
                          ********************************** **************** ***** **
                                           DDR7
1ALcasTaBradi2g14730      CTTAGAAGGTTTTAGT---TGTCGAGACAGAGCCCGGGTGGTT-GGGTGTGTACTTTGAT 4814
1DLcasTaBradi2g14730      CTTAGAAAGTCTTAGTC-TTGTCGAGACAGAGCCTGGGTTGTT-GGGTGTGTACTTTGAT 4821
1BLcasTaBradi2g14730      CTTAGAAAGTTTTAGTTGTTGTCGAGACAGAGCCTGGGTGGTTTGGGTGTGTACTTTGAT 4844
                          ******* ** *****   *************** **** *** ****************

1ALcasTaBradi2g14730      TTCCTTTAAGAAACTTATGGTTACTGTTTCTTCCCAGTTAATTCCAGTTTCTTTCTCTGT 4874
1DLcasTaBradi2g14730      TTCCTTTAAGAAACTTATGGTTACTGTTTCTTCCCAGTTAATTCCAGTTTCTTTCTCTGT 4881
1BLcasTaBradi2g14730      TTCCTTTAAGAAACTTATGGTTACTGTTTCTTCCCAGTTAAATCCAGTTTCTTTCTCTGT 4904
                          ****************************************** *****************

1ALcasTaBradi2g14730      TTGTAGTTTGTAGAGCTAACTAAGATAAGCTTCTTTGCATTCAAATTAAAAGTATTTGGG 4934
1DLcasTaBradi2g14730      TTATAGTTTGTAGAGCTAACTAAGATAAGCTTCTTTGCATTCAAATTAAAAGTATTTGGG 4941
1BLcasTaBradi2g14730      TTGTAGTTTGTAGAGCTAACTAAGATAAGCTTCTTTGCATTCAAATTAGAAGTATTTGGG 4964
                          ** ********************************************* ***********
                                  DDR8
1ALcasTaBradi2g14730      TCAGTCACATGGCAGTACAGCACTTTTGTTGATTGGAATGCTTTAACCATATTTATGTTG 4994
1DLcasTaBradi2g14730      TCAATCACATGGCAGTACAGCACTTTTGTTGATTGGAATGCTTTAACCATATTTATGTTG 5001
1BLcasTaBradi2g14730      TCAGTCACATGGCAGTACAGCACTTTT------TAAGTCGTTTCAA---TATGTTTCTTG 5015
                          *** ***********************      *     * ** **   *** * * ***

1ALcasTaBradi2g14730      ATCAGATTATGTCGTTTCAATAT------------------AACGGTTTTACATGAAAAG 5036
1DLcasTaBradi2g14730      ATCAGATTATGTCGTTTCAATATGTTTCTTGATATTTTCATAACGGTTTTACATGAAAAG 5061
1BLcasTaBradi2g14730      AT---ATT-------TTCA---------------------TAACAGTTTTACATAAAAAG 5044
                          **   ***       ****                      *** ********* *****

1ALcasTaBradi2g14730      AACATCCAAGCCAAAATATTCTTATAATAGCATAATTCACTCGAGCATTATTAATCTATG 5096
1DLcasTaBradi2g14730      AATATCCAAGCCAAAATATTCTTATAATAGCATAATTCACTCGAGCATTATTAATCTATG 5121
1BLcasTaBradi2g14730      AACATCCAAGCCAAAATATTCTTATAATAGCATAATTTACTCGAGCATTATTAATCTACT 5104
                          ** ********************************** ********************
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Appendix 4.9 TaBradi2g14190

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1BLcasTaBRADI2G14190      ------------GGAG---GCGGAGCCGGGAGATCCATATCGCTGGCCGCCTCCAGGGCC 45
1DLcasTaBRADI2G14190      AAAGGAGTAGGAGGCG---GCGGAGCCGGGAGATCCATATCGCTGGCCGCCTCCAGGGCC 2277
1ALcasTaBRADI2G14190      AAAGGAGGAGGAGGAGCAGGCGGATCCGGGAGATCCATATCGCTGGCCGCCTCCAGGGCC 5684
                                      ** *   ***** ***********************************
                                casTaBradi2g14190_DF1  Exon2
1BLcasTaBRADI2G14190      AAGCTCGCCGCAGCCACC---------AAGAAAGCTACTACTACTAGTACAGCCGG-AGG 95
1DLcasTaBRADI2G14190      AAGCTCGCCGCGGCCACCGCCAGCGCCAAGAAAGCAGCTGCTACTA---CAGCTAGCGGG 2334
1ALcasTaBRADI2G14190      AAGCTCGCCGCCGCCACCGCCGCCGCCAAGAAAGCCGCTACTAC------AGCTAGCGGC 5738
                          *********** ******         ******** ** ****      ***  *  *
                                                            casTaBradi2g14190_ngsF1
1BLcasTaBRADI2G14190      CGGGC--GGGGCAAGGGCAAGGCGGCCAAGAAGGTCTTCTCCCTCACCGGCCAGAAGTTC 153
1DLcasTaBRADI2G14190      CGGGGCAAGGGCAAGGGCAAGGCCGCCAAGAAGGTCTTCTCCCTCACCGGCCAGAAGTTC 2394
1ALcasTaBRADI2G14190      CGGGGCAAGGCCAAGGCCAAGG---CCAAGAAGGTCTTCTCCCTCACCGGCCAGAAGTTC 5795
                          ****    ** ***** *****   ***********************************

1BLcasTaBRADI2G14190      GAAACACCAGAGGAGGT-----------CTCTCTCAAATTCTTCTTTCAT-CATACTCCT 201
1DLcasTaBRADI2G14190      GATATCCCAGAGGAGGTGA---------TTCCCTCAAATTCTTCTTTCATGTATGCTTTC 2445
1ALcasTaBRADI2G14190      GACACCCCAGAGGAGGTACAATTTCTTCTTTCATCATACTTATCATACTTGTATGCTTCC 5855
                          ** *  ***********            *   *** * *  ** * * *  ** **

1BLcasTaBRADI2G14190      ACTTGTAGTATGTATCTCATCTG-------ATCTGCACAAGA-AAATTCTCTACTGATTT 253
1DLcasTaBRADI2G14190      AGTT----CAAGCATCTGATTTGGGAACC-ATTTTTGCAATC-AATTTCTCT-------T 2492
1ALcasTaBRADI2G14190      AGTT----CAAGCATCTGATTTGGGAACCCTTTTTTGCAATGGAATTTGGCT-------T 5904
                          * **     * * **** ** **        * *   ***   ** **  **       *
                                                            Exon3
1BLcasTaBRADI2G14190      GATTTCACTCGCAGAGGGAGCCCCTGAGGATCTTCTATCAATCGCTCTCCAACCAGATCC 313
1DLcasTaBRADI2G14190      GGCTGGGCTGGCAGAGGGAGCCCCTTCGGATCTTCTACGAATCGCTCTCCAAGCAGATCC 2552
1ALcasTaBRADI2G14190      TGCTTGGCTGCCAGAGGGAGCCCCTGAGGATCTTCTACGAATCGCTCTCCAAGCAGATCC 5964
                             *   **  **************  **********  ************* *******
                                       casTaBradi2g14190_DF2
1BLcasTaBRADI2G14190      CATCCAGCGACATGGCCGAATTCTGGTACCTACCCACCCCACC----------------- 356
1DLcasTaBRADI2G14190      CATCCAGCGACATGGCCGAATTCTGGTACCTACCAACCCCATCTCACCTCTGCTCTTCTC 2612
1ALcasTaBRADI2G14190      CATCCAGCGACATGGCCGAATTCTGGTACGTCTCTGCCTCTGCTC----------TCCTC 6014
                          ***************************** *  *  ** *  *

1BLcasTaBRADI2G14190      ---TCTGCTCCACCAATTGCTCACCTGTTACTA--TACTAGTGCTTGCTTGA----CCAC 407
1DLcasTaBRADI2G14190      TGCTCTGCTCCACCAATTAATCACCACTTACTACTTACTAGTGCTTGCTTGCTTGTCCAC 2672
1ALcasTaBRADI2G14190      TGCTCTGCTCCACCAATTAATCGCCACTTACTGC-------TGCTTGCCCACAAG-TTAC 6066
                             ***************  ** **  *****         *******          **

1BLcasTaBRADI2G14190      AAGT---------------------------TACTAGTGCTAGTCTGATC---CATCCAT 437
1DLcasTaBRADI2G14190      AAGTCAAGTTATCCCCACCCAGTTACTCAGTTACTAGGACTGTTCTCATC---GATGCAT 2729
1ALcasTaBRADI2G14190      TAGTAGAGTAGGCTGCAATCC-CAACCCAGTTACTAGTAGAGTACTAGTCTCTGATTGAT 6125
                           ***                           ******       **  **    **  **

1BLcasTaBRADI2G14190      CCATTGATTTCTCTTCTCTGAATGTCACTCAA---TCTAGATACGTCCATTTTCGAGACA 494
1DLcasTaBRADI2G14190      CCATTGATTTCTCT-----GAATGTCACTCAAATCCTTAGCTAGCTTCCCTCCC------ 2778
1ALcasTaBRADI2G14190      CCATTGATTTCTCT-----GAATGTCACTCAAATCCTTCCTTAGCT--CTTCCC------ 6172
                          **************     *************     *   **  *    *  *

1BLcasTaBRADI2G14190      AGTAATTTCGAACGGAGGCACATC---TACAGTTTGCGACCTAATTACACTAGTAGTAGT 551
1DLcasTaBRADI2G14190      ------TCCCTGCA----CACACC---TA------GCTACCTAATTACACTAGTGGTC-- 2817
1ALcasTaBRADI2G14190      ------TCCCTGCA----CACATCACGTATA----GCTACCTAATTACTACACTAGCA-- 6216
                                * *   *     **** *   **      ** **********   * * *

1BLcasTaBRADI2G14190      ATTCACAGACAACTTCACTCTCAAACTCTGAATTACACCTCCATAGT---TCACACACAC 608
1DLcasTaBRADI2G14190      -TTCACAAACAACTTCACTCT--------GAATTACCCCTCCCTCAT---TCACACACAC 2865
1ALcasTaBRADI2G14190      -TTCACAAACAACTTCACTCTCAAACTCTCAATTATCCCTCCCTGATGATTCACACACAC 6275
                           ****** *************         *****  ***** *  *   **********

1BLcasTaBRADI2G14190      -----------TT-GAAAAATGTATCCTCTTCCAAATTTACTACTCCATCAATATTATAC 656
1DLcasTaBRADI2G14190      -----------TTCAAAAAAATGTATCCTCTTCCAAATTTACTACTCCA------------ 2902
1ALcasTaBRADI2G14190      ACACACACACACTTCAAAAATGTACCCTCTTCCAAATTTACTAC---------------- 6319
                                      *  ********* *******************

1BLcasTaBRADI2G14190      TGCTGCTGCAGACTTCCCTATACTGCTACTCCACCAATATTTTACTACAGCAACAACAGT 716
1DLcasTaBRADI2G14190      ---------------------------------CCAATATTTTACTACAGCAACATCATT 2929
1ALcasTaBRADI2G14190      ------------------------------------GTATACTGCTGCCG-AGTACTACT 6342
                                                               ***  * ** * *  *  * *
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BLcasTaBRADI2G14190        CGGACCTCACCTCAAGGGGTTACACACAGAATCACCTACTAGTAGT---TTACTGCAGCA 773
1DLcasTaBRADI2G14190        CAGGCCTGACCTCACGGACGGGCTTACAGAATCACCTACTACTAGTTTTTTACTGCAGCA 2989
1ALcasTaBRADI2G14190        ---ACTCCACTCCACCAATAT-TTTACTAAAGCAACAAC----AGT-------CACACCT 6387
                                *   **  **           **  **  **  *  **    ***         **  *

1BLcasTaBRADI2G14190        ATATGTATGTTATACCACCACACCATTGCTCTGCAATGTATGTATGTATGTATGTATGTA 833
1DLcasTaBRADI2G14190        ATATGT----TATACCACCACACCATTGCTCTGCAATGTATGTATGTATGTATGTG---- 3041
1ALcasTaBRADI2G14190        GTATGTA---TGTAT----GTA----TG-TATGTA-TGTATGTATGTATGTATGTG---- 6430
                             *****    * **       *    ** * ** * *******************

                                           casTaBradi2g14190_DF3
1BLcasTaBRADI2G14190        TATATGTGTGTATGTAATAATACTTACCTGACAGACACAACACACACACACACACATCTT 893
1DLcasTaBRADI2G14190        -------------------ATACTTATCTGACAGACACGACATACATAAA---ACCTCTT 3079
1ALcasTaBRADI2G14190        -------------------ATTCTTACCTGACAGACACAACATACACACA------TATT 6465
                                               ** **** *********** *** *** * *      * **

                                 Exon4                  casTaBradi2g14190_ngsR1
1BLcasTaBRADI2G14190        -GCAGGCTAATGGAGCACGGCCTGTTATCTCCGGAGAGAGCCAAGAAAGCCTACGACAGG 952
1DLcasTaBRADI2G14190        CGCAGGTTAATGGAGCATGGGCTGTTATCTCCGGAGAGAGCCAAGAAAGCCTATGACAGA 3139
1ALcasTaBRADI2G14190        -GCAGGTTAATGGAGCATGGGCTGTTATCTCCGGAGAGAGCCAAGAAAGCCTATGACAGA 6524
                             ***** ********** ** ******************************** *****

                                                                  casTaBradi2g14190_DR1
1BLcasTaBRADI2G14190        AAGCTCAAACGGCAGCAGCAGATCAAATCAGGGATCCCCATCAAGTCGTCAAATTCCACC 1012
1DLcasTaBRADI2G14190        AAGCTCAAACGGCAGCAGCAGATCAAATCAGGGACCCCGATCAAGTCGTCAAATTCCAAC 3199
1ALcasTaBRADI2G14190        AAGCTCAAACGGCAGCAGCAGATCAAATCAGGGACCCCCATCAAGTCGCCAAATTCCACC 6584
                            ********************************** *** ********* ********* *

                casTaBradi2g14190_DF4                    casTaBradi2g14190_DF5
1BLcasTaBRADI2G14190        ACTGTCAACAAGCACAATAACAACAATAAACCTGCAGAGAGCTGGAAGAAACCTGTACCA 1072
1DLcasTaBRADI2G14190        ACTGTCAGCAAACACAACAACAACAA---ACCTGCAGAGACCTGGAAGAAACCGGCACCA 3256
1ALcasTaBRADI2G14190        ACTGTCACCAAACACAA------------ACCTGCAGAGAGCTGGAAGAAACCGGTACCA 6632
                            ******* *** *****            *********** ************ * ****

                                                           BS00003725 A putative KASPar SNP
1BLcasTaBRADI2G14190        GTGGTTTCTTCTTCTTCCACAGCGCGTCACAACACAGATCATTCCGCCGGCAAGGCCAAG 1132
1DLcasTaBRADI2G14190        GTGGTTTCTTCTTCTTCCACAGCGCGTCACAACACGGATCATACCGCCGCCAAGGCCAAG 3316
1ALcasTaBRADI2G14190        CTGGTTTCTTCTTCTTCCACAGCGCGTCACAACACAGATCATTCCGCCGCCAAGGCCAAG 6692
                             ********************************** ****** ****** **********

1BLcasTaBRADI2G14190        AGAAGAGTCGAGTACAGCAGCGACGACGACGACGACGACAAAGAATTCATTGTCAAGCTC 1192
1DLcasTaBRADI2G14190        AGAAGAGTCGAGTACAGCAGCGACGACGACGAC------AAAGAATTCATTGTCAAGCTC 3370
1ALcasTaBRADI2G14190        AGAAGAGTTGAGTACAGCAGCGACGATGACCACGACGACAAAGAATTCGTTGTCAAGCTC 6752
                            ******** ***************** *** **      ********* ***********

                                                CasTaBradi2g14190_DR2
1BLcasTaBRADI2G14190        AAGAGACCCAATTTCAACTCCAACTCCAATTCCACTTCCAGGGGTGGCTGAACTGCTCCT 1252
1DLcasTaBRADI2G14190        AAGAGACCCAATTTCAACTCCAACTCCAACTCCAGTTCCAGGGGTGGCTGAACTGCTCCT 3430
1ALcasTaBRADI2G14190        AAGAGACCCAATTTCAACTCCAACTCCAATTCCAATTCCAGGGGTGGCTGAACAACTCCT 6812
                            ***************************** **** ******************  *****

1BLcasTaBRADI2G14190        CAAC-TTGATGAATGGGCCTGTCTGTCTGTTTGTTTGTTTCTTTCCGGCTA-GCACATAT 1310
1DLcasTaBRADI2G14190        CAAC-TTGATGAATGGGCCTGTCTGTCTGTCTGTTTGTTTCTTTCCAGCTA-GCACATAT 3488
1ALcasTaBRADI2G14190        CAACATTGATGAATGGGCCCGTCTGTCT----GTTTGTTTCTTTCCAGCTAAGCACATAT 6868
                            **** ************** ********    ************** **** ********

1BLcasTaBRADI2G14190        CCTACTACATGGATCATCAAGCAATACCATCTCTGATTCAGATTCAGATCACTAACTCGA 1370
1DLcasTaBRADI2G14190        CCTACTACATGGATCA---AGCAATACCGTCTCAGATTCAGATTCAGATCACTAACTCGA 3545
1ALcasTaBRADI2G14190        CCTACTACATGGATCA---AGCAATACCATCTCAGATTCAGACTCAGATCACTAACTCGA 6925
                            ****************   ********* **** ******** *****************

1BLcasTaBRADI2G14190        CTTT----TATTTATTTTGTTTTTCACCCTACAAGTACAACAACGAATTGGCTCTTCTG- 1425
1DLcasTaBRADI2G14190        CTTTTTTATATTTATTTTGTTTTTCACCCTACAAGTACAACAATGAATTGGCTCTTCTGA 3605
1ALcasTaBRADI2G14190        CTTT----TATTTATTTTGTTTTTCACCCTACAAGTACAACAATGAATTGGCTCTTCTGA 6981
                            ****    *********************************** ***************

                                                          casTaBradi2g14190_DR3
1BLcasTaBRADI2G14190        -TTCTGAC-TACATATATATGTCTGTCTGTGTATTTGATTTCAGAGACAAGATAGAC--- 1480
1DLcasTaBRADI2G14190        CTACATACATATATATATATGTCTGTCTGTGTATTTCAGTTCAGAGAGAAGATATAC--- 3662
1ALcasTaBRADI2G14190        CTACATAC----ATATATATGCCTGTCTGTGTATTTGAGTTCAGAGACAAGATAGACATT 7037
                             * *  **    ********* ************** * ******** ****** **

                                   casTaBradi2g14190_DR4
1BLcasTaBRADI2G14190        C-TTACCTTTTTGTTGTAAGCAATGCCTATATTGTGAAAATAATGAATGAATGAATAAAT 1539
1DLcasTaBRADI2G14190        CATTACATTTTTGTTGTAAGCAATGCCCG----GTGAAAATAATGAGTGAAT----AAAT 3714
1ALcasTaBRADI2G14190        TACTACCTTTTTGTTGTAAGCAATGCCTG----GTGAAAATAATGAATGAAT----AAAT 7089
                               *** ********************      ************* *****    ****
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1BLcasTaBRADI2G14190      GAACACACTCAGTCTGTT----TCTTCCCGATGAGGAAGAGGAGTTTTTTTTTG--GATT 1593
1DLcasTaBRADI2G14190      GAACACACTCAGTAAGTTCG--TCTGCATATTGTGTCTG-----TTTGTTCCCGATGAGG 3767
1ALcasTaBRADI2G14190      GAACACATTCAGTAAGTTCGTATGTGTATATTGTGTCTG-----TTTGTTCCCGTTGACG 7144
                          ******* *****  ***    * *      ** *   *     *** **   *  **

1BLcasTaBRADI2G14190      GATAAAGAGCTTTTTTT---------------------GTTAACTCACTCATAATGCAGC 1632
1DLcasTaBRADI2G14190      AAGAGGGAGTCTTTTTT---------------------GTTAACTCACTCATAATGCAGC 3806
1ALcasTaBRADI2G14190      AAGAGGGAGTTTTTTTTTGGTTGATAAAGGGCGTTTTTGTTAACTCTCTCATAATGTAGC 7204
                           * *  ***  ******                     ******** ********* ***

1BLcasTaBRADI2G14190      ATCAAGCTGATAGAA----------------TGCAGCCCCTGCATGATTAGGATGCACAC 1676
1DLcasTaBRADI2G14190      ATCAAGCTGATAGAA----------------TGCGGCCTCTGCATGATTAGGATGCGCAC 3850
1ALcasTaBRADI2G14190      ACCAACCTGATAGAAAGCATAACGAGTGACATGCGGCCTCTGCATGATTACGATGCGCAC 7264
                          * *** *********                **** *** *********** ***** ***

1BLcasTaBRADI2G14190      TAGCATAACCTGAT---AAGAAATAAAAAGGAAATATAGGAAACAGTAAAGCCACATGAG 1733
1DLcasTaBRADI2G14190      TAGCATAACCTGATGATAAGAAATAAAAAGGACATATAGGAAACAGTAGAGCCACATGAG 3910
1ALcasTaBRADI2G14190      AAGCATAACCTGAT---AAGAAATAAAAAAGACATATAGAAAACAATAAAGCCCTATGAG 7321
                           *************   ************ ** ****** ***** ** ****  *****

                                     casTaBradi2g14190_DR5
1BLcasTaBRADI2G14190      GCCGAAACTATGCCTATGTCGAAGAGGATGGTGGTCCTATTCAGAGAGTATGCCGCT-AT 1792
1DLcasTaBRADI2G14190      ACCGAAACTATGCCTATATTGAAA------------CTATTCAGAGAGTATGCCGCT-AT 3957
1ALcasTaBRADI2G14190      ACCGAAACTATGCCTATGTCGAAG--------------A---GGATAGTG-GCCACTTGT 7363
                           **************** * ***               *    ** ***  *** **  *
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Appendix 4.10a TaBradi2g14130

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1BL_2_casTaBradi2g14130      CAAGGTATCATTGACGGAACCGATGACATTGCTGTTGAGAAACAAGAGAA 64
1BL_casTaBradi2g14130        CAAGGTATCATTGACGGAACCGATGACATTGCTGTTGAGAAACAAGAGAA 64
1ALcasTaBradi2g14130         CAAGGTATCATTGACGGAACCGATGACATTGCTGTTGAGAAGCAAGAGAA 1029
1DLcasTaBradi2g14130         CAAGGTATCATTGACGGAACCGATGACATTGCTGTTGAGAAACAAGAGAA 712
                             ***************************************** ********

1BL_2_casTaBradi2g14130      AGTGCTGGAGCAATGTTCAAGAGCAACTACGGATGCGTACACTGTCAAAG 114
1BL_casTaBradi2g14130        AGTGCTGGAGCAATGTTCAAGAGCAACTACGGATGCGTACACTGTCAAAG 114
1ALcasTaBradi2g14130         AGTGCTGGAGCAATGTTCAAGAGCAACCAAGGATGAGTACACTGTCAAAG 1079
1DLcasTaBradi2g14130         AGTGCTGGAGCAATGTTCAAGAGCAACCAAGGATGAGTACACTGTCAAAG 762
                             *************************** * ***** **************

1BL_2_casTaBradi2g14130      AAAAGGAGATGGTGGTGGAGCAAGGTGTCATTGACCCAAGGTACATGGAT 164
1BL_casTaBradi2g14130        AAAAGGAGATGGTGGTGGAGCAAGGTGTCATTGACCCAAGGTACATGGAT 164
1ALcasTaBradi2g14130         AAAAGGAGATGGTGGTGGAGCAAGGTGTCATTGACCCAAGGTACATGGAT 1129
1DLcasTaBradi2g14130         AAAAGGAGATGGTGGTGGAGCAAGGTGTCATTGACCCAAGGTACATGGAT 812
                             **************************************************

                                casTaBradi2g14130_DF1
1BL_2_casTaBradi2g14130      CTTGCCACGGAAGATCAGGTTAAGTTGTCGATCATAGACGACCAGGGTAC 214
1BL_casTaBradi2g14130        CTTGCCACGGAAGATCAGGTTAAGTTGTCGATCATAGACGACCAGGGTAC 214
1ALcasTaBradi2g14130         CTTGCCACGGAAGATCAGGTTAAGTTGTCGATCGTAGACGACCAGGGTAC 1179
1DLcasTaBradi2g14130         CTTGCCACGGAAGATCAGGTCAAGTTGTCGATCGTAGACGACCAGGGTAC 862
                             ******************** ************ ****************

1BL_2_casTaBradi2g14130      AGTGCCCATGGATGAGGCAGTGGTGAAAGGCCATGATGAGGCAGTGGTGC 264
1BL_casTaBradi2g14130        AGTGCCCATGGATGAGGCAGTGGTGAAAGGCCATGATGAGGCAGTGGTGC 264
1ALcasTaBradi2g14130         AGTGCCCATGGATGATATTGTGGTGAAAGACCATGATAAGGCGGTGGCGC 1229
1DLcasTaBradi2g14130         AGTGCCCATGGATGATATTGTGGTGAAAGACCATGATAAGGCTGTGGTGC 912
                             ***************    ********** ******* **** **** **

                               casTaBradi2g14130_ngsF1
1BL_2_casTaBradi2g14130      AATATGCCAGCGATGCAATAGTAACAATCGAGGATGAGGCTCCTGTGGAG 314
1BL_casTaBradi2g14130        AATATGCCAGCGATGCAATAGTAACAATCGAGGATGAGGCTCCTGTGGAG 314
1ALcasTaBradi2g14130         AATATGCCAGCGATGCAATAGTAACAATCAAGGATGAGAGTCCTGTGGAG 1279
1DLcasTaBradi2g14130         AATATGCCAGCGATGCAATAGTAACAATCAAGGATGAGAGTCCTGTGGAG 962
                             ***************************** ********  **********

1BL_2_casTaBradi2g14130      GAACATGATACGGTGGGGAATCAAGGTGTCATCGACGAAAAGGGCAGAAC 364
1BL_casTaBradi2g14130        GAACATGATACGGTGGGGAATCAAGGTGTCATCGACGAAAAGGGCAGAAC 364
1ALcasTaBradi2g14130         GAACATGATACGGTGGGGAATCAAGGTGTCATCGACAAAAATGGCAGAAC 1329
1DLcasTaBradi2g14130         GAACATGATACGGTGGGGAATCAAGGTGTCATCGACAAAAATGGCAGAAC 1012
                             ************************************ **** ********

1BL_2_casTaBradi2g14130      CAAGGATGTTATTGATGTGGAGGGACATGGCTATGTGAATGAACAGGTCA 414
1BL_casTaBradi2g14130        CAAGGATGTTATTGATGTGGAGGGACATGGCTATGTGAATGAACAGGTCA 414
1ALcasTaBradi2g14130         CAAGGATGATATTGATGTGGAGGGACATGGCTATCTGAAGGAACAGGTCA 1379
1DLcasTaBradi2g14130         CAAGGATGATATTGATGTGGAGGGACATGGCTATGTGAAGGAACAGGTCA 1062
                             ******** ************************* **** **********

1BL_2_casTaBradi2g14130      TTGTCAATAACTGGGGTACATCCAGTGATGCTACTGCTTTGGAAGGGCAT 464
1BL_casTaBradi2g14130        TTGTCAATAACTGGGGTACATCCAGTGATGCTACTGCTTTGGAAGGGCAT 464
1ALcasTaBradi2g14130         TCGTCGATAACTGGGGTACATCCAGTGATGCTACTGCTTTGGAAGGTCAG 1429
1DLcasTaBradi2g14130         TCGTCGATAACTGGGGTACATCCAGTGATGCTACTGCTTTGGAAGGTCAG 1112
                             * *** **************************************** **

1BL_2_casTaBradi2g14130      AAGAATGAGGCTGAGCCATGGATCGGTGAAGAACAGATAGCAGGCAAGGA 514
1BL_casTaBradi2g14130        AAGAATGAGGCTGAGCCATGGATCGGTGAAGAACAGATAGCAGGCAAGGA 514
1ALcasTaBradi2g14130         AAGAATGAGGCTGAGCCACGCATCGGTGATGCACAGATAGCAGGCAAGGA 1479
1DLcasTaBradi2g14130         AAGAATGAGGCTGAGCCACGCATCGGTGATGAACAGATAGCAGGCAAGGA 1162
                             ****************** * ******** * ******************

1BL_2_casTaBradi2g14130      CATGGATGGTGTTCATGCTGAGGGGAACATGTTGGAGCAAAGGACCAGCG 564
1BL_casTaBradi2g14130        CATGGATGGTGTTCATGCTGAGGGGAACATGTTGGAGCAAAGGACCAGCG 564
1ALcasTaBradi2g14130         CATGGATGGTGTTCATGCTGAGGGGAACATGATGGGGCAAAGGACCGGCG 1529
1DLcasTaBradi2g14130         CATGGATGGTGTTCATGCTGAGGGGAACATGTTGGAGCAAAGGACCGGCG 1212
                             ******************************* *** ********** ***

1BL_2_casTaBradi2g14130      ATAAACAGGGAGCAACACAGTCTGATTTCACTGTTGATAAGCTCAAGGAT 614
1BL_casTaBradi2g14130        ATAAACAGGGAGCAACACAGTCTGATTTCACTGTTGATAAGCTCAAGGAT 614
1ALcasTaBradi2g14130         ATAAACAGGGAGCAACACAGTCTGATTTCACTGTTGATAAGCACAAGGAT 1579
1DLcasTaBradi2g14130         ATAAACAGGGAGCAACACAGTCTGATTTCACTGTTGATAAGCACAAGGAT 1262
                             ****************************************** *******
                                 casTaBradi2g14130_DF2
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1BL_2_casTaBradi2g14130      GTAGCGGAGCGTGTCCGCCATGGGTGGGGTGCACCTGAGGATGATCTTGC 664
1BL_casTaBradi2g14130        GTAGCGGAGCGTGTCCGCCATGGGTGGGGTGCACCTGAGGATGATCTTGC 664
1ALcasTaBradi2g14130         GTAGTGGAGCGTGTCCGCCATGAGTGGGGTGCACCTGAGGATGATCGTGC 1629
1DLcasTaBradi2g14130         GTAGCGGAGCGTGTCCGCCATGAGCGGGGTGCACCTGAGGATGATCGTGC 1312
                             **** ***************** * ********************* ***

1BL_2_casTaBradi2g14130      TATGGACAGGACAGCTTACCAAGGTACCAGAGATTGGGGTATAGTTAACA 714
1BL_casTaBradi2g14130        TATGGACAGGACAGCTTACCAAGGTACCAGAGATTGGGGTATAGTTAACA 714
1ALcasTaBradi2g14130         TATAGACACGGCAGCTTATCAAGGTACCGGCGATTGGGGTATAGTTAGCG 1679
1DLcasTaBradi2g14130         TAT----------------------------------------------- 1315
                             ***
1BL_2_casTaBradi2g14130      AGGAGAAGGTTAAGCTGCCTGAGGATGATCGTGCTATGGACACGGCAGCT 764
1BL_casTaBradi2g14130        AGGAGAAGGTTAAGCTGCCTGAGGATGATCGTGCTATGGACACGGCAGCT 764
1ALcasTaBradi2g14130         AGGAGAAGGTTAAGCTGCCTGAGGATGATCGTGCTATGGACACGGCAGCT 1729
1DLcasTaBradi2g14130         -------------------------------------GGACAGGACAGCT 1328
                                                                  ***** * *****

1BL_2_casTaBradi2g14130      TATCAAGGTACCGGAGATTGGGGTATAGTTAACAAGGAGAAGGTGCTGCC 814
1BL_casTaBradi2g14130        TATCAAGGTACCGGAGATTGGGGTATAGTTAACAAGGAGAAGGTGCTGCC 814
1ALcasTaBradi2g14130         TATCAAGGTACCGGAGATTGGGGTACAGCTA------------------- 1760
1DLcasTaBradi2g14130         TATCAAGGTACCGGAGATTGGGGTATAGTTA------------------- 1359
                             ************************* ** **

1BL_2_casTaBradi2g14130      TGAGGATGATCGTGCTATGGACATGGCAGCTTATCAAGGTACCGGAGATT 864
1BL_casTaBradi2g14130        TGAGGATGATCGTGCTATGGACATGGCAGCTTATCAAGGTACCGGAGATT 864
1ALcasTaBradi2g14130         --------------------------------------------------
1DLcasTaBradi2g14130         --------------------------------------------------

1BL_2_casTaBradi2g14130      GGGGTATAGTTAGCAAGGAGAAGTATACGTTGCCTGCTAGAAGATATCCA 914
1BL_casTaBradi2g14130        GGGGTATAGTTAGCAAGGAGAAGTATACGTTGCCTGCTAGAAGATATCCA 914
1ALcasTaBradi2g14130         ------------GCAAGGAGAAGTATAAGCTGCCTGCTAGAAGATATCCA 1798
1DLcasTaBradi2g14130         ------------GCAAGGAGAAGTATAAGTTGCCTGCTAGAAGATATCCA 1397
                                         *************** * ********************

1BL_2_casTaBradi2g14130      CAGAAGCCCAGAAAACTTAACTGCCCCTCTTACATGTCAAAAGGGACCTG 964
1BL_casTaBradi2g14130        CAGAAGCCCAGAAAACTTAACTGCCCCTCTTACATGTCAAAAGGGACCTG 964
1ALcasTaBradi2g14130         CAAAAGCCCAGAAAACTTAACTGCCCCTCTTACATGTCAAAAGGGACCTG 1848
1DLcasTaBradi2g14130         CAAAAGCCCAGAAAACTTAACTGCCCCTCTTACATGTCAAAAGGGACCTG 1447
                             ** ***********************************************

                                       casTaBradi2g14130_ngsR1
1BL_2_casTaBradi2g14130      CACATACGGGCCCTCATGCCACTTCAATCACCCACCGGTAAAATCTGCGT 1014
1BL_casTaBradi2g14130        CACATACGGGCCCTCATGCCACTTCAATCACCCACCGGTAAAATCTGCGT 1014
1ALcasTaBradi2g14130         CACATACGGGCCCTCATGCCACTTCAATCACCCACCGGTAAAATCTGCGT 1898
1DLcasTaBradi2g14130         CACATACGGGCCCTCATGCCACTTCAATCACCCACCGGTAAAATCTGCGT 1497
                             **************************************************

1BL_2_casTaBradi2g14130      CACTTTACTATCATATTATGTATTACTCTAAACTTTTTT-GGCAAGAAAA 1063
1BL_casTaBradi2g14130        CACTTTACTATCATATTATGTATTACTCTAAACTTTTTT-GGCAAGAAAA 1063
1ALcasTaBradi2g14130         CACTTTACTATCATATTATGTATTACTTTAAACTTTTTTTGGCAAGAAAA 1948
1DLcasTaBradi2g14130         CACTTTACTATCATATTATGTATTACTCTAAACTTTTTT-GGCAAGAAAA 1546
                             *************************** *********** **********

1BL_2_casTaBradi2g14130      CTTTGTTGGTTTCCGTACTACGTAGAATATGCTGCAATTTTGCTTAGCAC 1113
1BL_casTaBradi2g14130        CTTTGTTGGTTTCCGTACTACGTAGAATATGCTGCAATTTTGCTTAGCAC 1113
1ALcasTaBradi2g14130         CTTTGTTGGTTTCCGTACTTCGTTGAAT--GATGCAATTTTGCTTAGCAC 1996
1DLcasTaBradi2g14130         CTTTGTTGGTTTCCGTACTTCGTTGAAT--GCTGCAATTTTGCTTAGCAC 1594
                             ******************* *** ****  * ******************
                                     casTaBradi2g14130_DR1
1BL_2_casTaBradi2g14130      AATAGGTTGTGTAAATTATCGCTGTCATATCCGTGCCATTTGTCATGCAA 1163
1BL_casTaBradi2g14130        AATAGGTTGTGTAAATTATCGCTGTCATATCCGTGCCATTTGTCATGCAA 1163
1ALcasTaBradi2g14130         AATAGGTTGTGTAAATTATCGCTGTCATATCCATGCCATTTGTCATGCAA 2046
1DLcasTaBradi2g14130         AATAGGTTGTGTAAATTATCACCGTCATATCCGTGCCATTTGTCATGCAA 1644
                             ******************** * ********* *****************

1BL_2_casTaBradi2g14130      CTGTGCAGGTGGTAC----------------------------------- 1178
1BL_casTaBradi2g14130        CTGTGCAGGTGGTAC----------------------------------- 1178
1ALcasTaBradi2g14130         CTGTGTAGGTAGTAT----------------------------------- 2061
1DLcasTaBradi2g14130         CTGTGTAGGTAGTGTAAATTATCACCGTCATATCCGTGCCATTTTTCATG 1694
                             ***** **** **
                                                   casTaBradi2g14130_DF3
1BL_2_casTaBradi2g14130      ------------------TGGGATCTATATTTCAGTGCATTAAGCTCACA 1210
1BL_casTaBradi2g14130        ------------------TGGGATCTATATTTCAGTGCATTAAGCTCACA 1210
1ALcasTaBradi2g14130         ------------------TGGGATCTATATTTCAATGCATTAAGCTCACA 2093
1DLcasTaBradi2g14130         CAACTGTGTAGGTAGTACTGGCATCCATATTTCAACGCATTAAACTCACA 1744
                                               *** *** ********  ******* ******

1BL_2_casTaBradi2g14130      CCTGCAGTCCCTGCTGTATGCTTCTACATATATGTTCATATGCATGCCCT 1260
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1BL_casTaBradi2g14130        CCTGCAGTCCCTGCTGTATGCTTCTACATATATGTTCATATGCATGCCCT 1260
1ALcasTaBradi2g14130         CCTGCAGTCCCTGCTGTATGCTTCTACATATATGTTCATATGCATGGCCT 2143
1DLcasTaBradi2g14130         CCTGCAGTCCCTGCTGTATGCTTCTACATATATGTTCATATGCATGCCCT 1794
                             ********************************************** ***

1BL_2_casTaBradi2g14130      TTTCTGTATAAAAA-TGTAGTCTCTCGCATCCTTTCTGGTCTCTAGATAA 1309
1BL_casTaBradi2g14130        TTTCTGTATAAAAA-TGTAGTCTCTCGCATCCTTTCTGGTCTCTAGATAA 1309
1ALcasTaBradi2g14130         TTTCTGTATAAAAA-TGTAGTCTCTCGCATCCTTTCTAGTCCCTAGATAA 2192
1DLcasTaBradi2g14130         TTTCTGTATAAAAAATGTAGTCTCTCGCATCCTTTCTGGTCCCTAGATAA 1844
                             ************** ********************** *** ********

1BL_2_casTaBradi2g14130      GCAGGAGATGATGTGGCATTTTAAAAGTTTTATGTGCTGATAATTGTAGT 1359
1BL_casTaBradi2g14130        GCAGGAGATGATGTGGCATTTTAAAAGTTTTATGTGCTGATAATTGTAGT 1359
1ALcasTaBradi2g14130         GCAAGAGATGATGTAGCATTTTAAAAGTTCTATGTGCTGATAATTGTAGT 2242
1DLcasTaBradi2g14130         GCAGGAGATGATGTAGCATTTTAAAAGTTTTATGTGCTGATAATTGTAGT 1894
                             *** ********** ************** ********************
                                     5UTR
1BL_2_casTaBradi2g14130      GGACGTTTGAAAGCCTGATTAATATGTACCTCATTCACTACTTTGTTCAT 1409
1BL_casTaBradi2g14130        GGACGTTTGAAAGCCTGATTAATATGTACCTCATTCACTACTTTGTTCAT 1409
1ALcasTaBradi2g14130         GGACGTTTGAAAGCCTGATTAATATGTACCTCATTCACTACTTTGTTCAT 2292
1DLcasTaBradi2g14130         GGACGTTTGAAAGCCTGATT------------------------------ 1914
                             ********************

1BL_2_casTaBradi2g14130      GAGCTATTTAGTAACTTATCATCCTCTTTTTTGATGATGTTGTCACTGCA 1459
1BL_casTaBradi2g14130        GAGCTATTTAGTAACTTATCATCCTCTTTTTTGATGATGTTGTCACTGCA 1459
1ALcasTaBradi2g14130         GAGCTATTTAGTAACTTATCATCCTCCTTTTTGATGATGTTGTCACTGCA 2342
1DLcasTaBradi2g14130         --------TAGTAACTTATCATCCTCCTTTTTGATGATGTTGTCACTGCA 1956
                                     ****************** ***********************

1BL_2_casTaBradi2g14130      GCAGCTTAAATCTAGGTCAGATGAATCATGGCGTCCCTCTGAACGAAGGA 1509
1BL_casTaBradi2g14130        GCAGCTTAAATCTAGGTCAGATGAATCATGGCGTCCCTCTGAACGAAGGA 1509
1ALcasTaBradi2g14130         GCAGCTTAAATCTAGGTCAGATGAATCATGGCGTCCCTCTGAAAGAAGAA 2392
1DLcasTaBradi2g14130         GCAGCTTAAATCTAGGTCAGATGAATCATGGCGTCCCTCTGAACGAAGAA 2006
                             ******************************************* **** *

1BL_2_casTaBradi2g14130      ACCATGGCGCTGCAGAAATTCTGGAACTGAACTGCCTTGGCCTTCCCATT 1559
1BL_casTaBradi2g14130        ACCATGGCGCTGCAGAAATTCTGGAACTGAACTGCCTTGGCCTTCCCATT 1559
1ALcasTaBradi2g14130         ACCATGGCGCTGCAGAAATTCTGGAACTGAACCGCCTTGGCCTTCCCATT 2442
1DLcasTaBradi2g14130         ACCATGGCGCTGCAGAAATTCTGGAACTGAACCGCCTTGGCCTTCCCATT 2056
                             ******************************** *****************

1BL_2_casTaBradi2g14130      AGAGAAGTATGCCTATGCTATCTTTTCATCTGTTGGAGTTGGTACTTATG 1609
1BL_casTaBradi2g14130        AGAGAAGTATGCCTATGCTATCTTTTCATCTGTTGGAGTTGGTACTTATG 1609
1ALcasTaBradi2g14130         CGAGAAGTATGCCTATGCTATCTTTTCATCTGTTGGAGTTGGTACTTATG 2492
1DLcasTaBradi2g14130         CGAGAAGTATGCCTATGCTATCTTTTCATCTGTTGGAGTTGGTACTTATG 2106
                              *************************************************

                                   casTaBradi2g14230_DF4
1BL_2_casTaBradi2g14130      ATTTATATTGGAAAATGTTGAAACTGAATGGCAGTCCAAATTACTGTTCA 1659
1BL_casTaBradi2g14130        ATTTATATTGGAAAATGTTGAAACTGAATGGCAGTCCAAATTACTGTTCA 1659
1ALcasTaBradi2g14130         ATTTATAT-GGAAAATGTTGAAACTGAATGGTAGTCTAAATTACTTTTCA 2541
1DLcasTaBradi2g14130         ATTTATAT-GGAAAATGTTGAAACTGAATGGTAGTCTAATTTACTTTTCA 2155
                             ******** ********************** **** ** ***** ****

                                                 casTaBradi2g14130_DR2
1BL_2_casTaBradi2g14130      GGGAGCAAGAAACTGTGACTACTCTATGCGAACTGGTGCTTGCAGATATG 1709
1BL_casTaBradi2g14130        GGGAGCAAGAAACTGTGACTACTCTATGCGAACTGGTGCTTGCAGATATG 1709
1ALcasTaBradi2g14130         GGGAGCAAGAAACTGTGACTACTATATGCGAACTGGTGCTTGCAGATATG 2591
1DLcasTaBradi2g14130         GGGAGCAAGAAACTGTGACTACTATATGCGAACCGGTGCTTGCAGATATG 2205
                             *********************** ********* ****************

1BL_2_casTaBradi2g14130      GCAAAAACTGCCATTTTAACCATCCAGACCATGTGATTGATGCTCAGTTC 1759
1BL_casTaBradi2g14130        GCAAAAACTGCCATTTTAACCATCCAGACCATGTGATTGATGCTCAGTTC 1759
1ALcasTaBradi2g14130         GCAAAAACTGCCATTTTAACCATCCAGACCATGTCATTGATGCTCAGTTC 2641
1DLcasTaBradi2g14130         GCAAAAACTGCCATTTCAACCATCCAGACCATGTCATTGATGCTCAGTTC 2255
                             **************** ***************** ***************

                                    5UTR                  Exon1 start
1BL_2_casTaBradi2g14130      AATCCACCAACAGGGTGGGAGGATAATGCTTTGCA---AATGGAGAAATC 1806
1BL_casTaBradi2g14130        AATCCACCAACAGGGTGGGAGGATAATGCTTTGCA---AATGGAGAAATC 1806
1ALcasTaBradi2g14130         AATCCACCAACAGGGTGGGAGGATAATGCTTTGCAGCAAATGGAGAAATC 2691
1DLcasTaBradi2g14130         AATCCACCAACAGGGTGGGAGGATAATGCTTTGCA---AATGGAGAAATC 2302
                             ***********************************   ************
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1BL_2_casTaBradi2g14130      TTCTGATCATACATTAGATGAGACATCACGCATGAAGAAATCTTCCGATG 1856
1BL_casTaBradi2g14130        TTCTGATCATACATTAGATGAGACATCACGCATGAAGAAATCTTCCGATG 1856
1ALcasTaBradi2g14130         TTCTGACCGTACATTAGATGAGACATCACACATGAAGAAATCTTCCGATG 2741
1DLcasTaBradi2g14130         TTCTGACCATACATTAGATGAGACATCACGCATGAAGAAATCTTCCGATG 2352
                             ****** * ******************** ********************

1BL_2_casTaBradi2g14130      ATGCGACCTTCGATGACAGATCAGACATGAAGAAATCTTCCGATGATGCG 1906
1BL_casTaBradi2g14130        ATGCGACCTTCGATGACAGATCAGACATGAAGAAATCTTCCGATGATGCG 1906
1ALcasTaBradi2g14130         ATGCGACCTTAGATAACAGATCACACATGAAGAAATCTTCCGATGATGCG 2791
1DLcasTaBradi2g14130         ATGCGACCTTCGATGACAGATCACACATGAAGAAATCTTCCGATGATGCG 2402
                             ********** *** ******** **************************

1BL_2_casTaBradi2g14130      GCGTT--------------------------------------------- 1911
1BL_casTaBradi2g14130        GCGTT--------------------------------------------- 1911
1ALcasTaBradi2g14130         ACCTTCAATGACAGATCACACTTGAAGAAACCTTCTGATGGTGCGACCTT 2841
1DLcasTaBradi2g14130         ACCTT--------------------------------------------- 2407
                              * **
1BL_2_casTaBradi2g14130      AGATGACAGATCACACTTGAAGAAACCTTCTGATGGTGCGATCGTAGATG 1961
1BL_casTaBradi2g14130        AGATGACAGATCACACTTGAAGAAACCTTCTGATGGTGCGATCGTAGATG 1961
1ALcasTaBradi2g14130         AGATGACAGATCACACTTGAAGAAACCTTCTGATGGTGCGATCGTAGATG 2891
1DLcasTaBradi2g14130         AGATGACAGATCACACTTGAAGAAACCTTCTGATGGTGCGATCGTAGATG 2457
                             **************************************************

1BL_2_casTaBradi2g14130      ACACATCATACTCAAAGAAGTCTTCTGACAATGACAACTCATCTAGCTCT 2011
1BL_casTaBradi2g14130        ACACATCATACTCAAAGAAGTCTTCTGACAATGACAACTCATCTAGCTCT 2011
1ALcasTaBradi2g14130         ACACATCATACTCAAAGAAGTCTTCTGACCATGACAACTCATGTAGCTCT 2941
1DLcasTaBradi2g14130         ACACATCATACTCAAAGAAGTCTTCTGACCATGACAACTCATCTAGCTCT 2507
                             ***************************** ************ *******
                                                                Exon1
1BL_2_casTaBradi2g14130      GGTGTCCTGCCACCAAGCATATTTAGAATGCTTCTACCTCCCCCAAAAGT 2061
1BL_casTaBradi2g14130        GGTGTCCTGCCACCAAGCATATTTAGAATGCTTCTACCTCCCCCAAAAGT 2061
1ALcasTaBradi2g14130         GGTGTCCTGCCACCAAGCATATTTAGAATGCTTCTACCTCCCCAAAAAGT 2991
1DLcasTaBradi2g14130         GGTGTCCTGCCACCAAGCATATTTAGAATGCTTCTACCTCCCCAAAAAGT 2557
                             ******************************************* ******

                                                  casTaBradi2g14130_DR3
1BL_2_casTaBradi2g14130      ACTGCCTAGCACGGAAGGAAAGGCGAAAAAGGTACGTGCTGTTTCTTCCC 2111
1BL_casTaBradi2g14130        ACTGCCTAGCACGGAAGGAAAGGCGAAAAAGGTACGTGCTGTTTCTTCCC 2111
1ALcasTaBradi2g14130         ACTGCCTGGTACGGAAGGAAAGGCGAAAAAGGTACGTGCTGTTTCTTACC 3041
1DLcasTaBradi2g14130         ACTGCCTAGTACGGAAGGAAAGGCGAAAAAGGTACATGCTGTTTCTTCCC 2607
                             ******* * ************************* *********** **

1BL_2_casTaBradi2g14130      TATATTATGCGATGTTTAGATCTGCATTTGCACACATCTCTTGGATA--T 2159
1BL_casTaBradi2g14130        TATATTATGCGATGTTTAGATCTGCATTTGCACACATCTCTTGGATA--T 2159
1ALcasTaBradi2g14130         TATATTATGCGATGTTTTGATCTTCATTTGCACACATCTCTTGGATA--C 3089
1DLcasTaBradi2g14130         TATATTATGCGATGTTTTGATCTGCATTTGCACACATCTCTTGGATATAC 2657
                             ***************** ***** ***********************

1BL_2_casTaBradi2g14130      TGCTACTTTGCGACACTGCACTGTACATTCCTAGATTTTGACTGGTCTGT 2209
1BL_casTaBradi2g14130        TGCTACTTTGCGACACTGCACTGTACATTCCTAGATTTTGACTGGTCTGT 2209
1ALcasTaBradi2g14130         TGCTACTTTGTGACACTGCACTGTGCTTTCCTAGATTTTGACTGCTCTGT 3139
1DLcasTaBradi2g14130         TGCTACTTTGTGACACTGCACTGTGCTTTCCTAGATTTTGACTGGTCTGT 2707
                             ********** ************* * ***************** *****

1BL_2_casTaBradi2g14130      GCCTTTTTTTTTTTGCTAATTTCCT---CCTATCTGCTTCATGCAGAAGT 2256
1BL_casTaBradi2g14130        GCCTTTTTTTTTTTGCTAATTTCCT---CCTATCTGCTTCATGCAGAAGT 2256
1ALcasTaBradi2g14130         GCCTTTTTT-----GTTAATTTCCTTATCGTATCTGCTTCATGCAGAAGT 3184
1DLcasTaBradi2g14130         GCCTTTTTT-----GTTAATTTCCTTGTCCTATCTGCTTCATGCAGAAGT 2752
                             *********     * *********   * ********************

1BL_2_casTaBradi2g14130      CAGACTGGTCATCAGACGATTCCGATGGTTGCTGTTCAGCAGATAGTTCA 2306
1BL_casTaBradi2g14130        CAGACTGGTCATCAGACGATTCCGATGGTTGCTGTTCAGCAGATAGTTCA 2306
1ALcasTaBradi2g14130         CAGGCTGGTCATCAGACGATTCCGATGGTTGCTGTTCAGCAGATAGTTCA 3234
1DLcasTaBradi2g14130         CAGACTGGTCATCAGACGATTCGGATGGTTGCTGTTCAGCAGATAGTTCA 2802
                             *** ****************** ***************************

1BL_2_casTaBradi2g14130      GATGGACCTTTGTGCAAGCAGGGGGAGCACGTGGATTACGCTGAGAGGCC 2356
1BL_casTaBradi2g14130        GATGGACCTTTGTGCAAGCAGGGGGAGCACGTGGATTACGCTGAGAGGCC 2356
1ALcasTaBradi2g14130         GATGGACCTTTGTGCAAGCAGGGGGGGCACGTGGATTACCCTGAGAGGCC 3284
1DLcasTaBradi2g14130         GATGGACCTTTGTGCAAGCAGGGGGAGCACGTGGATTACCCTGAGAGGCC 2852
                             ************************* ************* **********
                                                         casTaBradi2g14130_DF5
1BL_2_casTaBradi2g14130      TGGCAGACCAGAATATCACCACCCAAAACAGTCAAAAGACAAAGAAGAGG 2406
1BL_casTaBradi2g14130        TGGCAGACCAGAATATCACCACCCAAAACAGTCAAAAGACAAAGAAGAGG 2406
1ALcasTaBradi2g14130         TGGCAGACCAGAATATCACCACCCAAAACAGTCAAAAGACAAAGAAGAGG 3334
1DLcasTaBradi2g14130         TGGCAGACCAGAATATCACCACCCAAAACAGTCAAAAGACAAAGAAGAGG 2902
                             **************************************************
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                                                   casTaBradi2g14130_DR4
1BL_2_casTaBradi2g14130       TAAACTATCCTGAGAGGCCTGGCAAACCAGATTGCCCCTTCTACATGAGA 2456
1BL_casTaBradi2g14130         TAAACTATCCTGAGAGGCCTGGCAAACCAGATTGCCCCTTCTACATGAGA 2456
1ALcasTaBradi2g14130          TAAACTATCCTGAGAGGCCTGGCAAACCAGATTGCCCCTTCTACATGAGA 3384
1DLcasTaBradi2g14130          TACACTACCCGAGAGGCCTGGCAGAGCAGATTGCCCCTTCTACATGAGA 2952
                              ** **** ** ************* * ***********************

1BL_2_casTaBradi2g14130       TTTGGTGATTGTAAATTTGCATCAGCATGCAACTATCACCACCCAAAAGA 2506
1BL_casTaBradi2g14130         TTTGGTGATTGTAAATTTGCATCAGCATGCAACTATCACCACCCAAAAGA 2506
1ALcasTaBradi2g14130          TTTGGTGATTGTAAATTTGCATCAGCATGCAACTATCACCACCCAAAAGA 3434
1DLcasTaBradi2g14130          TTTGGTGATTGTAAATTTGCATCAGCATGCAACTATCACCACCCAAAAGA 3002
                              **************************************************

1BL_2_casTaBradi2g14130       CAAATACCCAGCTGGGAGACCTGATGAACCAGAATGCCCATTCCTTATGA 2556
1BL_casTaBradi2g14130         CAAATACCCAGCTGGGAGACCTGATGAACCAGAATGCCCATTCCTTATGA 2556
1ALcasTaBradi2g14130          CAAATACCCAGCTGGGAGACCTGATGAACCAGAATGCCCATTCCTTATGA 3484
1DLcasTaBradi2g14130          CAAATACCCAGCTGCGAGACCTGATGAACCAGAATGCCCATTCCTTATGA 3052
                              ************** ***********************************

1BL_2_casTaBradi2g14130       AGCGTGGGTACTTTAAACTTAGGGCACAATGTAAGTTTTATCACCCAGAG 2606
1BL_casTaBradi2g14130         AGCGTGGGTACTTTAAACTTAGGGCACAATGTAAGTTTTATCACCCAGAG 2606
1ALcasTaBradi2g14130          AGCGTGGGTACTGTAAACTTAGGGCACAATGTAAGTTTTATCACCCAGAG 3534
1DLcasTaBradi2g14130          AGCGTGGGTACTGTAAATTTGGGGCACAATGCAAGTTTTATCACCCAGAG 3102
                              ************ **** ** ********** ******************

1BL_2_casTaBradi2g14130       GCTTCAAATCCTACCATGCAGAGCCCAACAGATGCAAAAAGATCTGTTAC 2656
1BL_casTaBradi2g14130         GCTTCAAATCCTACCATGCAGAGCCCAACAGATGCAAAAAGATCTGTTAC 2656
1ALcasTaBradi2g14130          GCTTCAAATCCTACCATGCAGAGCCCAACAGATGCAAAAAGATCTGTTAC 3584
1DLcasTaBradi2g14130          GATTCAAATCCTACCGTGCAGAGCCCAACAGATGCAAAAAGATCTGTTAC 3152
                              * ************* **********************************

1BL_2_casTaBradi2g14130       CACTGATGAACATCATCCATCTACAGGAATCACATTACAAGACTATATGC 2706
1BL_casTaBradi2g14130         CACTGATGAACATCATCCATCTACAGGAATCACATTACAAGACTATATGC 2706
1ALcasTaBradi2g14130          CACTGATGAACATCATCCATCTACAAGAATCACATTACAAGACTATATGC 3634
1DLcasTaBradi2g14130          CACTGATGAACATCATCCATCTACAAGAATCACATTACAAGACTATATGC 3202
                              ************************* ************************

1BL_2_casTaBradi2g14130       TTCCCCAGCAACCGCAGTATCCTGAGAGGCCTGGTCAGCC-GAGTGCCGG 2755
1BL_casTaBradi2g14130         TTCCCCAGCAACCGCAGTATCCTGAGAGGCCTGGTCAGCC-GAGTGCCGG 2755
1ALcasTaBradi2g14130          TTCCCCAGCAACCGCAGTATCCCGAGAGACCTGGTCAGCCAGAGTGCCGG 3684
1DLcasTaBradi2g14130          TTCCCCAGCAACCGCAGTATCCTGAGAGACCTGGTCAGCCAGAGTGCCGG 3252
                              ********************** ***** *********** *********

1BL_2_casTaBradi2g14130       TACTACTTGCAGTTTGGGAAATGCAAATATCTGTCTGCATGTATATTTCA 2805
1BL_casTaBradi2g14130         TACTACTTGCAGTTTGGGAAATGCAAATATCTGTCTGCATGTATATTTCA 2805
1ALcasTaBradi2g14130          TACTACTTGCAGTTTGGGAAATGCAAATATCTGTCTGCTTGTATATTTCA 3734
1DLcasTaBradi2g14130          TACTACATGCAGTTTGGGAAATGCAAATATCTGTCTGCATGTATATTTCA 3302
                              ****** ******************************* ***********

                                                          casTaBradi2g14130_DF6
1BL_2_casTaBradi2g14130       CCATCCAAAAGATGGAGTTGCAGCTCACTCTGATCAGGTTGGACCTG--- 2852
1BL_casTaBradi2g14130         CCATCCAAAAGATGGAGTTGCAGCTCACTCTGATCAGGTTGGACCTG--- 2852
1ALcasTaBradi2g14130          CCATCCAAAAGATAGACTTGCAGCTCACTCTGATCAGATTGGACCTG--- 3781
1DLcasTaBradi2g14130          CCATCCAAAAGATAGACTTGCAGCTCACTCGGATCAGATTGGACCTGAAA 3352
                              ************* ** ************* ****** *********

1BL_2_casTaBradi2g14130       ------GCATGCCAGATTGTCCTTTCTATATGAAAGCTGGGAAATGTCAA 2896
1BL_casTaBradi2g14130         ------GCATGCCAGATTGTCCTTTCTATATGAAAGCTGGGAAATGTCAA 2896
1ALcasTaBradi2g14130          ------GCATGCCAGATTGTCCTTTCTATATGAAAACTGGGAAATGTCAA 3825
1DLcasTaBradi2g14130          TACATGGCATGCCAGATTGTCCTTTCTATATGAAAGCTGGGAAATGTCAA 3402
                                    ***************************** **************

1BL_2_casTaBradi2g14130       TTTGGATCAGCATGTGAATTTCGTCATCCCAAAGATATACATTCAAGTTC 2946
1BL_casTaBradi2g14130         TTTGGATCAGCATGTGAATTTCGTCATCCCAAAGATATACATTCAAGTTC 2946
1ALcasTaBradi2g14130          TTTGGATCAGCATGTGAATTTCGTCATCCCAAAGATATACATTCAAGTTC 3875
1DLcasTaBradi2g14130          TTTGGATCAGCATGTGAATTTCGTCATCCCAAAGATATACATTCAA---- 3448
                              **********************************************

1BL_2_casTaBradi2g14130       AACTACAGAGGTATATTCTATTATCAGTGGTCAATGTTCAAGTAAACACT 2996
1BL_casTaBradi2g14130         AACTACAGAGGTATATTCTATTATCAGTGGTCAATGTTCAAGTAAACACT 2996
1ALcasTaBradi2g14130          AACTACAGAGGTATATTCTATTATCAGTGGTCGATGTTCAAGTAAACACT 3925
1DLcasTaBradi2g14130          --CTACAGAGGTATATTCTATTATTAGTGGTCGATGTTCAAGTAAACACT 3496
                                ********************** ******* *****************
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                                                     CasTaBradi2g14230_DR5
1BL_2_casTaBradi2g14130      GTTGATTCAATCATAACTAGTTTGCAATTGTTCCTTTTTCTCTGGCTGAT 3046
1BL_casTaBradi2g14130        GTTGATTCAATCATAACTAGTTTGCAATTGTTCCTTTTTCTCTGGCTGAT 3046
1ALcasTaBradi2g14130         GTTGATTCAATCATAACTAGTTTGCAATTGTTCCTTTTTCTCTGGCTGAT 3975
1DLcasTaBradi2g14130         ATTGATTCAATCATAACTAGTTTGCAATTTTTATTTTTTCTCTGGCTGAT 3546
                              **************************** **  ****************

1BL_2_casTaBradi2g14130      CCCTGTTGCATTTTTAGGCATGCCTTTAAGTATAGTAAATAGTACTGGTC 3096
1BL_casTaBradi2g14130        CCCTGTTGCATTTTTAGGCATGCCTTTAAGTATAGTAAATAGTACTGGTC 3096
1ALcasTaBradi2g14130         CCCTGTTGCATTTTTAGGCATGCCATTAAGTATAGTAAATGGTACTGGTC 4025
1DLcasTaBradi2g14130         CCCTGTTGCATTTTTAGGCATGCCATTAAGTATAGTAAATAGTACTGGTC 3596
                             ************************ *************** *********

1BL_2_casTaBradi2g14130      AGCTCAGTCCTGTGTACTGGGAACTGGGAAAGACA--------------- 3131
1BL_casTaBradi2g14130        AGCTCAGTCCTGTGTACTGGGAACTGGGAAAGACA--------------- 3131
1ALcasTaBradi2g14130         AGCTCAGTCCTGTGTAATGGGAACCGGGGAAGAAAACTATGTTTGCTTCT 4075
1DLcasTaBradi2g14130         AGCTCAGTCCTGTGTAATGGGAACCGGGGA-GAAAACTATGTTTGCTTCT 3645
                             **************** ******* *** * ** *

1BL_2_casTaBradi2g14130      --------------TCTTTACTAGCATTGACATTTATGCAAATGAAAACT 3167
1BL_casTaBradi2g14130        --------------TCTTTACTAGCATTGACATTTATGCAAATGAAAACT 3167
1ALcasTaBradi2g14130         CTACTGGATAGAGATCTTTACTAGCATTGACATTTATGCAAATGAAAACT 4125
1DLcasTaBradi2g14130         CTACTGGATA----------CTAGCATTGACATTTATGCAAATGAAAACT 3685
                                                 ******************************

1BL_2_casTaBradi2g14130      GAATAAATTGTGCGTT-GAGAATTCTTGTCCAATTTACAGTGAGTACAGT 3216
1BL_casTaBradi2g14130        GAATAAATTGTGCGTT-GAGAATTCTTGTCCAATTTACAGTGAGTACAGT 3216
1ALcasTaBradi2g14130         GAATAAATCGTGTGTTTGAGAATTCTTGTCCAATTTACAGTGGGAGTGTT 4175
1DLcasTaBradi2g14130         GAATAAATCGTGTGTTTGAGAATTCTTGTCCAATTTACAGTGAGTATGTT 3735
                             ******** *** *** ************************* *     *

                                            casTaBradi2g14130_DF7
1BL_2_casTaBradi2g14130      ACTATTTTC-TGTGCTTGTTTACTACCTCATCGTACGAATGAAATCTGTT 3265
1BL_casTaBradi2g14130        ACTATTTTC-TGTGCTTGTTTACTACCTCATCGTACGAATGAAATCTGTT 3265
1ALcasTaBradi2g14130         ACTATTTCTATACGCTTGTTTACTACCTCATTGTATGAATGAAGTCTGTT 4225
1DLcasTaBradi2g14130         ACTATTTCTATACGCTTGTTTACTACCTCATTGCACGAATGAAGTCTGTT 3785
                             *******   *  ****************** * * ******* ******

1BL_2_casTaBradi2g14130      CTGAACCTTTTCGGTTCCTATTGCACATCTGAACTCCGAATGTTTGAAGT 3315
1BL_casTaBradi2g14130        CTGAACCTTTTCGGTTCCTATTGCACATCTGAACTCCGAATGTTTGAAGT 3315
1ALcasTaBradi2g14130         TAGAACCTTTTCCGTTCCTATTGCACATCTGCACTACGAATGTTTGAAGT 4275
1DLcasTaBradi2g14130         TAGAACCTTTTCCGTTCCTATTGCACATCTGCACTACGAATGTTTGAAGT 3835
                               ********** ****************** *** **************

1BL_2_casTaBradi2g14130      ATCCACACAACACAAAGATGGCCACTGAAAAAA--TGATGGTATGGACTA 3363
1BL_casTaBradi2g14130        ATCCACACAACACAAAGATGGCCACTGAAAAAA--TGATGGTATGGACTA 3363
1ALcasTaBradi2g14130         ATTCACACGACACAAAGATGGTCACTGAAAAAAAATGACGGTGTGGACTA 4325
1DLcasTaBradi2g14130         ATTCACACGACACAAAGATGGTCACTGAAAAAAAATGACGGTATGGACTA 3885
                             ** ***** ************ ***********  *** *** *******

1BL_2_casTaBradi2g14130      TGGAGTGCTAGGAGAGGCTAAATAGTAAATATT----------------A 3397
1BL_casTaBradi2g14130        TGGAGTGCTAGGAGAGGCTAAATAGTAAATATT----------------A 3397
1ALcasTaBradi2g14130         TGGAGCGCTAGGAGTAG-TAAATATTGGTTGTCTGTGTAGTAGCAAGCAA 4374
1DLcasTaBradi2g14130         TGGAGCGCTAGGAGTAG-TAAATATTGGTTATCTGTGTAGTAGCAAGCAA 3934
                             ***** ********  * ****** *   * *                 *

1BL_2_casTaBradi2g14130      CTCCCTCCGT-------CCCA----CAATGTAAAATG------------- 3423
1BL_casTaBradi2g14130        CTCCCTCCGT-------CCCA----CAATGTAAAATG------------- 3423
1ALcasTaBradi2g14130         TTTCTTTCATCTACAATCTCAAGTGCAATGCAGGGTGCTCTTTGACTTCC 4424
1DLcasTaBradi2g14130         TTTCTTTCATATACAATCTCAAGTGCAATGCAGT---------------- 3968
                              * * * * *       * **    ***** *

1BL_2_casTaBradi2g14130      --------------------------------------------------
1BL_casTaBradi2g14130        --------------------------------------------------
1ALcasTaBradi2g14130         ATACAATGTTGATCGTGGTCTTGTTGAATTTTCTTCATTTCTCAGAAGTA 4474
1DLcasTaBradi2g14130         --------------------------------------------------

1BL_2_casTaBradi2g14130      --------------------------------------------------
1BL_casTaBradi2g14130        --------------------------------------------------
1ALcasTaBradi2g14130         GGAATATATCATGTCACCCAGTTGAAACAAAATAGTTATGGTTATCTGTG 4524
1DLcasTaBradi2g14130         --------------------------------------------------
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1BL_2_casTaBradi2g14130      --------------------------------------------------
1BL_casTaBradi2g14130        --------------------------------------------------
1ALcasTaBradi2g14130         TAATAGCAAACAATTTTTTTTTTATCTACAATCTCAAGTGCAATGCAGGG 4574
1DLcasTaBradi2g14130         --------------------------------------------------

1BL_2_casTaBradi2g14130      ---TTTTTG---------CAA----------------GCTAAAATAGCTT 3445
1BL_casTaBradi2g14130        ---TTTTTG---------CAA----------------GCTAAAATAGCTT 3445
1ALcasTaBradi2g14130         TGCTCTTTGACTTTCATACAATGTTGATCGTGGTCTTGTTGAATTTTCTT 4624
1DLcasTaBradi2g14130         TGCTCTTTGACTTTCATACAATGTTGATCGTGGTCTTGTTGAATTTTCTT 4018
                                * ****         ***                * * ** *  ***

1BL_2_casTaBradi2g14130      ------------GCAAAAATGTCTTACGTTG------TGGGACAGAGGGA 3477
1BL_casTaBradi2g14130        ------------GCAAAAATGTCTTACGTTG------TGGGACAGAGGGA 3477
1ALcasTaBradi2g14130         CATTTCTCAGAAGTAGAAATATATCATGTCACCCAGTTGAAACAAAATAG 4674
1DLcasTaBradi2g14130         CATTTCTCAGAAGCAGAAATATATCATGTCACCCAGTTGAAACAAAATAG 4068
                                         * * **** * * * **        **  *** *
                                                     casTaBradi2g14130_DR6
1BL_2_casTaBradi2g14130      GTA--GTTATCTGTGTAGTAGCAAAGAATTTTTTTTAATCTACAATCTGA 3525
1BL_casTaBradi2g14130        GTA--GTTATCTGTGTAGTAGCAAAGAATTTTTTTTAATCTACAATCTGA 3525
1ALcasTaBradi2g14130         TTATGGTTATCTGTGTAATAGCAAACAATTTTTTT--ATCTACAATCTCA 4722
1DLcasTaBradi2g14130         TTATGGTTATCTGTGTAATAGCAAACAATTTTTTT--ATGTACAATCTCA 4116
                              **  ************ ******* *********  ** ******** *

1BL_2_casTaBradi2g14130      AGTGCAATGCAGGTTGCTCTTT--------ATTTCTACAATGTTGATCAT 3567
1BL_casTaBradi2g14130        AGTGCAATGCAGGTTGCTCTTT--------ATTTCTACAATGTTGATCAT 3567
1ALcasTaBradi2g14130         AGTGCAATGCAGGTTGCTCTTTGACCTTGTATTGCTACAATACTGATCGC 4772
1DLcasTaBradi2g14130         AGTGCAATGCAGGTTGCTCTTTGACCTTGTATTGCTACAATACTGATCGC 4166
                             **********************        *** *******  *****

1BL_2_casTaBradi2g14130      GATCTTGTT-GATTTTTCTTCATTTATCAGAAGTAGAAATATGTATGTCA 3616
1BL_casTaBradi2g14130        GATCTTGTT-GATTTTTCTTCATTTATCAGAAGTAGAAATATGTATGTCA 3616
1ALcasTaBradi2g14130         GACCTTGTTAGATTTTTTTTCATTTCTCAGAACCAGAGATA----TGTTG 4818
1DLcasTaBradi2g14130         GACCTTGTTAGATTTTTTT-CATTTCTCAGAACTAGAGAGAG--ATGTTG 4213
                             ** ****** ******* * ***** ******  *** * *    ***

1BL_2_casTaBradi2g14130      TGTCACCCAATTGAAAGAACATAGATGCTCGGTT---TTGTT-------- 3655
1BL_casTaBradi2g14130        TGTCACCCAATTGAAAGAACATAGATGCTCGGTT---TTGTT-------- 3655
1ALcasTaBradi2g14130         GGTCACCCGACTGAAACGAAGTAGATGCTCAATTCAGTTGTTCCTCCCTG 4868
1DLcasTaBradi2g14130         GGTCACCCGACTGAAACAAAGTAGATGCTCAATTCAGTTGTTCCTCCCTG 4263
                              ******* * *****  *  *********  **   *****

1BL_2_casTaBradi2g14130      -------ACCAGTGAATGCTCATGGATGTCATTCTGTTCCAGGAAGCATT 3698
1BL_casTaBradi2g14130        -------ACCAGTGAATGCTCATGGATGTCATTCTGTTCCAGGAAGCATT 3698
1ALcasTaBradi2g14130         ATTTCTTACCCATGG-TGCTCATGGATGTTATGCTGTTTCAGGAAGCATT 4917
1DLcasTaBradi2g14130         ATTTCCTACCCATGG-TGCTCATGGATGTTATGCTGTTTCAGGAAGCATT 4312
                                    ***  **  ************* ** ***** ***********

1BL_2_casTaBradi2g14130      TTGTAAGAGAAGTGGGTCTGGGGCGTACCACAATTTGTCAAGGTCAGATA 3748
1BL_casTaBradi2g14130        TTGTAAGAGAAGTGGGTCTGGGGCGTACCACAATTTGTCAAGGTCAGATA 3748
1ALcasTaBradi2g14130         TGGTGAGAGAACTGGCTCGGGGGCGTACGATAGTTTGACAAGGTCAGATA 4967
1DLcasTaBradi2g14130         TGGTCAGAGAACTGGCTCGGGGGCATACGACAATTTGTCAAGGTCAGATA 4362
                             * ** ****** *** ** ***** *** * * **** ************

1BL_2_casTaBradi2g14130      ATGGTGTGGAGCAACAAGA---GAGCATCATGTATCCTGAAAGGCCCGGT 3795
1BL_casTaBradi2g14130        ATGGTGTGGAGCAACAAGA---GAGCATCATGTATCCTGAAAGGCCCGGT 3795
1ALcasTaBradi2g14130         ATGGTGTGGAGCAACAAGAAGAGAGCATCATGTATCCTGAGAGGCCCGGT 5017
1DLcasTaBradi2g14130         ATGGTGTGGAGCAACAAGAAGAGAGCATCATGTATCCTGAAAGGCCCGGT 4412
                             *******************   ****************** *********

1BL_2_casTaBradi2g14130      GAACCCAAGTGTGCCCACTACATGAGGCAGGGCTACTGTTAGTTTCAGAT 3845
1BL_casTaBradi2g14130        GAACCCAAGTGTGCCCACTACATGAGGCAGGGCTACTGTTAGTTTCAGAT 3845
1ALcasTaBradi2g14130         GAACCTGAGTGTAACCACTACATGAGGCAGGGCTACTGTAAGTTCCAGAT 5067
1DLcasTaBradi2g14130         GAACCAGAGTGTGCCCACTACATGAGGCAGGGGTACTGTAAGTTTCAGAT 4462
                             *****  *****  ****************** ****** **** *****

                                          casTaBradi2g14130_DF8
1BL_2_casTaBradi2g14130      GAACTGCAAATACCATCATCCAGGAGACCGGCTGTCTAAGAAACAGTATG 3895
1BL_casTaBradi2g14130        GAACTGCAAATACCATCATCCAGGAGACCGGCTGTCTAAGAAACAGTATG 3895
1ALcasTaBradi2g14130         GAACTGCAAGTACCATCATCCAGGAGACCGGCTGTCTAAGAAACAGTATG 5117
1DLcasTaBradi2g14130         GAACTGCAAATACCATCATCC---------------TAAGAAACAGTATG 4497
                             ********* ***********               **************

1BL_2_casTaBradi2g14130      TATGTA----AGACTCGTATAAATTTTCAGAAAAAGCTCGATTCCGCTGC 3941
1BL_casTaBradi2g14130        TATGTA----AGACTCGTATAAATTTTCAGAAAAAGCTCGATTCCGCTGC 3941
1ALcasTaBradi2g14130         TATGTATGTAAGACTCGTATAAATTTTTAGAAAAAGCTCGATTCCGCTGC 5167
1DLcasTaBradi2g14130         TATGTA----AGCCTCGTATAAATTTTCAGAAAAAGCTCGATTCCGCTGC 4543
                             ******    ** ************** **********************
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                                                   casTaBradi2g14130_DF9
1BL_2_casTaBradi2g14130      CTTTTAGATGATGTTGATGATGATTTTCTGCGAGTGTTGTTTCAATTGCA 3991
1BL_casTaBradi2g14130        CTTTTAGATGATGTTGATGATGATTTTCTGCGAGTGTTGTTTCAATTGCA 3991
1ALcasTaBradi2g14130         CTTT-AGATGATGTTGATGATGATGTG-TGCGAGTGTTGTTTCAATTGCA 5215
1DLcasTaBradi2g14130         CTTT-AGATGATGTTGATGATGATGTG-TGCGAGTGTTGTTTCGATTGCA 4591
                             **** ******************* *  *************** ******
                                   casTaBradi2g14130_DR7
1BL_2_casTaBradi2g14130      GTGAAGTCATCCGCAGCGACCACTTGAGCAAAGCAGGGACACGCTGGTTA 4041
1BL_casTaBradi2g14130        GTGAAGTCATCCGCAGCGACCACTTGAGCAAAGCAGGGACACGCTGGTTA 4041
1ALcasTaBradi2g14130         GTGAAGTCATCCGCACCGACCACTTGAGCAAAGCAGGGACACGCTGGTTA 5265
1DLcasTaBradi2g14130         GTGAAGTCATCCGCGCCGACCACTTGAGCAAAGCAGGGACACGCTGGTTA 4641
                             **************  **********************************

1BL_2_casTaBradi2g14130      CCGCACGAATGCTACCAACAGAAAGGTA---------------GTGATGT 4076
1BL_casTaBradi2g14130        CCGCACGAATGCTACCAACGGAAAGGTAGGTACCTCTTGTGCAGTGATGT 4091
1ALcasTaBradi2g14130         CCGCACGAATGCTACCAACGGAAAGGTA--TACCTCTTGTGCAGTGATCT 5313
1DLcasTaBradi2g14130         CCGCATGAATGCTACCAACGGAAAGGTG--TACCTCTTGTGCAGTGATCT 4689
                             ***** ************* *******                ***** *

1BL_2_casTaBradi2g14130      TGCTGATAGGAGTTGCTATTGCTTTGGAATTCTCCCGAAACAGCCTCCCC 4126
1BL_casTaBradi2g14130        TGCTGATAGGAGTTGCTATTGCTTTGGAATTCTCCTGAAACAGCCTCCCC 4141
1ALcasTaBradi2g14130         TGCCGATAGGAGTTGCTATTGCTTTGCAATTCTCCTAAAACAGCTTCCCC 5363
1DLcasTaBradi2g14130         TGCTGATAGGAGTTGCCATTGCTTTGCAATTCTCCTAAAACAGCCTCCCC 4739
                             *** ************ ********* ********  ******* *****

1BL_2_casTaBradi2g14130      TTGGCGTGGCCGACTTAACTTGGTGCCTGTTTGTTA----TTGTTTTGCA 4172
1BL_casTaBradi2g14130        TTGACATGGCCGACTTAACTTGGTGCCTGTTTGTTTTGTTTTGTTTTGCA 4191
1ALcasTaBradi2g14130         TTGATGTGGCCGACTTAACTTGGTGCCTATTTGTT-----TTGTTTTGCA 5408
1DLcasTaBradi2g14130         TTGACGTGGCTGACTTAACTTGGTGCC----TGTT-----TTGTTTCGCA 4780
                             ***   **** ****************    ****     ****** ***


1BL_2_casTaBradi2g14130      GCATTGTCTTGATGTGTGAGCAGGTGTTGTTAGAGCAGGCTGGCTGGCTC 4222
1BL_casTaBradi2g14130        GCATTGTCTTGATGTGTGAGCAGGTGTTGTTAGAGCAGGCTGGCTGGCTC 4241
1ALcasTaBradi2g14130         GCATTGTCTTGATGTGTCGCCAGGTGTTGTTAGAGCAGGCTGTCTGGCTC 5458
1DLcasTaBradi2g14130         GCATTGTCTTGATGTGTCGCCAGGTGTTGTTAGAGCAGGCTGGCTGGCTC 4830
                             *****************   ********************** *******

                                                        Exon 6
1BL_2_casTaBradi2g14130      AAG-----------TGTGGGCGTGACTGACGACTGAAGAGAGAGGAGTAG 4261
1BL_casTaBradi2g14130        AAG-----------TGTGAGCGTGACTGACGACTGAAGAGAGAGGAGTAG 4280
1ALcasTaBradi2g14130         AAG-----------TGTGAGTGTGTCTGACGACTGAAGAGAGAGGAGTAG 5497
1DLcasTaBradi2g14130         AAGGAGGCGGTGCGTGTGAGTGTGACTGACGACTGAAGAGAGAGGTGTAG 4880
                             ***           **** * *** ******************** ****

                              casTaBradi2g14130_DR8
1BL_2_casTaBradi2g14130      GA---TTCTGATGAATGGACCAAAGCTTGGAGCTAATATAATCGTCGTAG 4308
1BL_casTaBradi2g14130        GAGGATTCTGATGAATGAACTAAAGCTTGGAGCTAATATAATCGTCATCG 4330
1ALcasTaBradi2g14130         GAGGATTCTGATGAACTAACCAAAGCTTGGAG------------TCATCG 5535
1DLcasTaBradi2g14130         GAGGATTCTGATGAACCAACCAAAGCTTGGAGCTAATATAATCGTCGTCG 4930
                             **   **********   ** ***********            ** * *

                                                         casTaBradi2g14130_DR9
1BL_2_casTaBradi2g14130      TTTTTCTGGG--------AGCGAGTAGTTGCTAGTTATGTCTGA--TGAA 4348
1BL_casTaBradi2g14130        TTTTTCTGGGGTTGTATGAGCGAGTAGTTGCTAGTTATGTCTGTTTTGAG 4380
1ALcasTaBradi2g14130         TTTTTCTGGGGGTCTATGAGCGAGTAGTTGCTAGTTATGTCCGTTTTGAG 5585
1DLcasTaBradi2g14130         TTTTTCTGGGGGTCTATGAGCGAGTAGTTGCTAGTTATGTCGGTTTTGAG 4980
                             **********        *********************** *   ***

1BL_2_casTaBradi2g14130      TGAACCAAAGTT-------TGAGAGTTA---------------------- 4369
1BL_casTaBradi2g14130        CGCGTTTGAGCTGTGTTGGTGAAAGGTACGGCCACG----------ACGA 4420
1ALcasTaBradi2g14130         CGCGTTTGAGCTGTGTTGGTGAAAGGCACTCCCTCCCTCCCTCCATTTGC 5635
1DLcasTaBradi2g14130         CGCGTTTGAGCTATGTTGGTGAAAGGCACT----------------TTGC 5014
                              *      ** *       *** **  *
```

Appendix 4.10b The sequence generated my primers DF3R3 for the gene TaBradi2g14130.

The Spark and Rialto sequences are identical.

>Spa rkTaBradi2g14130 DF3R3
TCTACATATATGTTCATATGCATGCCCTTTTCTGTATAAAAAATGTAGTCTCTCGC
ATCCTTTCTGGTCCCTAGATAAGCAGGAGATGATGTAGCATTTTAAAAGTTTTAT
GTGCTGATAATTGTAGTGGACGTTTGAAAGCCTGATTTAGTAACTTATCATCCTC
CTTTTTGATGATGTTGTCACTGCAGCAGCTTAAATCTAGGTCAGATGAATCATGG
CGTCCCTCTGAACGAAGAAACCATGGCGCTGCAGAAATTCTGGAACTGAACCGC
CTTGGCCTTCCCATTCGAGAAGTATGCCTATGCTATCTTTTCATCTGTTGGAGTTG
GTACTTATGATTTATATGGAAAATGTTGAAACTGAATGGTAGTCTAATTTACTTTT
CAGGGAGCAAGAAACTGTGACTACTATATGCGAACCGGTGCTTGCAGATATGGC
AAAAACTGCCATTTCAACCATCCAGACCATGTCATTGATGCTCAGTTCAATCCAC
CAACAGGGTGGGAGGATAATGCTTTGCAAATGGAGAAATCTTCTGACCATACAT
TAGATGAGACATCACGCATGAAGAAATCTTCCGATGATGCGACCTTCGATGACA
GATCACACATGAAGAAATCTTCCGATGATGCGACCTTAGATGACAGATCACACTT
GAAGAAACCTTCTGATGGTGCGATCGTAGATGACACATCATACTCAAAGAAGTC
TTCTGACCATGACAACTCATCTAGCTCTGGTGTCCTGCCACCAAGCATATTTAGA
ATGCTTCTACCTCCCCAAAAAGTACTGCCTAGTACG
>Rialto TaBradi2g14130 DF3R3
TCTACATATATGTTCATATGCATGCCCTTTTCTGTATAAAAAATGTAGTCTCTCGC
ATCCTTTCTGGTCCCTAGATAAGCAGGAGATGATGTAGCATTTTAAAAGTTTTAT
GTGCTGATAATTGTAGTGGACGTTTGAAAGCCTGATTTAGTAACTTATCATCCTC
CTTTTTGATGATGTTGTCACTGCAGCAGCTTAAATCTAGGTCAGATGAATCATGG
CGTCCCTCTGAACGAAGAAACCATGGCGCTGCAGAAATTCTGGAACTGAACCGC
CTTGGCCTTCCCATTCGAGAAGTATGCCTATGCTATCTTTTCATCTGTTGGAGTTG
GTACTTATGATTTATATGGAAAATGTTGAAACTGAATGGTAGTCTAATTTACTTTT
CAGGGAGCAAGAAACTGTGACTACTATATGCGAACCGGTGCTTGCAGATATGGC
AAAAACTGCCATTTCAACCATCCAGACCATGTCATTGATGCTCAGTTCAATCCAC
CAACAGGGTGGGAGGATAATGCTTTGCAAATGGAGAAATCTTCTGACCATACAT
TAGATGAGACATCACGCATGAAGAAATCTTCCGATGATGCGACCTTCGATGACA
GATCACACATGAAGAAATCTTCCGATGATGCGACCTTAGATGACAGATCACACTT
GAAGAAACCTTCTGATGGTGCGATCGTAGATGACACATCATACTCAAAGAAGTC
TTCTGACCATGACAACTCATCTAGCTCTGGTGTCCTGCCACCAAGCATATTTAGA
ATGCTTCTACCTCCCCAAAAAGTACTGCCTAGTACG

Appendix 4.11 TaBradi2g13790 assembly and position of primers (cloured sections)

```
                                                   F1
1DL_casTaBradi2g13790       ATTCCGGTGAGAACCCAGTTAAACACGAAACTACAACGTAGTACAGGAAA 641
1AL_casTaBradi2g13790       ATTCCGGTGAGAAACCAGTTAAACACGAAACTACAACGT---ACAAGAAA 64
1BL_casTaBradi2g13790       ATTCCGGTGAGAAACCATTTAAACACGAAACTGCAACGT---ACAAGAAA 429
                            ************* *** ************** ******   *** ****

                                                  Ngs_F1                F1b
1DL_casTaBradi2g13790       ATAATGCCATCGCCAGTTCTAATGAGTGCCGCCGGTCTTCATAAACGCAA 691
1AL_casTaBradi2g13790       -TAATGCCACTGCCAGTTCTAATGAGTGCCGCCGGTCTTCATAAACGCAA 113
1BL_casTaBradi2g13790       ATAATGCCATCGCCCGTTCTAATGAGTGCCGCCGGTCTTCATAAACGCAA 479
                             ********  *** ***********************************

1DL_casTaBradi2g13790       CGACTCGGAGCCTCACTCAGTGCCCCGGTCGGCCAGTCCCCACTGGAAAG 741
1AL_casTaBradi2g13790       CGACTCCGAGCCTCACTCAGTGCCCCGGTCGGCCAGTCCCCACTGGAAAG 163
1BL_casTaBradi2g13790       CGACTCCGAGCCTCACTCAGTGCCCCGGTCGGCCAGTCCCCACTGGAAAG 529
                            ****** *******************************************
                                           Exon1 start!
1DL_casTaBradi2g13790       CGCAGCCCCGCGTTCCTCCTCCTCCCATGGCCGCCGTCGCTCCCGCTCCT 791
1AL_casTaBradi2g13790       CGCAGCGCCGCGTTCCGCCTCCTCCCATGGCCGCCGTC-CTCCCGCTCCT 212
1BL_casTaBradi2g13790       CGCAGCACCGCGTTCCTCTTCCTCCCATGGCCGCCGTC-------CTCCT 572
                            ****** ********* * *******************       *****

1DL_casTaBradi2g13790       CCTCCTCCTCCTAGCCCTCGCGCTCCCCGCCGCCACCAACGCGCTCACCG 841
1AL_casTaBradi2g13790       CCTCCTCCT---AGCCCTCGCGCTCCCCGCCGCCACCGACGCGCTCACCG 259
1BL_casTaBradi2g13790       CCTCCTCCT---AGCCCTCGCGCTCCCCGCCGCCACCAACGCGCTCACCG 619
                            *********   ************************* ************

1DL_casTaBradi2g13790       CCGACGGCCAGGCGCTGCTCTCCTTCAGGGCCGCCGTCCTGCAGGACCCC 891
1AL_casTaBradi2g13790       CCGACGGCCAGGCGCTGCTCTCCTTCCGGGCCGCCGCCTCGCGGGACCCC 309
1BL_casTaBradi2g13790       CCGACGGCCTGGCGCTGCTCTCCTTCAGGGCCGCCGTCCTGCAGGACCCC 669
                            ********* **************** ********* *  ** *******

1DL_casTaBradi2g13790       ACAGGGGCCCTCGCCGACTGGAACGCCTCCGAT-GCCGACCCCTGCTCCT 940
1AL_casTaBradi2g13790       ACGGGGGCCCTCGCCGACTGGAACGCCTCCGATCGCCGACCCCTGCTCCT 359
1BL_casTaBradi2g13790       ACGGGGGCCCTCGCCGACTGGAACGCCTCCGAT-GCCGACCCCTGCTCCT 718
                            ** ****************************** ****************

1DL_casTaBradi2g13790       GGAACGGCGTCGCCTGCGACGACGCCGGCATCCGCCGGGTCGTCGCGCTC 990
1AL_casTaBradi2g13790       GGAACGGCGTCGCCTGCGACGACGCCGCCATCCGCCGGGTCGTCGCGCTC 409
1BL_casTaBradi2g13790       GGAACGGCGTCGCCTGCGACGACGCCGGCGTCCGCCGGGTCGTCGCGCTC 768
                            ************************** * ********************

1DL_casTaBradi2g13790       TCCCTTCCCAGGAAGGGCCTCGTCGCCGCCCTACCGGCGTCCCCGCTCCC 1040
1AL_casTaBradi2g13790       TCCCTTCCCAGGAAGGGCCTCGTCGCCGCCCTACCGGCGTCCGCGCTCCC 459
1BL_casTaBradi2g13790       TCCCTTCCCAGGAAGGACCTCGTCGCCGCCCTACCGGCGTCCCCGCTCCC 818
                            **************** ************************* *******

1DL_casTaBradi2g13790       GGCCTCCCTCCGCCACCTCAACCTCCNNNNNNNN---------------- 1074
1AL_casTaBradi2g13790       GGCCTCCCTCCGCCACCTCAACCTCCGCGGCAACCGCCTCTACGGCGCCC 509
1BL_casTaBradi2g13790       GGACTCCCTCCGCCACCTCAACCTCCGCGGCAACCGCCTCTACGGCACCC 868
                            ** ***********************

1DL_casTaBradi2g13790       -------------------------------------GAGCCTCGTCCTC 1087
1AL_casTaBradi2g13790       TGCCGCCCGCGCTCCTCGCCGGCGCCGCGGGGCTGCAGAGCCTCGTCCTC 559
1BL_casTaBradi2g13790       TGCCGCCCGCGCTCCTCGCCGGCGCCGCGGGGCTCCAGAGCCTCGTCCTC 918
                                                                 *************

1DL_casTaBradi2g13790       TACGGGAACGAGCTCGACGGGCCCGTCCCCGCGGAGCTCGGGGACCTCCC 1137
1AL_casTaBradi2g13790       TACGGGAACGAGCTCGACGGGCCCGTCCCCGCGGAGCTCGGGGACCTCCC 609
1BL_casTaBradi2g13790       TACGGGAACGAGCTCTACGGGCCCGTCCCCGCGGAGCTCGGGGACCTCCC 968
                            *************** **********************************
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                                             F2
1DL_casTaBradi2g13790         CTACCTCCAAATCTTGGACCTTTCCTCCAACAACCTCAACGGCTCTCTCC 1187
1AL_casTaBradi2g13790         CTACCTCCAAATCTTGGACCTCTCCTCCAACTCCCTCAACGGCTCTCTCC 659
1BL_casTaBradi2g13790         CTACCTCCAAATCTTGGACCTCTCCTCCAACGCCCTCAACGGCTCTCTCC 1018
                              ********************* *********  *****************

1DL_casTaBradi2g13790         CCGGGTCGATCCTGAAATGCAGGCGCCTCCGCAGGCTGTCCCTCGGCCGG 1237
1AL_casTaBradi2g13790         CCGGGTCGATCCTGAAATGCAGGCGCCTCCGCAGGCTGTCCCTCGGCCGG 709
1BL_casTaBradi2g13790         CCGGGTCGATCCTGAAATGCAGGCGCCTCCGCAGGCTGTCCCTCGGCCGG 1068
                              **************************************************

1DL_casTaBradi2g13790         AACAACCTCATGGGCCCGATCCCGCCGGGGTTCGGCCGGGAGCTCTCGGC 1287
1AL_casTaBradi2g13790         AACAACCTCACGGGCCCGATCCCGCCGGGGTTCGGCCGGGAGCTCTCGGC 759
1BL_casTaBradi2g13790         AACAACCTCACGGGCCCGATCCCGCCGGGGTTTGGCCGGGAGCTCTCGGC 1118
                              ********** ********************* *****************

                                                            R1
1DL_casTaBradi2g13790         GCTGGAGCAGCTCAATCTGTCCTACAACCGGCTCTCCGGCGCCATCCCGG 1337
1AL_casTaBradi2g13790         GCTGGAGCAGCTCAATCTGTCCTACAACCGCTTCTCCGGCGCCGTCCCGG 809
1BL_casTaBradi2g13790         GCTGGAGGAGCTCAATCTGTCCTACAACCGGTTCTCCGGCGCCGTCCCGG 1168
                              ******* **********************  *********** ******

                                             ngs_R1
1DL_casTaBradi2g13790         ATGACATCGGGAACCTGTCCAGGCTCGAGGGGACGGTGGACCTATCGCAC 1387
1AL_casTaBradi2g13790         ACGACATCGGGAACCTGTCCAGGCTCGAGGGGACGGTGGACCTGTCGCAC 859
1BL_casTaBradi2g13790         ATGACATCGGGAACCTGTCCAGGCTCGAGGGGACGGTGGACCTGTCGCAC 1218
                              * ***************************************** ******

1DL_casTaBradi2g13790         AATGACTTCTCCGGGCCGATTCCGGCGAGCCTGGGGAAATTGCCGGAGAA 1437
1AL_casTaBradi2g13790         AATGGCTTCTCCGGGCCGATTCCGGCGAGCCTGGGGAAATTGCCGGAGAA 909
1BL_casTaBradi2g13790         AATGACTTCTCCGGGCCGATTCCGGCGAGCCTGGGGAAATTGCCGGAGAA 1268
                              **** *********************************************

1DL_casTaBradi2g13790         GGTCTACATTGATCTCTCCTATAACAATTTGTCAGGGCCGATTCCGCAGA 1487
1AL_casTaBradi2g13790         GGTCTACATTGATCTCTCCTATAACAACCTGTCAGGGCCGATTCCGCAGA 959
1BL_casTaBradi2g13790         GGTCTACATTGATCTCTCCTATAACAATTTGTCAGGGCCGATTCCGCAGA 1318
                              ***************************  *********************
                                              F3
1DL_casTaBradi2g13790         ATGGGGCGCTTGACAACCGTGGCCCCACAGCGTTCTTGGGCAACCCAGGG 1537
1AL_casTaBradi2g13790         ATGGGGCGCTTGACAACCGTGGCCCCTCGGCGTTCTTGGGCAACCCAGGG 1009
1BL_casTaBradi2g13790         ATGGGGCGCTTGAGAACCGTGGCCCCACGGCGTTCTTGGGCAACCTAGGG 1368
                              ************* ************ * **************** ****

1DL_casTaBradi2g13790         TTGTGTGGGCCGCCGCTCGAGAACCCCTGCTCGCCGCCATCGTCCAACCC 1587
1AL_casTaBradi2g13790         CTGTGTGGGCCGCCACTCGAGAGCCCCTGCTCGCCGCCATCGTCCAACCC 1059
1BL_casTaBradi2g13790         CTTTGTGGGCCGCCGCTCGAGAACCCGTGCTCGCCGCCATCGTCCAACCC 1418
                               * *********** ******* *** ***********************

1DL_casTaBradi2g13790         GTCTGTTCCGAAGGATGGGGAGTCCGG-TGCCGGGGGC-AACGGGAG-TG 1634
1AL_casTaBradi2g13790         GTCTGTTCCGAAGGATGGGGAGTCCGG-TGCCGGGGGC-AACGGGAG-TG 1106
1BL_casTaBradi2g13790         GTCTGTTCCAAAGGATGGGGAGTCCGGGTGCCGGGGGCGAACGGGAGGTG 1468
                              ********* ***************** ********** ******** **

1DL_casTaBradi2g13790         GGAGGAGC-AAGGGGTTGGGGAAGGCTGCCATTGTGGCCATTGTTCTGGG 1683
1AL_casTaBradi2g13790         GGAGGAGC-AAGGGGTTGGGGAAGGCTGCCATTGTGGCCATTGTTCTGGG 1155
1BL_casTaBradi2g13790         GGAGGAGCGAAGGGGTTGGGGAAGGGTGACATTGTGGCCATTGTTCTGGC 1518
                              ******** **************** ** ******************** 

1DL_casTaBradi2g13790         TGATGTCGCAGGGATCTTGATCATTGCCCTGGT-GTTCT---ACTGCTAT 1729
1AL_casTaBradi2g13790         TGATGTGGTAGGGATCTTGATCATTGCCCTGGT-GTTCTTCTACTGCTAC 1204
1BL_casTaBradi2g13790         TGATGTGGCAGGGATCTTGATCATTGCCCTGGTTGTTCTTCTACTGCTAT 1568
                              ****** * ************************ *****   ******* 
                                                         R2
1DL_casTaBradi2g13790         TGGAAGAAAGTTTCCCCCAAGGAGAAAGGACATGGTGCGGGTCCCGGCTC 1779
1AL_casTaBradi2g13790         TGGAAGAAAGTTTCCCCCAAGGAGAAGGGACATGGTGCGGGCACCGGCTC 1254
1BL_casTaBradi2g13790         TGGAAGAGAGTTTCCCCCAAGGAGAAGGGACATGGTGCGGCTACGGGCTC 1618
                              ******* ****************** *************    * *****
```

```
1DL_casTaBradi2g13790      GAAAGAGTCGAGGTCTGGTTGTTTTAGCAGGGACGAGCCTGAGACTCCAT 1829
1AL_casTaBradi2g13790      CAAAGAGTCGAGGTCTGGTTGTTTTAGCAGGGACGAGCCTGAGACTCCAA 1304
1BL_casTaBradi2g13790      GAAAGAGTCGAGGTCTGGTTGTTTTAGCAGGGACGAGCCGGAGACTCCAT 1668
                            ************************************** ********* 

1DL_casTaBradi2g13790      CAGAGCAGCACGACCTCGTGCTGTTGGACCAGAAAGTGAGGTTTGATCTC 1879
1AL_casTaBradi2g13790      TAGAGCAGCACGACCTCGTGTTGTTGGACCAGAAAGTGAGGTTTGATCTC 1354
1BL_casTaBradi2g13790      CAGAGCAGCACGACCTCGTGCTGTTGGACCAGAAACTGAGGTTTGATCTC 1718
                            ******************* ************** **************

1DL_casTaBradi2g13790      GATGAGCTGCTTAAGGCATCAGCATTTGTGCTCGGGAAGAGTGGGATCGG 1929
1AL_casTaBradi2g13790      GATGAGCTGCTCAAGGCATCAGCATTTGTGCTCGGGAAGAGCGGGATAGG 1404
1BL_casTaBradi2g13790      GATGAGCTGCTCAAGGCATCAGCTTTTGTGCTCGGGAAGAGTGGGATCGG 1768
                           *********** *********** ***************** ***** **

1DL_casTaBradi2g13790      GATTGTGTACAAGGTAGTTCTTGAGGATGGGCTCACCATGGCGGTGAGGC 1979
1AL_casTaBradi2g13790      GATTGTGTACAAGGTAGTTCTTGAGGATGGGCTCACCATGGCGGTGAGGC 1454
1BL_casTaBradi2g13790      GATTGTGTACAAGGTAGTTCTTGAGGATGGGCTCACCATGGCGGTGAGGC 1818
                           **************************************************
                           F4
1DL_casTaBradi2g13790      GACTCGGTGAGGGGGGATTGCAAAGGTTTAAGGAGTTTCAGAGTGAGGTT 2029
1AL_casTaBradi2g13790      GGCTCGGCGAGGGGGGATTGCAAAGGTTTAAGGAGTTTCGGACTGAGGTT 1504
1BL_casTaBradi2g13790      GGCTTGGCGAGGGGGGATTGCAAAGGTTTAAGGAGTTTCAGAGTGAGGTT 1868
                           * ** ** ******************************* ** *******

1DL_casTaBradi2g13790      GAGGCCATTGGCAAGGTCCGGCATGCCAACATTGTTGCCTTGAGGGCCTA 2079
1AL_casTaBradi2g13790      GAGGCCATTGGCAAGGTTCAGCATCCCAACATTGTTACCTTGAGGGCCTA 1554
1BL_casTaBradi2g13790      GAGGCCATTGGCAAGGTCCGGCATCCCAACGTTGTTGCCTTGAGGGCCTA 1918
                           ***************** * **** ***** ***** *************

1DL_casTaBradi2g13790      CTACTGGTCCTTTGATGAGAAGTTGCTGATATATGATTACATCTCAAATG 2129
1AL_casTaBradi2g13790      CTACTGGTCGTTTGATGAGAAGTTGCTGATATATGATTACATTTCAAATG 1604
1BL_casTaBradi2g13790      CTACTGGTCGTTTGATGAGAAGTTGCTGATATATGATTACATCTCAAATG 1968
                           ********* ******************************** *******

1DL_casTaBradi2g13790      GCAGCCTCTCTTCAGCAATTCATGGTATGTGTTATCAACTGAATCGAGCT 2179
1AL_casTaBradi2g13790      GCAGCCTCTCTTCAGCAATTCATGGTATGTGTTATCAACTGAGTCGAGCT 1654
1BL_casTaBradi2g13790      GCAGCCTCTCTTCAGCAATTCATGGTATGTGTTATCAACTGAATCGAGCT 2018
                           ****************************************** *******

1DL_casTaBradi2g13790      CTCTAATGCCTAGCTTACATCATGTTTCCATTATTTTCT-GTCGCTTCAT 2228
1AL_casTaBradi2g13790      CTCTAATGCCTAGTTTACATCATGTTTCCATTATTTTTTTGTCATTTCGT 1704
1BL_casTaBradi2g13790      CTCTAATGCCTAGTTTACATCATGTT------------------------ 2044
                           ************* ************

1DL_casTaBradi2g13790      AGAACTGTTGACCAGTGATAGTAATTTGTA-GATCAGGATCCTCGTACTG 2277
1AL_casTaBradi2g13790      AGAACAGTTGACCAGTGATATTAATATGTA-GATCAGGATCCTCATACTG 1753
1BL_casTaBradi2g13790      ---------GACCAGTGATAGTAATATGTTTGATGAGAAGT----TACTG 2081
                                    *********** **** ***  *** ** *      *****
                                              R3
1DL_casTaBradi2g13790      ATATAATGTACTTCGACATTGATTAGTTTTGCCCCTTGTGATACGATTTT 2327
1AL_casTaBradi2g13790      ATGTAATGCACTTCGACATTGATTAGTTTTGCCT-TTGTGATACGATTTT 1802
1BL_casTaBradi2g13790      ATGTAATGCACTTCAACACTAATTAGTTTTGCCT-TTGTGATACGATTTT 2130
                           ** ***** ***** *** * ************  ***************

1DL_casTaBradi2g13790      TGTTGTTAATGACAAAGCTAGTACCTGGAGTTCAAGTGATATCTCTAGAA 2377
1AL_casTaBradi2g13790      TGTTGTTAACGACGAAACTAGTACCTGGAGTTCAAGTGATATCTCTAGAA 1852
1BL_casTaBradi2g13790      TGTTGTTAATGACGAAGCTATTACCTGGAGTTCAAGTGATATCTCTAGAA 2180
                           ********* *** ** *** *****************************
                                                F5
1DL_casTaBradi2g13790      TGCTCTTTCAGTCCATGTAAATTGTTTTGATACAGTACTGTCTCAGTGGT 2427
1AL_casTaBradi2g13790      TGCTCTTTCAGTCCATATAAATTGCTTTGATACAATATTGTCTCATTGGT 1902
1BL_casTaBradi2g13790      TGCTCTTTCAGTCCATGTAAATTGTTTTGATACAATATTGTCTCATTGGT 2230
                           **************** ******* ********* ** ******* ****
1DL_casTaBradi2g13790      ACTCT---GTTAAAGTTTGACTTTATTCATTTCTTTCTAAAAACAACTTT 2474
1AL_casTaBradi2g13790      ACTCT---GTTAAAGTTTGACTTTATTCATTTCTTTCTAAAAGTAATTTT 1949
1BL_casTaBradi2g13790      ACTCTCATGTTGAAGTTTGACTTTATTCATTTATTTCTAAAAATATTGTT 2280
                           *****   *** ******************** *********  *   **
```

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1DL_casTaBradi2g13790      TTTGAGAGGTAATTTACTTCTTTCTGATGTACTGTCTCTTATATTTATGT 2524
1AL_casTaBradi2g13790      TT--AGAGGTAATTTACTTCTTTCTGGTGTACTGCCTCTTATATTTATGT 1997
1BL_casTaBradi2g13790      TT-GAGAGGTAATCTACTTCTTTCTGATGTACTGCCTCTTATATTTACGT 2329
                           **  ********* ************ ******* ************ **

                                       R4
1DL_casTaBradi2g13790      ACAGAGGGGGTAGTTCTTTGCTAGCAAAGGTTACTAGAGTACATCCTCAC 2574
1AL_casTaBradi2g13790      ACAGAGTGAGTAATTCTTTGCTAGCAAAGGTTACTAGAGTACATCCTCAC 2047
1BL_casTaBradi2g13790      ACAGAGGGAGTAATTCTTTGCTAGCAAAGGTTACTAGAGTACATCCTCAC 2379
                           ****** * *** *************************************
                               F6a
1DL_casTaBradi2g13790      TGCAATGTTGAACCTATGTATTTATTTCAGGCTAGCGTTGCATTGGCTGA 2624
1AL_casTaBradi2g13790      TGCGTAGTACGACCTCTGTGTTTATTTAAGGCTAGTGTTGCATTGGCTGA 2097
1BL_casTaBradi2g13790      TGCGTAGTAGAACCTCTGTATTTATTTCAGGCTAGCGTTGCATTGACTGA 2429
                           ***   **   **** *** ******* ******* ********* ****

                                                  F6 ngsF2
1DL_casTaBradi2g13790      TTTGTTACTTTCAGGTAAACCTGGGACAATGACATTCACACCACTGACAT 2674
1AL_casTaBradi2g13790      TTTATTACTTTCAGGTAAACCTGGGACAATGACATTCACACCATTGACAT 2147
1BL_casTaBradi2g13790      TTTGTTACTTTCAGGTAAACCTGGGACAATGACATTCACACCATTGACAT 2479
                           *** *************************************** ******

1DL_casTaBradi2g13790      GGAATGCACGTCTAAAGATCATGAAAGGAGTCGCGAATGGGATGTCTTTC 2724
1AL_casTaBradi2g13790      GGAATGCACGTCTAAAGATCATGAAAGGAGTCGCAAATGGGATGTCTTTT 2197
1BL_casTaBradi2g13790      GGAATGCACGTCTAAAGATCATGAAAGGAGTCGCGAATGGGATGTCTTTC 2529
                           ********************************** **************

1DL_casTaBradi2g13790      TTGCATGAATTCAGTCCCAAGAAGTACGTACACGGGGACTTGAGGCCGAA 2774
1AL_casTaBradi2g13790      TTGCATGAATTCAGTCCCAAGAAGTATGTACATGGGGACTTGAGGCCGAA 2247
1BL_casTaBradi2g13790      TTGCATGAATTTAGTCCCAAGAAGTATGTACACGGGGACTTGAGGCCGAA 2579
                           *********** ************** ***** *****************

1DL_casTaBradi2g13790      CAATGTCCTTCTTGGAAAGGACATGGAACCGTATATTTCAGATTTCGGCC 2824
1AL_casTaBradi2g13790      CAATGTCCTTCTTGGAAAGGACATGGAACCGTATATTTCAGATTTCGGCC 2297
1BL_casTaBradi2g13790      CAATGTCCTTCTTGGAACGAACATGGAACCGTATATTTCAGATTTCGGCC 2629
                           ***************** * ******************************

1DL_casTaBradi2g13790      TCGGGCGACTAGCAAACATTGCTGGTGGAGCAGCACCTTCTTCGCAATCG 2874
1AL_casTaBradi2g13790      TCGGGCGACTAGCAAACATTGCTGGTGGAGCAGCACCTTCTTCGCAATCG 2347
1BL_casTaBradi2g13790      TCGGACGACTAGCAAACATTGCTGGTGGAGCAGCACCTTCTTCGCAGTCA 2679
                           **** ***************************************** **

1DL_casTaBradi2g13790      GATCGGATTGGCGTCGAAAAGGCTCAGAGTCTGCAGCCAGATTCCTCAAT 2924
1AL_casTaBradi2g13790      GATCGGATTGGCGTCGAAAAGGCTCAGAGTCTGCAGCCAGATTCCTCAAT 2397
1BL_casTaBradi2g13790      GATAGGATTGGCGTCGAAAAGGATCAGAGTCTGCAGCCAGATTCCTCAGT 2729
                           *** ****************** ************************* *
                               F7
1DL_casTaBradi2g13790      GAGCCCTCTTGTGAGCAAAGAAAGTTCATGCTACCAAGCACCAGAAGCGC 2974
1AL_casTaBradi2g13790      GAGCCCTCTTGTGAGCAAAGAAGGTTCATGCTACCAAGCACCAGAAGCAC 2447
1BL_casTaBradi2g13790      GAGCCCTCTTGTGAGCAAAGAAGGTTCATGCTACCAAGCACCAGAAGCGT 2779
                           ********************** *************************
                                                                         R5
1DL_casTaBradi2g13790      TGAAAACATTGAAACCGTCGCAGAAATGGGATGTCTACTCCTATGGCGTG 3024
1AL_casTaBradi2g13790      TGAAAACATTGAAACCGTCGCAGAAATGGGATGTCTACTCCTATGGTGTG 2497
1BL_casTaBradi2g13790      TGAAAACATTGAAACCGTCGCAGAAGTGGGATGTCTACTCCTATGGTGTG 2829
                           ************************* ******************** ***

1DL_casTaBradi2g13790      ATCTTGCTCGAAATGATTACTGGTAGATCGCCCGTCGCTCTCTTGGAAAC 3074
1AL_casTaBradi2g13790      ATCTTGCTCGAAATGATTACTGGTAGATCGCCCATCGCTCTCTTGGAAAC 2547
1BL_casTaBradi2g13790      ATCTTGCTCGAAATGATTACTGGTAGATCGCCCGTCGCTCTCTTGGAAAC 2879
                           ********************************* ****************

1DL_casTaBradi2g13790      TATGCAGATGGATCTTGTCCAGTGGGTCCAGTTCTGTATACAAGATAAGA 3124
1AL_casTaBradi2g13790      TATGCAGATGGATCTTGTCCAGTGGGTCCAGTTCTGTATAGAAGAGAAGA 2597
1BL_casTaBradi2g13790      TATGCAGATGGATCTTGTCCAGTGGGTCCAGTTCTGTATACAAGATAAGA 2929
                           **************************************** **** ****
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1DL_casTaBradi2g13790      AACCATCCGCTGATGTGCTCGACCCTTTCCTCGCGAGGGACTCGGAACAG 3174
1AL_casTaBradi2g13790      AACCATCCGCTGATGTGCTCGATCCTTTTCTCGCCGGGGACTCTGAACAG 2647
1BL_casTaBradi2g13790      AACCATCCGCTGATGTGCTTGACCCTTTCCTCGCCAGGGACTCGGAACAG 2979
                           ****************** ** ***** *****  ******* ******

1DL_casTaBradi2g13790      GAAGGTGAGATGATTGCTGTACTCAAAGTCGCTCTCGCTTGCGTTCATGC 3224
1AL_casTaBradi2g13790      GAAGGTGAGATGATCGCTGTACTCAAAGTCGCTCTCGCTTGCATTCATGC 2697
1BL_casTaBradi2g13790      GAAGGTGAGATGATTGCTGTACTCAAAGTCGCTCTCGCTTGCGTTCATGC 3029
                           ************** *************************** *******
                                                                ngs_R2
1DL_casTaBradi2g13790      TAATCCCGAGCGAAGACCGACGATGAGAAATGTCACAGAAACCTTGGAGC 3274
1AL_casTaBradi2g13790      TAATCCCGAGCGAAGACCGACGATGAGAAATGTCACAGAAACCTTGGAGC 2747
1BL_casTaBradi2g13790      TAATCCCGAGCGAAGACCGGTGATGAGAAATGTCACAGAAACCTTGGAGC 3079
                           ******************  ******************************

                                                                  R6
1DL_casTaBradi2g13790      GCCTGAGCGCTTCAGTTTCAAGCTAGAAAAGCACGACCACGAAAGGGCGG 3324
1AL_casTaBradi2g13790      GCCTGAGCGCTTCAGTTTCAAGCTAGAAAAGCACCACCACGAAAGGGCGG 2797
1BL_casTaBradi2g13790      GCCTGAGCGCTTCAGTTTCAAGCTAGAAAAACACCACCACGAAAGGGCGG 3129
                           ****************************** *** ***************

1DL_casTaBradi2g13790      TGATATGGTTGCAGAAAACATGTGATGGTTGTAAAGCTCAAGCATGGCAA 3374
1AL_casTaBradi2g13790      CGATATGGTTGCAGAAAACATTTGATGGTTGTAAAGCTCAAGCATGGCAA 2847
1BL_casTaBradi2g13790      CGATATGGTTGCAGAAAACATGTGATGGTTGTAA---------------- 3163
                            ******************** ************

1DL_casTaBradi2g13790      AGAAGGTTAGGGGAACACCAAGTGACATTTAGTTAACCATGTAAAATTAT 3424
1AL_casTaBradi2g13790      AGAAGGTTAGGGGAACACCAAGTGACATTTAGTTAACCATGTAAAATTAT 2897
1BL_casTaBradi2g13790      -GAAGGTTAGGGGAACACCCAGTGACATTTAGTTAACCATGTAAAATTAT 3212
                            ****************** ******************************

                             R6b                                   F8
1DL_casTaBradi2g13790      CGATTTCGGGGCCTTTAACAAGTTAGGTACCTATCATGTGTTAGCTTTTC 3474
1AL_casTaBradi2g13790      CATTTTCGGGACCTTTAACAAGTTAGGTACCTACCATGTGTTAGCCTTTC 2947
1BL_casTaBradi2g13790      CATTTTCAGGACCTTTAACAAGTTAGGTACCTACCATGTGTTAGCTTTTC 3262
                           *  **** ** ********************** *********** ****

1DL_casTaBradi2g13790      TTCTT---TGGGAGCAGAGCATGTAGTATCTGTTAGTATTTGCTACTGTA 3521
1AL_casTaBradi2g13790      TTCTTCTTTGGGAGCAGAGCATGTAGTATCTGTTGGTATTTGC-----TA 2992
1BL_casTaBradi2g13790      TTCTTCTTTGGGAGCAGAGCATGTAGTATCTGTTAGTATTTGC-----TA 3307
                           *****    ************************** ********     **
                             R7
1DL_casTaBradi2g13790      GTACTCTGTGTGAGAATGAATTCTGTGCACAGCTGCAGTTAACTCAG-CG 3570
1AL_casTaBradi2g13790      GTACTCTGTGTGAGAAGGAATTCTGTGCACAGCTGCAGTTAACTCAG-CG 3041
1BL_casTaBradi2g13790      GTACTCTGTGTGAGAAGGAATTCTGTGCACAGCTGCAGTTAACTCAGTCG 3357
                           **************** ****************************** **

1DL_casTaBradi2g13790      ATGAATGTACCACGTGGTTGATCAGTTGAAGACTTGCAATGAAATCCCAT 3620
1AL_casTaBradi2g13790      ATGAATGTACCACTAGGTTGATCGGTTGAAGACTTGCAATGAAATCCCTT 3091
1BL_casTaBradi2g13790      ATGAATGTACCACGTGGTTGATCAGTTGAAGACTTGCAATGAAATCCCTT 3407
                           *************  ******** ************************ *

1DL_casTaBradi2g13790      TCCTGATTGTTGTCTATCCTTGCAGTGAATATTAGGTGCAACAATTGCTC 3670
1AL_casTaBradi2g13790      TCCTGATTGTTGTCTATCCTTGCAGTGAATATCAGGTGCAACAATTGCTC 3141
1BL_casTaBradi2g13790      TCCTGATTGTTGTCTATCCTTGCAGTGAATATCAGGTGCAACAATTGCTC 3457
                           ******************************** *****************

1DL_casTaBradi2g13790      ATGTTGCAGACAACTTGGTAGCTCCTCAATTGCAAATAGTGCACACAAAA 3720
1AL_casTaBradi2g13790      ATGTTGCAGACAACTTGGCAGGTCCTCAATTGCAAATAGTGCACACAAAA 3191
1BL_casTaBradi2g13790      ATGTTGCAGACAACTTGGCAGCTCCTCAATTGCAAATAGTGCACGAAAAA 3507
                           ****************** ** **********************  ****

1DL_casTaBradi2g13790      AAAGGAAGCATGATATTAGAA------AAAAAAAAACATCATTTTTTTGT 3764
1AL_casTaBradi2g13790      AT-GGAAGCATGATATTAGGA------AAATAAA--CATAATTTTTTTGT 3232
1BL_casTaBradi2g13790      A--GGAAGCATGATATTTTTGTTCCTCAATTGCAAATATAAGTCTAT--- 3552
                           *  **************          **     *    ** * * * *
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1DL_casTaBradi2g13790      TCCTCTAGTGTATGATGGGCATGGACGCATGGTCAGGCATGTTCTTCAAT 3814
1AL_casTaBradi2g13790      TCCTCTAGTGTATGATAGGCATGGATGCATGGTCAGGCATGTTCCTCAAT 3282
1BL_casTaBradi2g13790      -CCT----TGTATGATAGGCATGGACGCATG-TCAGGCATGT-CCCCAAT 3595
                            ***    ******** ******** ***** ********** *  ****

1DL_casTaBradi2g13790      TGCAAATATCATGTTGCTTAATTAGATAGGATGGAAGCATGCATAATAGT 3864
1AL_casTaBradi2g13790      TGCAAATATCATGTTGCTTAATTAGATAGGATGGAAGCATGCATGATAGT 3332
1BL_casTaBradi2g13790      TGCAAGTATCATGTTACTCA---------GAT----------ATCACA-- 3624
                           ***** ********* ** *         ***          ** * *

1DL_casTaBradi2g13790      AGCATAGTGTTGAGTGCCTTTTGTTTTGCGGGG-ATAGTGTTGAGTACTT 3913
1AL_casTaBradi2g13790      GGCATACTGTTGAGTACCTTTTGTTTTGCGGGGGATAGTGTTGAGTACTT 3382
1BL_casTaBradi2g13790      ---ACCCTTTTGTGTGTGTGT-GTGTTGGGGGGGA--GTGTTGAGTACTT 3668
                              *   * *** **    * * ** *** **** *  *************

1DL_casTaBradi2g13790      TTGGTTCCTCAGATATCACAAACCTTGGCATCAT--CATTAGAAAAATGA 3961
1AL_casTaBradi2g13790      TTGGTTCCTCAGATATCACAACTCTTGGTATTATATCATTAGAAAAATGA 3432
1BL_casTaBradi2g13790      TTGGTTCCTCAGATATCACAAGCCTTGGTATTAT--CATTAGAAAAATGA 3716
                           *********************  ***** ** **  **************

                                             R8
1DL_casTaBradi2g13790      TCCATTTGAAATGTCATGTATGTATATTGCCACTAGTGTTCTAAGGACCT 4011
1AL_casTaBradi2g13790      TCCATTTGAAATATCATGTATGTATATCGCCTCTAGTGTTCTAAGGACCT 3482
1BL_casTaBradi2g13790      TCCCTTTGAAATATCATGTATGTATGTTGCCTCTAGTGTNNNNNNNNNNN 3766
                           *** ******** ************ * *** *******
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Appendix 4.12 TaBradi2g13750

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1ALcasTaBradi2g13750      -----------------------------------------------------------C 1
1DLcasTaBradi2g13750      -------------------------------------------------------GCGTC 5
1BLcasTaBRADI2G13750      CAAGCCACTGGCTGCATGTCTTGCTTCGTCCGACCCACGGGCGTCAACTGCGGCTGCATC 3240
                                                                                     *

1ALcasTaBradi2g13750      CGCCTTCTGTGAGCTGTCGGCGCCGCCGGCTGATGTGGCCCCATTCCTGCCTCTCGCGCC 61
1DLcasTaBradi2g13750      CGCCTTCTGTGAGCTGTCGGCGCCGCCGGCTGATGTGGCCCCATTCCTGCCTCTCGCGCC 65
1BLcasTaBRADI2G13750      CGCCTTCTGTGAGCTGTCGGCGCCGCCGGCTGATGTGGCCCCATTCCTGCCTCTCGCGCC 3300
                          ************************************************************

1ALcasTaBradi2g13750      TGACCTTTACAATCTGCTAACCACATCGCGCTCCAACTGGGCGCTCATCAAGGTGCTCAA 121
1DLcasTaBradi2g13750      TGACCTTTACAATCTGCTAACCACATCCCGCTCCAACTGGGCGCTCATCAAGGTGCTCAA 125
1BLcasTaBRADI2G13750      TGACCTTTACAATCTGCTAACCACATCCCGCTCCAACTGGGCGCTCATCAAGGTGCTCAA 3360
                          ************************** *********************************
                                               casTaBradi2g13750_DF1
1ALcasTaBradi2g13750      GATATTTGCTAGGCTGGCTCCTTTGGAGTCGCGTCTGGCCGCACGGATTGTTGATCCAGT 181
1DLcasTaBradi2g13750      GATATTTGCTAGGCTGGCCCCTCTGGAGTCGCGCCTAGCTGCGCGGATTGTTGATCCAGT 185
1BLcasTaBRADI2G13750      GATATTTGCTAGGCTGGCTCCTCTGGAGTCACGTCTAGCCGCACGGATTGTTGATCCAGT 3420
                          ****************** *** ******* ** ** ** ** *****************
                    casTaBradi2g13750_ngsF1
1ALcasTaBradi2g13750      CTGCCAGCTCCTCACTCGTTCTTCAGCCATGTCGCTGACATTCGAGTGTGTCCGCACAGT 241
1DLcasTaBradi2g13750      CTGCCAGCTCCTCACTCGTTCATCAGCCATGTCGCTGACATTCGAGTGTGTCCGCACGGT 245
1BLcasTaBRADI2G13750      CTGCCAGCTCCTCACTCGTTCTTCAGCCATGTCGCTGACATTCGAGTGTGTCCGCACGGT 3480
                          ********************* *********************************** **

1ALcasTaBradi2g13750      GCTAACTGCACTACCCGCGCATGGCGCTGCAGTGAGCCTTGCCATTGGGAAAGTCAAGGA 301
1DLcasTaBradi2g13750      GCTAACTGCACTACCAGCGCATGGTGCCGCAGTGAGCCTTGCCATTGGGAAAGTCAAGGA 305
1BLcasTaBRADI2G13750      GCTAACTGCACTACCGGCGCATGGTGCCGCAGTGAGCCTTGCCATTGGGAAAGTCAAGGA 3540
                          *************** ******** ** ********************************

1ALcasTaBradi2g13750      ATTCCTTGCTGCTTCTGATGATCCTAACCTGCGCTATCTCGGGCTCTTGGCACTTGGTAT 361
1DLcasTaBradi2g13750      ATTCCTTGCTGCTTCTGATGATCCTAACCTGCGCTATCTCGGGCTCTTGGCACTTGGTAT 365
1BLcasTaBRADI2G13750      ATTCCTTGCTGCTTCTGATGATCCTAACCTGCGCTATCTTGGCCTCTTGGCACTTGGTAT 3600
                          *************************************** ** *****************

1ALcasTaBradi2g13750      GCTTGGCCCAGCATATGCATCAACTGTCAATGAGAGCCGTGATGTGATTGCCCTGTCACT 421
1DLcasTaBradi2g13750      GCTTGGCCCAGCATATGCATCAACTGTCAATGAGAGCCGTGATGTGATTGCCCTGTCACT 425
1BLcasTaBRADI2G13750      GCTTGGCCCAGCATATGCATCAACTGTCAATGAGAGTCGTGATGTGATTGCCCTGTCACT 3660
                          ************************************ ***********************

1ALcasTaBradi2g13750      GGGTGATGCTGATTCAAACATCCGCAGGGAGGCATTGCACCTTATGATGGGAATGGTTGA 481
1DLcasTaBradi2g13750      GGGTGATGCTGACTCAAACATCCGTAGGGAGGCATTGCACCTTATGATGGGAATGGTTGA 485
1BLcasTaBRADI2G13750      GGGTGATGCTGACTCAAACATCCGTAGGGAGGCATTGCACCTTATGATGGGAATGGTTGA 3720
                          ************ *********** ***********************************

1ALcasTaBradi2g13750      TGAAAACAATGTCATGGATATTGCTGGCATGCTGGTCAGTCATGCCGCAAGGTCAGACCC 541
1DLcasTaBradi2g13750      TGAAAACAATGTCATGGATATTGCTGGCATGCTGGTCAGTCATGCCGCAAGGTCAGACCC 545
1BLcasTaBRADI2G13750      TGAAAACAATGTCATGGATATTGCTGGCATGCTGGTCAGTCATGCCGCAAGGTCAGACCC 3780
                          ************************************************************
                         casTaBradi2g13750_DF2
1ALcasTaBradi2g13750      AGAGTTTGCAAATGATATTCTTGGGGCCGTCCTAGCAGCATGTGGGCGCAATGTATATGA 601
1DLcasTaBradi2g13750      AGAGTTTGCAAATGACATTCTTGGTGCCGTCCTAGCAGCATGTGGGCGCAATGTATATGA 605
1BLcasTaBRADI2G13750      AGAGTTTGCAAATGATATTCTTGGGGCCGTCCTAGCAGCATGTGGGCGCAATGTATATGA 3840
                          *************** ******** ***********************************

1ALcasTaBradi2g13750      GCTGGTGTCAGATTTTGATTGGTATGTCTCGCTACTGGAAGATATGGCTAGGAGCTTGCA 661
1DLcasTaBradi2g13750      GCTGGTGTCAGATTTTGATTGGTATGTCTCACTACTCGCAGATATGGCTAGGAGCTTGCA 665
1BLcasTaBRADI2G13750      GCTGGTGTCAGATTTTGATTGGTATATCTCACTACTCGCAGATATGGCTAGGAGCTTGCA 3900
                          ************************* **** ***** * *********************

1ALcasTaBradi2g13750      TTGTGTGCAGGGGGATGAGATTGGTCGCCAGCTTGTTGATGTGGGACTTAGGGTGCATGA 721
1DLcasTaBradi2g13750      CTGTGCGCAGGGGGATGAGATTGGTCGCCAGCTTGTTGATGTGGGACTTAGGGTGCATGA 725
1BLcasTaBRADI2G13750      CTGTGCGCAGGGGGATGAGATTGGTCGCCAGCTTGTTGATGTGGGACTTAGGGTGCATGA 3960
                           **** ******************************************************

1ALcasTaBradi2g13750      TGCACGGCCAGAGCTTGTTCGTTCAGCTCGATCTCTCCTAATTGATCCTGCTTTGCTTGG 781
1DLcasTaBradi2g13750      TGCACGGCCAGAGCTTGTCCGTTCAGCTCGATCTCTCCTAATTGATCCTGCCTTGCTTGG 785
1BLcasTaBRADI2G13750      TGCACGGCCAGAGCTTGTCCGTTCAGCTCGATCTCTCTTAATTGATCCTGCTTTGCTTGG 4020
                          ****************** ****************** ************* ********
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                     casTaBradi2g13750_DR1         casTaBradi2g13750_DR1
1ALcasTaBradi2g13750        GAACAATCTCCTATGCTCTGTTCTTTCTGCTGCTGCATGGGTCTCTGGTGAGTATATTGA 841
1DLcasTaBradi2g13750        GAACAATCTCCTATGCTCTGTTCTTTCTGCTGCTGCATGGGTCTCTGGTGAGTATATTGA 845
1BLcasTaBRADI2G13750        GAACAATCTCCTATGCTCTGTTCTTTCTGCTGCTGCATGGGTCTCTGGTGAGTATATTGA 4080
                            ************************************************************

1ALcasTaBradi2g13750        TTGTAGCAAGGATCCTGTTGAGCTTGTTGAGGCACTATCACAGCCAAGGACTAGCCTCTT 901
1DLcasTaBradi2g13750        TTGTAGCAAGGATCCTGTTGAGCTTGTTGAGGCACTATCACAGCCAAGGACTAGCCTCTT 905
1BLcasTaBRADI2G13750        TTGTAGCAAGGATCCTGTTGAGCTTGTTGAGGCACTGTCACAGCCAAGGACTAGCCTCTT 4140
                            ************************************ ***********************

1ALcasTaBradi2g13750        GCCAATGTCAGTGAGAGCTGTCTACATCCAGGCAGTACTTAAAGTGGTCACCTTCTGTTG 961
1DLcasTaBradi2g13750        GCCAATGTCAGTGAGAGCTGTGTACATCCAGGCAGTACTTAAAGTGGTCACCTTCTGTTG 965
1BLcasTaBRADI2G13750        GCCAATGTCAGTGAGAGCTGTGTACATCCAGGCAGTACTTAAAGTGGTCACCTTCTGTTG 4200
                            ********************* **************************************

1ALcasTaBradi2g13750        CAATTTATATGTAGAGAGTTCGAATGATTCAAACAAGGAATCGGATATAGTGTTTGATGA 1021
1DLcasTaBradi2g13750        CAATTTATATGTAGAGAGTTCGAATGATTCAAACAAGGAATCGGATCTAGTGTTTGATGA 1025
1BLcasTaBRADI2G13750        CAATTTATATGTAGAGAGTTCGAATGATTCAAACAAGGAATCGGATCTAGTGTTTGATGA 4260
                            ********************************************** *************
                      castaBradi2g13750_DF3
1ALcasTaBradi2g13750        GTTAGCTGTTGATCAAACTGTTAGCAGGGGAATCAAGTCTGAAATTCGTCCTGCTGAAGA 1081
1DLcasTaBradi2g13750        GTTAGCTGTTGATCAAACTGTCAGTAGGGGAAGCAAGTCTGAAATTCAACCTGCTGAAGA 1085
1BLcasTaBRADI2G13750        GTTAGCTGTTGATCAAACTGTTAGTAGGGGAAGCAAGTCTGAAACTCAACCTGCTGAAGA 4320
                            ********************* ** ******* *********** **  ***********

1ALcasTaBradi2g13750        ACAAATCGTTATGCCAGGCACAGCTAAAAACGACCCCTTTTCAAACAAATCAATAGTTTA 1141
1DLcasTaBradi2g13750        ACAAATCGTTATGCCAGGCACAGCTAAAAATGACCCCTTTTCAAACAAATCAATAGTTTA 1145
1BLcasTaBRADI2G13750        ACAAATCATTATGCCAGGCACAGCTAAAAATGACCCCTTTTCAAACAAATCAATAGTTTA 4380
                            ******* ********************** *****************************

1ALcasTaBradi2g13750        CATGATTAACTTGGTTGAAACAACGGTTGGACCACTTGTTGAGTCCAAGGAAGTTGAGGT 1201
1DLcasTaBradi2g13750        CATGATTAACTTGATTGAAACAACGGTTGGGCCCCTTGTTGAGTCCAAGGAAGTTGAGGT 1205
1BLcasTaBRADI2G13750        CATGATTAACTTGATTGAAACAACGGTTGGGCCACTTGTTGAGTCCAAGGAAGTTGAGGT 4440
                            ************* **************** ** **************************

1ALcasTaBradi2g13750        CCTGGAGAGGGCACGCAACCTGATGGGTTTTGTCCATTTGTTAAGAGAGATCTGGGAGTT 1261
1DLcasTaBradi2g13750        CCTGGAGAGGGCGCGCAACCTGATGGGTTTTGTCCATTTGTTAAGAGAGATCTGGGAGTT 1265
1BLcasTaBRADI2G13750        CCTGGAGAGGGCACGCAACCTGATTGGTTTTGTCCATTTGTTAAGAGAGATCTGGGAGTT 4500
                            ************ *********** ***********************************
                                                      casTaBradi2g13750_DR2
1ALcasTaBradi2g13750        GAAGGAAAGGAAGGTCAGTGATCATAACAAGCATAACCGGGTCATGGAGCTCATTAATAG 1321
1DLcasTaBradi2g13750        GAAGGAAAGGAAGGTCAGTGATCATAACAAGCATAAACGGGTCGTGGAGCTCATTAATAG 1325
1BLcasTaBRADI2G13750        GAAGGAAAGGAAGGTCAGTGATCATAACAAGCATAACCGGGTCGTGGAGCTTATTAATAG 4560
                            ************************************ ****** ******* ********

1ALcasTaBradi2g13750        TATGCAAACAGTATTCTCTCAGGAATTAAGGCCTGTTTCTGTGAATGCCCAGAAGAAAAT 1381
1DLcasTaBradi2g13750        TATGCAAACAGTATTCTCTCAGGAATTAAGGCCTGTTTCTGTGAATGCCCAGAAGAAAAT 1385
1BLcasTaBRADI2G13750        TATGCAAAAAGTATTCTCTCAGGAATTAAGGCCTGTTTCTGTGAATGCCCAGAAGAAAAT 4620
                            ******** ***************************************************

1ALcasTaBradi2g13750        TTCCCTTCCTGAGGATCTTGTCTTGCATGAAAATCTGTCTGAACTTGCTGACATTTTAAG 1441
1DLcasTaBradi2g13750        TTCCCTTCCTGAGGATCTTGTCTTGCATGAAAATCTGTCTGAACTTGCTGACATTTTAAG 1445
1BLcasTaBRADI2G13750        TTCCCTTCCTGAGGATCTTGTCTTGCATGAAAATCTGTCTGAACTTGCTGACATTTTAAG 4680
                            ************************************************************

1ALcasTaBradi2g13750        TGAAGATGACACTACTCTGTCAACTTCAATTTCTTTTATCTCTCGCAACTGTCATTCTGT 1501
1DLcasTaBradi2g13750        TGAAGATGACACTATTCTGTCAACTTCAATCTCTTTTATCTCTCGCAACTGTCATTCTGT 1505
1BLcasTaBRADI2G13750        TGAAGATGACACTATTCTGTCAACTTCAATCTCTTTTATCTCTCGCAACTGTCATTCTGT 4740
                            ************** *************** *****************************

                                                            casTaBradi2g13705_DF4
1ALcasTaBradi2g13750        AGAGACTAGAGATGAGCCTGCAGTAGTGTCAGTTGATTCATCTTCTCTTTTTGAGCACCG 1561
1DLcasTaBradi2g13750        AGAGACTAGAGATGAGCCTGCAGTAGTGTCAGTTGATTCATCTTCTCTTTTTGAGCACCG 1565
1BLcasTaBRADI2G13750        AGAGACTAGAGATGAGCCTGCAGTAGTGTCAGTTGATTCATCTTCTCTTTTTGAGCACCG 4800
                            ************************************************************

1ALcasTaBradi2g13750        TAAACGGCATGGGATGTACTATCTCCCAACAGGAAAAGCTGAGGATGACGCAAATAACTA 1621
1DLcasTaBradi2g13750        TAAACGACACGGGATATACTATCTCCCAACAGGAAAAGCTGAGGATGACGCAAATAGCTA 1625
1BLcasTaBRADI2G13750        TAAACGGCACGGGATATACTATCTCCCAACAGGAAAAGCTGAGGATGACGCAAATAGCTA 4860
                            ****** ** ***** **************************************** ***

1ALcasTaBradi2g13750        CCCTCGTGCCAATGATCCTCTTCTTTCTGTTGAGAATGCAAGTGCCATGGAGGATAAATC 1681
1DLcasTaBradi2g13750        CCCTCGTGCCAATGATCCTCTTCTTTCTGCTGAGAATGCAAGTGCCATGGAGGATAAATC 1685
1BLcasTaBRADI2G13750        CCCTCGTGCCAATGATCCTCTTCTTTCCGCTGAGAATGCAAGTGCCATGGAGGATAAATC 4920
                            *************************** * ******************************
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1ALcasTaBradi2g13750      CGAGACTGTCCAGCCTGTATCTGCTGGGAAAAAATTGAAGGCCATGAGGTCCAGACCAAA 1741
1DLcasTaBradi2g13750      CGAGACTGTCCAGCCTGTATCTGCTGGGAAAAAATTGAAGGCCATGAGGTCCAGACCAAA 1745
1BLcasTaBRADI2G13750      CGAGACTGTCCAGCCTGTATCTGCTGGGAAAAAATTGAAGGCCATGAGGTCCAGACCAAA 4980
                          ************************************************************

1ALcasTaBradi2g13750      AGTAGTGAAATTGGATGGCGAAGATTTCCTAAGTTCCATGATGACTAGTGCAAATATTCT 1801
1DLcasTaBradi2g13750      AGTAGTGAAATTGGATGGCGAAGATTTCCTAAGTTCTATGATGACTAGTGCAAATATTCT 1805
1BLcasTaBRADI2G13750      AGTAGTGAAATTGGATGGCGAAGATTTCCTAAGTTCTATGATGACTAGTGCAAATATTCT 5040
                          ************************************ ***********************

1ALcasTaBradi2g13750      AAAGGCTGCAGATAAGTCGGAAGGCATGGGCAAAAAAATGGACACTGCCGAATCTAGTTC 1861
1DLcasTaBradi2g13750      AAAGGCTGCAGATAAGTCAGAAGTCATGGGCAAAAAAATGGACACTGGCGAATCTAGTTC 1865
1BLcasTaBRADI2G13750      AAAGGCTGCAGATAAGTCAGAAGTCATGGGCAAAAAAATGGACACTGGCGAATCTAGTTC 5100
                          ****************** **** *********************** ************

1ALcasTaBradi2g13750      TCAATGGATACAGAACATATATGCTGATACTGGAAGCCTTTCTACTTCAAGTTCTAGGAC 1921
1DLcasTaBradi2g13750      TCAATGGATACAGAACATATATGCTGATACTGGAAGCCTTTCTACTTCAAGTTCTAGGAC 1925
1BLcasTaBRADI2G13750      TCAATGGATACAGAACATATATGCTGATACTGGAAGCCTTTCTACTTCAAGTTCTAGGAC 5160
                          ************************************************************
                       casTaBradi2g13750_DR3
1ALcasTaBradi2g13750      AAGTAAGCAACATGATCTTACTAAAGAGAAGAGCACA---CCTCCTGACATTGATAGGAA 1978
1DLcasTaBradi2g13750      AAGTAAGCAACCCGATCTTACTAAAGAGAAGAGCACAATACCTCTTGACAGTGATAAGAA 1985
1BLcasTaBRADI2G13750      AAGTAAGCAACACGATCTTACTAAAGAGAAGAGCACAATACCTCCTGACAGTGATAAGAA 5220
                          ***********  ************************    **** ***** ***** ***

1ALcasTaBradi2g13750      AGAGGCGAGAAAGCATAAAACCTCTTCTAGGAGTGGGCATCGTCAAGGAAAACATACGCA 2038
1DLcasTaBradi2g13750      AGAGCCGAGAAAGCATAGAACCTCTTCTAGGAGTGGGCATCGTCAAGGAAAACATACACA 2045
1BLcasTaBRADI2G13750      AGAGCCGAGAAAGCATAGAACCTCTTCTAGGAGTGGGCATCGTCAAGGAAAACATACGCA 5280
                          **** ************ *************************************** **

1ALcasTaBradi2g13750      CAGAGAAAGACCTAGTACTCAGCCTGATGTTGCACCTCAAGCTCCGGTTGTTCAAGATTT 2098
1DLcasTaBradi2g13750      CAGAGAAAGACCTAGTACTCAGCCTGATGTTGCACCTCAAGCTCCGGTTGTTCAAGATTT 2105
1BLcasTaBRADI2G13750      CAGAGAAAGACCTAGTACTCAGCCTGATGTTGCACCTCAAGCTCCGGTTGTTCAAGATTT 5340
                          ************************************************************

1ALcasTaBradi2g13750      CCTTCTGTAGCTGCCGAGATTTTTTTTTTGCTTGGTACGTTACAATTACGAAATACAAGT 2158
1DLcasTaBradi2g13750      CCTTCTGTAGCTGCCGAGATTTTTTT--TGCTTGGTACGTTACAATTACGAAATACAAGT 2163
1BLcasTaBRADI2G13750      CCTTCTGTAGCTGCCGAGATTTTTTT--TGCTTGGTAAGTCACAATTACGAAATACAAGT 5398
                          **************************  ********* ** *******************

1ALcasTaBradi2g13750      TGATGTGTTGTAATGTTCATTTGAACGAGGAAGAACATAGGTGTACATGGATGTTAACCT 2218
1DLcasTaBradi2g13750      TGATGTGTTGTATTGTTCATTTGAATGAGGAAGAACATAGGTGTACATGGATGTTAACCT 2223
1BLcasTaBRADI2G13750      TGATGTGTTGTAATGTTCATTTGAATGAGGAAGAACATAGGTGTACATGGATGTTAACCT 5458
                          ************ ************ **********************************
                                         casTaBradi2g13750_DF5
1ALcasTaBradi2g13750      CTTCTGGTAAATTTTCTGTTAGGTCTTTGTATACTATTCCAAAGGCTAGTTAAACTAGAT 2278
1DLcasTaBradi2g13750      CTTCTGCTAAATTTTCTGTTAGGTCTTTGTATACTATCCCAAAGGTTAGTTAAACTAGAT 2283
1BLcasTaBRADI2G13750      CTTCTGGTAAATTTTCTGTTAGGTCTTTGTATACTATCCCAGAGGCTAGTTAAACTAGAT 5518
                          ****** ****************************** *** *** **************
                                 casTaBradi2g13750_DR4
1ALcasTaBradi2g13750      GACCATCTAAGAAAATGTGGTACATGAAAGTTCCAGTGAAGATCAAAGAT--TTTTTTTT 2336
1DLcasTaBradi2g13750      GCCCATTTAAGAAAATTTGGTGCATGAAAGTGCCAGTGAAAATCAAAGGT--TTTTTT-- 2339
1BLcasTaBRADI2G13750      GCCCATTTAAGAAAATGTGGTACATGAAAGTGCCAGTGAAAATCAAAGTTCTTTTTTTTT 5578
                          * **** ********* **** ********* ******** ******* *  ******

1ALcasTaBradi2g13750      GTGTGTGGTTGGTGTTTAAAAAGAGTATTTTGACTAGAGACGTGGTAAATAAAAGAGGTG 2396
1DLcasTaBradi2g13750      --GTGTGGTTGGTGTTTATAAAGAGTATTTTGACTAGAGACG-GTTAAATAAAAGACG-G 2395
1BLcasTaBRADI2G13750      GTGTGTGGTTGGTGTTTAAAAAGAGTATTTTGACTAGAGACGTCTTAGATAAAAGATGTG 5638
                            **************** ***********************    ** ******** * *

1ALcasTaBradi2g13750      GAGTGGGAAG-------------------------------------------------- 2406
1DLcasTaBradi2g13750      AAGTGATAGTC------------------------------------------------- 2406
1BLcasTaBRADI2G13750      GAGTGGGAGGTGATAGATGTTTGTTTTGTGGTTGGCGTACATGGATGTTAACCTCTTCTG 5698
                           ****  *

1ALcasTaBradi2g13750      ------------------------------------------------------------
1DLcasTaBradi2g13750      ------------------------------------------------------------
1BLcasTaBRADI2G13750      GTAAATTTTCTGTTAGGTCTTTGTATACTATCCCAGAGGCTAGTTAAACTAGATGCCCAT 5758


1ALcasTaBradi2g13750      ------------------------------------------------------------
1DLcasTaBradi2g13750      ------------------------------------------------------------
1BLcasTaBRADI2G13750      TTAAGAAAATGTGGTACATGAAAGTGCCCGTGAAAATCAAAGTTCTTTTTTTTGTGTGGT 5818
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1ALcasTaBradi2g13750      ------------------------------------------------------------
1DLcasTaBradi2g13750      ------------------------------------------------------------
1BLcasTaBRADI2G13750      TGATGTTTAAAAGGAGTATTTTGACTAGAGACGTCTTAGATAAAAGATGTGGAGTGGGAA 5878

1ALcasTaBradi2g13750      -TGATAGATGTTTGTTTAGTGAGGAAAAATAACCTATAGACCCTTTATTTCTG------- 2458
1DLcasTaBradi2g13750      -TGATAGATGTTTGTTTTGTTAGGAAAAAAAAGCTATAGACCCTCTATTTCTGCACTGTT 2465
1BLcasTaBRADI2G13750      GTGATAGATGTTTGTTTTGTGAGGAGAAATAAGCTATAGACCCTCTATTTCTGCAGCGTT 5938
                           **************** ** **** *** ** *********** ********

1ALcasTaBradi2g13750      ------------------------------------------------------------
1DLcasTaBradi2g13750      CTATTGCTAGATATATCTGGAGTTCTGGATTATAGTGAAATGTGTGTTTTGGTATTGATT 2525
1BLcasTaBRADI2G13750      CTATTGCTAGATATATCTGGAGTTCTGGATTGTAGTGAAATGTGTGTTTTGGTATTGATT 5998

1ALcasTaBradi2g13750      ------------------------TTTGTG---------TAGCGTTCTATGGTAAGGATG 2485
1DLcasTaBradi2g13750      TTCGAGTAGACACAGTAAATGATCTTTGTAAGTATGTGTTAGCCTTCGATGGTAAGGATG 2585
1BLcasTaBRADI2G13750      TTCGAGTAGAGACAGTAAATGATCTTTGTAAGTATGTGTTAGCCTTCGATGGTAAGGACA 6058
                                                  *****          **** *** **********

1ALcasTaBradi2g13750      CACAGCTAATTTCTGTTGTGCTTTGGGCAATCTGAAAGCAAGAAATGCTGCGCACTGCAA 2545
1DLcasTaBradi2g13750      CACAGCTAATTTCTGTTGCGCTGTGGGCAATCTGAAAGCAAGAAATGCTGCGCACTTCAA 2645
1BLcasTaBRADI2G13750      CACAGCTAATTTTTGTTGTGCTGTGGGCAATCTGAAAGCAAGAAATGCTGCGCATTTCAA 6118
                          ************ ***** *** ******************************* * ***

1ALcasTaBradi2g13750      CAAAAAGTTCCCTTTTGATCTTACAGCAGTATAGTTTCTCAGGATTTTTGTTGGCTGACC 2605
1DLcasTaBradi2g13750      CAAAAAGTTCCCTTTTGATCCTACAGCATTATAGTTTCTCAGGATTTTTGCTGGCTGACC 2705
1BLcasTaBRADI2G13750      CAAAAAGTTCCCTTTTGATCCTACAGCAGTGTAGTTTCTCAGGATTTTTGCTGGCTGACC 6178
                          ******************** ******* * ******************* *********

1ALcasTaBradi2g13750      TTTAGGGCTGGTATACATAGACGAAACCCGCAAAAGGCGCAACGACAAGGGGCAAAAAAG 2665
1DLcasTaBradi2g13750      TTTAGGGCGGTTATACATAGACGAAACCTGCAAAAGGCGTGACGACAAGGGGCAAAAAAA 2765
1BLcasTaBRADI2G13750      TTTCGGG----------------AAACCTGCAAAAGGTGCAACGACAAGGGGCAAAAAAG 6222
                          *** ***                ***** ******** *  ******************

1ALcasTaBradi2g13750      T-TTCAGCTAGTAGCAGTTGAAATCTTCCATCGTCGAAAAGGGTGGAGGCCTATGGTAAG 2724
1DLcasTaBradi2g13750      TCTTCAGCTAGTAGCGGTTGAAATCTTCCATCGTCGAAAAGGGTGGAGGCCTATGGTAAG 2825
1BLcasTaBRADI2G13750      C-TTCAGCTAGTAGCGGTTGAAATCTTCCATCGTCGAAAAGGGTGGCAGCCTATGGTAAG 6281
                            ************* ******************************  ************

1ALcasTaBradi2g13750      TCAAATGTTGCAAGGTGGCTGTGAACTTGGTAGGTTCTTGATGGTA-----GGACTGAGC 2779
1DLcasTaBradi2g13750      TCAAATGTTGCAAGGTGGCTGTGAACTTGGTAAGTTTTTGATGGTA-----GGACTGAGT 2880
1BLcasTaBRADI2G13750      TCAAATGTTGCAAGGTGGCTGTGAACTTGGTGGGTTTTTGGTGGTACTCTAGGACTGAGC 6341
                          *******************************  *** *** *****     ********

1ALcasTaBradi2g13750      TCTGTTTTGTTCTATTTGAGGTCTTTGAGAATTGAGTTGGCTCCTGTGGTGTTTTGGTTC 2839
1DLcasTaBradi2g13750      TCTGTTTTGTTCTGTTTGAGGTCTTCGAGAATTTAGTTGGCTCCTGTGGTGTTTTGGTTC 2940
1BLcasTaBRADI2G13750      TCTGTTTTGTTCTGTTTGAGGTCTTCGAGAATTTAGTTGGCTCCTGTGGTGTTTTGGTTC 6401
                          ************* *********** ******* **************************

                                     casTaBradi2g13750_DF6
1ALcasTaBradi2g13750      TTGAGGCTGAGTGTAGCTGTAGGATGGTTTGGAGATTGCGAGGTCAGTCTGTGTGGCTTG 2899
1DLcasTaBradi2g13750      TCGAGGCTGAGTGTAGCTGTAGGATGGTTTGGAGCTTGCGAGGTCAGTCTGTGTGGCTTG 3000
1BLcasTaBRADI2G13750      TCGAGGCTGAGTGTAGCTGTATGATGGTTTGGAGGTTGCGAGGTCAGTCTGTGTGGCATG 6461
                          * ******************* ************ ********************** **

1ALcasTaBradi2g13750      TGCCACCTGACAGAATGGTTATCTTGATGTGGAACTTGGTTGTTGTTCAGTTTTCATGGA 2959
1DLcasTaBradi2g13750      TGCCACCTGACAGAATGGGTATCTTGATGTGGAACTTGGTTGTTGTTCAGTTTTCATGGA 3060
1BLcasTaBRADI2G13750      TGCCACCTGACAGAATGGGTATCTTGATGTGGGACTTGGTTGTTGTTCAGTTTTCATGGA 6521
                          ****************** ************* ***************************

1ALcasTaBradi2g13750      AATGAAAATTGGGGAAGGGAGGCCCTTGGGTTGAAAGAGAATACGTT-GATGTGTTGTTC 3018
1DLcasTaBradi2g13750      AATGAAAATTGGGGAGCGGGGAGCCCCTTGGGTCGAAAAAGAATACGTTTGATGTGTTGTTC 3120
1BLcasTaBRADI2G13750      AATGAAAATTGGGGCAGGGAGGCCCTTGGGTCGAAAAAGAATACGTT-GATGTGTTGTTC 6580
                          **************  ***** ********* **** ********** ************

                            CasTaBradi2g13750_DR5
1ALcasTaBradi2g13750      ACTTTTTGTGCATTTTCTTTTTTCTTAT----ATTTTCATCGTCAAGCACTTAAATAGTT 3074
1DLcasTaBradi2g13750      ACCTTTTGCACATTTTCTTTTTTTCTTTTCTTATTTTCATCGTCAAGCACTTAAATAGTT 3180
1BLcasTaBRADI2G13750      ACTTTTTGCGCATTTTCTTTTTTTCTTATAT---TTTCATTGGCAAGCACTTAAATAGTT 6637
                          ** *****  *************  * *      ******* * ****************

1ALcasTaBradi2g13750      CCATGCCCCCCTCCCCGCCCC-GAGGAGTTGGTTGACTCATCAGGCTCATGACCTGAAGA 3133
1DLcasTaBradi2g13750      CCATGCCCCC-TCCCAGCCCCTGAGGAATTGGTCGACTCATCAGGCTCATGACCTGAAGC 3239
1BLcasTaBRADI2G13750      CCATGCCCCCCTCCCCGCCCC-GAGGAATTGGTCGACTTATCAGGCTCATGGCC--AAGA 6694
                          ********** **** ***** ***** ***** **** ************ **  ***
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                                   casTaBradi2g13750_DF7
1ALcasTaBradi2g13750      CCGCAGGTTCGAATCATGTCCCTGTCTCTGCATAAGCATCCACGCTTTTCAC-GTGATTA 3192
1DLcasTaBradi2g13750      CTGCAGGTTCGAATCCTGTAGCTGCCTCTGCATAAGTATCCACGCTTTTCACAGTGATTA 3299
1BLcasTaBRADI2G13750      CTGCAGGTTCGAATCCTGTCCCTGCCTCTGCATAAGCATCCACGCTTTTCAC-GTGATTA 6753
                          * ************* ***  *** *********** *************** *******

1ALcasTaBradi2g13750      TAGGTACTCTTTT-CTTGATCGTAGAACCTAATTT------------------------- 3226
1DLcasTaBradi2g13750      TAGGTACCCTTTTTCTTGATCGTAGAACCTAATTTTCTA--------------------- 3338
1BLcasTaBRADI2G13750      TAGGTACTCTTTTTCTTGATCATAGAACCTAATTTTCTATTCCCTCCGTTCCTAAATATT 6813
                          ******* ***** ******* *************

1ALcasTaBradi2g13750      ------------------------------------------------------------
1DLcasTaBradi2g13750      ------------------------------------------------------------
1BLcasTaBRADI2G13750      TATTTTTCTAGAGATTTCAACAAGTGACTACATACGGAGCAAAGTGAGTGGATCTACACT 6873


1ALcasTaBradi2g13750      ------------------------------------------------------------
1DLcasTaBradi2g13750      ------------------------------------------------------------
1BLcasTaBRADI2G13750      CTAAAATATGTCTATATATATCCGTATGTGGTAATCCATTTGAAATTCTAAAAAGACAAA 6933


1ALcasTaBradi2g13750      ------------------------------------------------------------
1DLcasTaBradi2g13750      ------------------------------------------------------------
1BLcasTaBRADI2G13750      TACTCCCTCCGTTCCAAATTACTTGTTGCTGAAATGGATGTATCTAGAACTAAAATACAT 6993


1ALcasTaBradi2g13750      --------------------------------------GAGGGC---TTTA--------- 3236
1DLcasTaBradi2g13750      ---------------------------GAATAGAGCTGGATGGC---TTTG--------- 3359
1BLcasTaBRADI2G13750      CTAGATACATCCATATGTGCGACAAGTAATTTGGAACGGAGGGAGTATTTAGGAACGGAG 7053
                                                              ** **     ***

1ALcasTaBradi2g13750      -----------------------TTTGTGCAATTTCGCTCGCAATACCCTCTCCCCCGGC 3273
1DLcasTaBradi2g13750      -----------------------TTTGTGCAATTTCGCTCGCAATACCCTCTCCTCCGGC 3396
1BLcasTaBRADI2G13750      GGCGTAGAATAGAGCTGAACGGCTTTGTGCAATTTCGCTCGCAATACCCTCTCCCCCGGC 7113
                                                 ******************************* *****

1ALcasTaBradi2g13750      GAGCCTGTGATCGCTGTCTCTAACTGAATAATGCGA---GATGCAACCAATCTGCAGGCC 3330
1DLcasTaBradi2g13750      GAGCTTGCGATCGCTGTCTCTAACTGAATGATGCGACGAGATGCAACCAATCTGCAGGCC 3456
1BLcasTaBRADI2G13750      GAGCCTGCGA---CTGTCTCTAAC-GAATGATGCGA---GACGCAACCAATTTGCAGGC- 7165
                          **** ** **    *********** **** ******    ** ********* *******

1ALcasTaBradi2g13750      TTTCTATTTCTATTTGCGGACTT-GGTACAGTTTGCTTATGTTTTCTAAAAAGAACTACT 3389
1DLcasTaBradi2g13750      TTTCTATTTTGATTTGGGGACTTTGGTACAGTTTGCTTATGTTTTGTAAAAAGAACTGCT 3516
1BLcasTaBRADI2G13750      -------------TTGGGGACTT-GGTACAGTTTGCTTATGTTTTCTAAAAAAAACTGCT 7211
                                       *** ****** ********************* ****** **** **

                                                 casTaBradi2g13750_DR6
1ALcasTaBradi2g13750      TGAGGACGCCGGCCGTGCAGGAGAATGAAGGGCATGGCCTCACGGGACTTCACCTGATCC 3449
1DLcasTaBradi2g13750      -------------------GAAGAACGAAGGGCATGGCCTCGCGGGATTTCACCTGATCG 3557
1BLcasTaBRADI2G13750      GAAGGACGCCGGCCGTGCAGGAGAATGAAGGGCATGGCCTCACGGGACTTCACCTGATCG 7271
                                             * **** *************** ***** ***********

1ALcasTaBradi2g13750      CGCTCTGCCAAAGGG----------------TTTGTCATGGCTGCAGCTGCGGAAGCACT 3493
1DLcasTaBradi2g13750      CGCTCTTCCAAAGGGGCTTTCGCGTGATGGGTTTGTCATGGCTGCAGCTGCGGAAGCACT 3617
1BLcasTaBRADI2G13750      CGCTCTGCCAAAGGG-CTTTCGCGTGA----TGGGTCATGGCTGCAGCTGCGGAAGCACT 7326
                          ****** ********                *  **************************

1ALcasTaBradi2g13750      TCTTTTAT--CGACCGGAACAGATGGGCAAGCACCGGTCCAGCTGAACGC--AGCAACA- 3548
1DLcasTaBradi2g13750      TTTTGTAT--CGATCGGAACACATGGGCAAGCACCGGTCCAGCTGAATGCCAAGCGGTGT 3675
1BLcasTaBRADI2G13750      TCTTTTATATCGATCGGAACACATGGGCAAGCACCGGTCCAGCTGAATGC----CAACA- 7381
                          * ** ***   *** ******* ************************* **     *
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Appendix 6.1 different species *FT3* mRNA

Start ATG and stop TAG codons

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Zea_mays               ATGTCAGCAACCGATCATTTGGTTATGGCTCGTGTCATACAGGATGTATTGGATCCCTTTA 61
Sbicolor
2Zea_mays              ATGTCAGCAACCGATCCTTTGGTTATGGCTCGTGTCCTACAGGATGTGTTGGATACCTTTA 61
2Bdistachyon           TTGTCGGCAGTGGATCCCTTAGTTGTGGCTCATGTCATACAAGATGTGTTGGATCCATTTA 61
3Bdistachyon             GTCGGCAGTGGATCCCTTAGTTGTGGCTCATGTCATACAAGATGTGTTGGATCCATTTA 59
Spark_TaFT3-B1         ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
Eroica_TaFT3-B1        ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
Prokhorovka_TaFT3-B1   ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
CS_TaFT3-B1            ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
Rialto_TaFT3-B1        ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
Bagder_TaFT3-B1        ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
Cadenza_TaFT3-B1       ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
Banco_TaFT3-B1         ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
William_TaFT3-B1       ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
Solid_TaFT3-B1         ATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTA 61
Spark_TaFT3_DD         ATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTA 58
CadenzaTaFT3_DD        ATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTA 58
Rialto_TaFT3_DD        ATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTA 58
CS_TaFT3_DD            ATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTA 58
Charger_TaFT3_DD       ATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTA 58
Badger_TaFT3_DD        ATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTA 58
Avalon_TaFT3_DD        ATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTA 58
A_tauschii_FT3         ATGTCGGCTGCGGATCCATTGGTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTA 58
Cadenza_TaFT3-A1A      ATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTA 61
urartu_TaFT3           ATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTA 61
Avalon_TaFT3-A1A       ATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTA 61
Badger_TaFT3-A1A       ATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTA 61
Charger_TaFT3-A1A      ATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTA 61
Rialto_TaFT3-A1A       ATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTA 61
Spark_TaFT3-A1A        ATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTA 61
CS_TaFT3-A1A           ATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTA 61
HvFT3_Pane             ATGTCTGCAGCGGATCCATTGGTTGTGGCTCATGTTATGCAAGATGTGCTTGATCCATTTA 61
Aedes_aegypti                GCAGCGGATCCCATGGTTGTGGCCCATGTTATACA-GATGTGTTGGATCCATTTA 54
Bdistachyon            ATGTCCACTGTGGGATCATTGGTTCTAGGCCATGTCATAGAGGAGGTTTTGGATCCATTTA 61

Zea_mays                CACCAACCATTCCACTAAGAATAACGTACAACAATAGGCTACTTCTGCCAAGTGCTGAGC 180
Sbicolor
2Zea_mays              CACCAACCATTCCACTAAGAATAACATACAACAATAGTCAAGTTCTGGCAGGTGCTGAGC 172
2Bdistachyon           CACCAACCACTCCACTGAGAATAGCCTACAATAATAGGTTACTTTTACCAGGGACTGAGC 121
3Bdistachyon           CACCAACCACTCCACTGAGAATAGCCTACAATAATAGGTTACTTTTACCAGGGACTGAGC 119
Spark_TaFT3-B1         CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Eroica_TaFT3-B1        CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Prokhorovka_TaFT3-B1   CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
CS_TaFT3-B1            CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Rialto_TaFT3-B1        CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Bagder_TaFT3-B1        CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Cadenza_TaFT3-B1       CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Banco_TaFT3-B1         CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
William_TaFT3-B1       CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Solid_TaFT3-B1         CATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Spark_TaFT3_DD         CATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCTAGTTCTGGCAGGTGCTGAGC 118
CadenzaTaFT3_DD        CATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCTAGTTCTGGCAGGTGCTGAGC 118
Rialto_TaFT3_DD        CATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCTAGTTCTGGCAGGTGCTGAGC 118
CS_TaFT3_DD            CATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCTAGTTCTGGCAGGTGCTGAGC 118
Charger_TaFT3_DD       CATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCTAGTTCTGGCAGGTGCTGAGC 118
Badger_TaFT3_DD        CATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCTAGTTCTGGCAGGTGCTGAGC 118
Avalon_TaFT3_DD        CATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCTAGTTCTGGCAGGTGCTGAGC 118
A_tauschii_FT3         CATCAACTGTTCCACTCAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 118
Cadenza_TaFT3-A1A      CATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGC 121
urartu_TaFT3           CATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGC 121
Avalon_TaFT3-A1A       CATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGC 121
Badger_TaFT3-A1A       CATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGC 121
Charger_TaFT3-A1A      CATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGC 121
Rialto_TaFT3-A1A       CATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGC 121
Spark_TaFT3-A1A        CATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGC 121
CS_TaFT3-A1A           CATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGC 121
HvFT3_Pane             CATCAACCGTTCCATTAAGGATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 121
Aedes_aegypti          CATCAACTGTTCCACTAAGAATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGC 114
Bdistachyon            CACCAGCTACCCCCCTCAGAATAACCTACAACAATAGGCTACTTCTTGCAGGTGTTGAGC 124
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Zea_mays                   TAAAGCCATCCGCGGTTGTAAGTAAACCACGAGTCGATATCGGTGGCAGTGACATGAGGG 240
Sbicolor                                                                ATGAGGG 7
2Zea_mays                  TAAAGCCATCTGCGGTTATAAGTAAACCACGAGTCGATATCGGTGGCAATGACATGAGGA 232
2Bdistachyon               TAAGACCATCTGCAGTTGTAAGCAAGCCGCGAGTTGATATTGGTGGTAATGACATGAGAG 181
3Bdistachyon               TAAGACCATCTGCAGTTGTAAGCGAGCCGCGAGTTGATATTGGTGGTAATGACATGAGAG 179
Spark_TaFT3-B1             TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Eroica_TaFT3-B1            TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Prokhorovka_TaFT3-B1       TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
CS_TaFT3-B1                TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Rialto_TaFT3-B1            TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Bagder_TaFT3-B1            TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Cadenza_TaFT3-B1           TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Banco_TaFT3-B1             TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
William_TaFT3-B1           TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Solid_TaFT3-B1             TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Spark_TaFT3_DD             TAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAG 178
CadenzaTaFT3_DD            TAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAG 178
Rialto_TaFT3_DD            TAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAG 178
CS_TaFT3_DD                TAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAG 178
Charger_TaFT3_DD           TAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAG 178
Badger_TaFT3_DD            TAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAG 178
Avalon_TaFT3_DD            TAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAG 178
A_tauschii_FT3             TAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAG 178
Cadenza_TaFT3-A1           TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAG 181
urartu_TaFT3               TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAG 181
Avalon_TaFT3-A1            TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAG 181
Badger_TaFT3-A1            TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAG 181
Charger_TaFT3-A1           TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAG 181
Rialto_TaFT3-A1            TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAG 181
Spark_TaFT3-A1             TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAG 181
CS_TaFT3-A1                TAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAG 181
HvFT3_Pane                 TAAGACCATCTGCAATTGTAAGTAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAG 181
Aedes_aegypti              TAAGGACATCTGCAGTTGTAAGCAAGCCACGAGTTGATATCGGTGGCAATGACATGAGAG 174
Bdistachyon                TTAAACCATCTGCAGTTGCGAACAAGCCAAGAGTTGATGTTGGTGGCAATGATCTTAGGG 184
                                                                 * **

Zea_mays                   CTTTCTACACCCTG---GTACTGATTGACCCGGATGCCCCAAGTCCAAGCCATCCATCAC 297
Sbicolor                   CTTTCTACACCCTGAAGGTACTGATTGACCCGGATGCTCCAAGTCCAAGCCATCCATCAC 67
2Zea_mays                  CTTTCTACACCCTG---GTACTGATTGACCCGGACGCCCCAAGTCCAAGCCATCCATCAC 289
2Bdistachyon               TTCTCTACACCCTG---GTACTGGTGGATCCGGATGCCCCAAGCCCAAGCCACCCATCAC 238
3Bdistachyon               TTCTCTACACCCTG---GTACTGGTGGATCCGGATGCCCCAAGCCCAAGCCACCCATCAC 236
Spark_TaFT3-B1             TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Eroica_TaFT3-B1            TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Prokhorovka_TaFT3-B1       TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
CS_TaFT3-B1                TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Rialto_TaFT3-B1            TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Bagder_TaFT3-B1            TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Cadenza_TaFT3-B1           TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Banco_TaFT3-B1             TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
William_TaFT3-B1           TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Solid_TaFT3-B1             TCCTCTATACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Spark_TaFT3-D1             TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 235
CadenzaTaFT3-D1            TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 235
Rialto_TaFT3-D1            TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 235
CS_TaFT3-D1                TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 235
Charger_TaFT3-D1           TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 235
Badger_TaFT3-D1            TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 235
Avalon_TaFT3-D1            TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 235
A_tauschii_FT3             TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 235
Cadenza_TaFT3-A1           TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
urartu_TaFT3               TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Avalon_TaFT3-A1            TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Badger_TaFT3-A1            TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Charger_TaFT3-A1           TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Rialto_TaFT3-A1            TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
Spark_TaFT3-A1             TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
CS_TaFT3-A1                TTCTCTACACCCTG---ATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCAC 238
HvFT3_Pane                 TTCTACACACCCTG---ATATTGGTGGATCCAGACGCTCCAAGCCCAAGTCACCCATCAC 238
Aedes_aegypti              TTCTCTACACCCTG---ATACTGGTGGACCCAGACGCCCCAAGCCCAAGTCAACCATCAC 231
Bdistachyon                TGTTCTACACGCTG---GTACTGGTGGATCCGGATGCCCCAAGCCCAAGCAATCCATCAC 241
                              *  * ** ***    ** ** * ** ** ** ** ***** *****  * *******
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Zea_mays                 TAAGGGAGTACTTGCACTGGATGGTGACAGATATTCCAGAAACAACTAGTGTCAACTTTGGC 357
Sbicolor                 TAAGGGAGTACTTGCACTGGATGGTGACAGATATTCCTGAAACAACTAGTGTCAACTTTGGC 127
2Zea_mays                TAAGGGAGTACTTGCACTGGATGGTGACAGATATTCCTGAAACAACTAGTGTCAACTTCGGC 349
2Bdistachyon             TAAGGGAGTACTTGCACTGGATGGTGGCAGATATCCCAGGAACAACTGGTGTCAGCTTCGGC 298
3Bdistachyon             TACGGGAGTACTTGCACTGGATGGTGGCAGATATCCCAGGAACAACTGGTGTCAGCTTCGGC 296
Spark_TaFT3-B1           TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCAGC 298
Eroica_TaFT3-B1          TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCAGC 298
Prokhorovka_TaFT3-B1     TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCAGC 298
CS_TaFT3-B1              TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGC 298
Rialto_TaFT3-B1          TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGC 298
Bagder_TaFT3-B1          TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGC 298
Cadenza_TaFT3-B1         TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGC 298
Banco_TaFT3-B1           TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGC 298
William_TaFT3-B1         TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGC 298
Solid_TaFT3-B1           TAAGGGAGTACTTGCACTGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGC 298
Spark_TaFT3-D1           TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 295
CadenzaTaFT3-D1          TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 295
Rialto_TaFT3-D1          TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 295
CS_TaFT3-D1              TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 295
Charger_TaFT3-D1         TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 295
Badger_TaFT3-D1          TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 295
Avalon_TaFT3-D1          TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 295
A_tauschii_FT3           TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 295
Cadenza_TaFT3-A1         TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGC 298
urartu_TaFT3             TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGC 298
Avalon_TaFT3-A1          TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGC 298
Badger_TaFT3-A1          TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGC 298
Charger_TaFT3-A1         TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGC 298
Rialto_TaFT3-A1          TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGC 298
Spark_TaFT3-A1           TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGC 298
CS_TaFT3-A1              TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGC 298
HvFT3_Pane               TAAGGGAGTACTTGCACTGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGC 298
Aedes_aegypti            TAAGGGAGTACTTGCACTGGATGGTGGCAGACATCCCTGGAACAACTGGTGTCAACTTCGGC 291
Bdistachyon              TAAGGGAGTACTTGCACTGGATGGTGATAGATATCCCTGGGACAACTGGAGCTAGCTTTGGC 301
                         ** ********************    ** ** ** *  ****** * *  * ***

Zea_mays                 CAAGAGCTAATATTTTATGAGAGGCCGGACCCAAGATCTGGCATCCACAGGCTGGTAT 418
Sbicolor                 CAAGAGCTAGTATTTTATGAGCGACCGGACCCAAGATCTGGCATCCACAGGCTGGTAT 188
2Zea_mays                CAAGAGCTAGTATTTTATGAGAGACCAGATCCAAGATCTGGTATCCACAGGCTGGTAT 410
2Bdistachyon             CAAGAGCTTGAAATTTATGAAAGACCAGAACCAAGATCTGGTATCCACAGGATGGTAT 359
3Bdistachyon             CAAGAGCTTGAAATTTATGAAAGACCAGAACCAAGATCTGGTATCCACAGGATGGTAT 357
Spark_TaFT3-B1           CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
Eroica_TaFT3-B1          CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
Prokhorovka_TaFT3-B1     CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
CS_TaFT3-B1              CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
Rialto_TaFT3-B1          CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
Bagder_TaFT3-B1          CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
Cadenza_TaFT3-B1         CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
Banco_TaFT3-B1           CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
William_TaFT3-B1         CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
Solid_TaFT3-B1           CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTAT 359
Spark_TaFT3-D1           CAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTAT 356
CadenzaTaFT3-D1          CAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTAT 356
Rialto_TaFT3-D1          CAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTAT 356
CS_TaFT3-D1              CAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTAT 356
Charger_TaFT3-D1         CAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTAT 356
Badger_TaFT3-D1          CAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTAT 356
Avalon_TaFT3-D1          CAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTAT 356
A_tauschii_FT3           CAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTAT 356
Cadenza_TaFT3-A1         CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTAT 359
urartu_TaFT3             CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTAT 359
Avalon_TaFT3-A1          CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTAT 359
Badger_TaFT3-A1          CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTAT 359
Charger_TaFT3-A1         CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTAT 359
Rialto_TaFT3-A1          CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTAT 359
Spark_TaFT3-A1           CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTAT 359
CS_TaFT3-A1              CAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTAT 359
HvFT3_Pane               CGAGAGCTTGTAGTTTATGAAAGACCAGAACCAAGATCTGGTATCCACCGGATGGTAT 359
Aedes_aegypti            CAAGAGCTTGTAGTATATGAACGACCAGAACCAAGATCTGGTATCCATCGGATGGTAT 352
Bdistachyon              CAGGAACTTGTGGTCTACGAAAGACCAGAACCAAGAATCGGCATCCATCGCATGGTAT 362
                         *  ** ***      ** **     ** ** ** ***    ** ** **   *   ******
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Zea_mays                TTGTGCTGTTCCGTCAACTTGGCAGGGGGACAGTTTTTGCACCAGAAATGCGCCACAACT 477
Sbicolor                TTGTGCTGTTCCGTCAACTTGGCAGGGGGACAGTTTTTGCACCAGAAATGCGCCACAACT 247
2Zea_mays               TTGTGTTGTTCCGCCAACTTGGCAGGGGTACGGTTTTTGCACCAGAAATGCGCCAAAACT 469
2Bdistachyon            TTGTGCTGTTCCAGCAACTAGGTAGGGGGACAGTTTTTGCACCAGACATGCGACACAACT 418
3Bdistachyon            TTGTGCTGTTCCAGCAACTAGGTAGGGGGACAGTTTTTGCACCAGACATGCGACACAACT 416
Spark_TaFT3-B1          TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
Eroica_TaFT3-B1         TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
Prokhorovka_TaFT3-B1    TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
CS_TaFT3-B1             TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
Rialto_TaFT3-B1         TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
Bagder_TaFT3-B1         TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
Cadenza_TaFT3-B1        TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
Banco_TaFT3-B1          TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
William_TaFT3-B1        TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
Solid_TaFT3-B1          TTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATT 418
Spark_TaFT3-D1          TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACT 415
CadenzaTaFT3-D1         TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACT 415
Rialto_TaFT3-D1         TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACT 415
CS_TaFT3-D1             TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACT 415
Charger_TaFT3-D1        TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACT 415
Badger_TaFT3-D1         TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACT 415
Avalon_TaFT3-D1         TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACT 415
A_tauschii_FT3          TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 415
Cadenza_TaFT3-A1        TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 418
urartu_TaFT3            TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 418
Avalon_TaFT3-A1         TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 418
Badger_TaFT3-A1         TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 418
Charger_TaFT3-A1        TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 418
Rialto_TaFT3-A1         TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 418
Spark_TaFT3-A1          TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 418
CS_TaFT3-A1             TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACT 418
HvFT3_Pane              TTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTCCGACAAAACT 418
Aedes_aegypti           TTGTGTTGTTCCAGCAACTAGGTAGGGGGACCGTTTTTGCGCCAGACATGCGACAGAACT 411
Bdistachyon             TTGTGCTTTTCCAACAACTTGGCAAGGGGACAGTTTTTGCACCAGAAGTGCGACACAACT 421
                        ***** * ****  ***** ** * *** ** ******** *****  * ** ** ** *

Zea_mays                TCAACTGCAGAAGCTTTGCACGGCAATATCACCTCAGCATTGCCACCGCTACACATTTCA 537
Sbicolor                TCAACTGCAGAAGCTTTGCACGGCAATATCACCTCAGTGTTGCCACTGCTACATATTTCA 307
2Zea_mays               TCAACTGCAGAAGCTTTGCACGGCAATATCACCTCAGCATTGCCAGTGCTACACATTTCA 529
2Bdistachyon            TCAGCTGCAGGAGCTTTGCACATCAGCACCACCTCAATATTGTGGCTGCCACATATTTCA 478
3Bdistachyon            TCAGCTGCAGGAGCTTTGCACATCAGCACCACCTCAATATTGTGGCTGCCACATATTTCA 476
Spark_TaFT3-B1          TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
Eroica_TaFT3-B1         TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
Prokhorovka_TaFT3-B1    TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
CS_TaFT3-B1             TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
Rialto_TaFT3-B1         TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
Bagder_TaFT3-B1         TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
Cadenza_TaFT3-B1        TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
Banco_TaFT3-B1          TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
William_TaFT3-B1        TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
Solid_TaFT3-B1          TCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCA 478
Spark_TaFT3-D1          TCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 475
CadenzaTaFT3-D1         TCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 475
Rialto_TaFT3-D1         TCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 475
CS_TaFT3-D1             TCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 475
Charger_TaFT3-D1        TCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 475
Badger_TaFT3-D1         TCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 475
Avalon_TaFT3-D1         TCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 475
A_tauschii_FT3          TCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 475
Cadenza_TaFT3-A1        TCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCA 478
urartu_TaFT3            TCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCA 478
Avalon_TaFT3-A1         TCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCA 478
Badger_TaFT3-A1         TCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCA 478
Charger_TaFT3-A1        TCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCA 478
Rialto_TaFT3-A1         TCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCA 478
Spark_TaFT3-A1          TCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCA 478
CS_TaFT3-A1             TCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCA 478
HvFT3_Pane              TCAGCTGCAGGAACTTTGCACGGCAGTACCACCTAAACGTTGTGGCTGCCTCATATTTCA 478
Aedes_aegypti           TCAGCTGCAGGAGCTTTGCACGCCAGCACCACCTCAACATTGTGGCTGCCTCATATTTCA 471
Bdistachyon             TTAACTGCAGGAGCTTTGCACATCAATACAACCTGGACACTGTGGCTGCCACATATTTTA 481
                        * * ****** * ********  **  *  ****      **     *   ** **** *
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                                                                                   Stop!
Zea_mays             ACTGTCAAAGGGAAGGTGGATCCGGCGGAAGAAGGTTTAGG---------------GAAGAGTAG 525
Sbicolor             ACTGTCAAAGGGAAGGTGGATCGGGCGGAAGAAGGTTTCGG---------------GAAGAGTAG 328
2Zea_mays            ACTGTCAAAGGGAAGGTGGATCGGGTGGAAGAAGGTTTAGG---------------GAAGAGTAG 525
2Bdistachyon         ATTGTCAAAGGGAAGGTGGATCGGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
3Bdistachyon         ATTGTCAAAGGGAAGGTGGATCGGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 541
Spark_TaFT3-B1       ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Eroica_TaFT3-B1      ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Prokhorovka_TaFT3-B1 ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
CS_TaFT3-B1          ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Rialto_TaFT3-B1      ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Bagder_TaFT3-B1      ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Cadenza_TaFT3-B1     ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Banco_TaFT3-B1       ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
William_TaFT3-B1     ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Solid_TaFT3-B1       ACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Spark_TaFT3-D1       ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGACCAGAAAGTTCTCAAGGGGAGTAG 540
CadenzaTaFT3-D1      ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGACCAGAAAGTTCTCAAGGGGAGTAG 540
Rialto_TaFT3-D1      ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 540
CS_TaFT3-D1          ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 540
Charger_TaFT3-D1     ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 540
Badger_TaFT3-D1      ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 540
Avalon_TaFT3-D1      ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 540
A_tauschii_FT3       ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 540
Cadenza_TaFT3-A1     ACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
urartu_TaFT3         ACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Avalon_TaFT3-A1      ACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Badger_TaFT3-A1      ACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Charger_TaFT3-A1     ACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Rialto_TaFT3-A1      ACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Spark_TaFT3-A1       ACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
CS_TaFT3-A1          ACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
HvFT3_Pane           ACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTAG 543
Aedes_aegypti        ATTGTCAAAGGGAAGGTGGATCGGGCGGAAGAAGGTTTAGGCCCGAAAGTTCTCAAGGGGAGTAG 536
Bdistachyon          ACTGTCAAAGGGAAGCTGGTTCTGGTGGAAGAAGATTCGGGCCCCGAACTTCT---------TAG 537
                     * ************* *** ** ** ******** **   *
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Appendix 6. 2 *TaFT3-A1* _B_ D amino acid sequence mutation

S106 instead of G106

```
Spark_TaFT3-B1              METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
Eroica_TaFT3-B1             METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
Prokhorovka_TaFT3-B1        METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
CS_TaFT3-B1                 METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
Rialto_TaFT3-B1             METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
Badger_TaFT3-B1             METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
Cadenza_TaFT3-B1            METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
Banco_TaFT3-B1              METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
William_TaFT3-B1            METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
Solid_TaFT3-B1              METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 60
CS_TaFT3-A1                 METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDISGSD 60
Spark_TaFT3-A1              METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDISGSD 60
Rialto_TaFT3-A1             METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDISGSD 60
Charger_TaFT3-A1            METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDISGSD 60
Badger_TaFT3-A1             METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDISGSD 60
Avalon_TaFT3-A1             METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDISGSD 60
Cadenza_TaFT3-A1            METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDISGSD 60
urartu_TaFT3-A1             METSAADPLVVAHVLQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDISGSD 60
Spark_TaFT3-D1              METSAADPLVV-HVIQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 59
Cadenza_TaFT3-D1            METSAADPLVV-HVIQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 59
Rialto_TaFT3-D1             METSAADPLVV-HVIQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 59
CS_TaFT3-D1                 METSAADPLVV-HVIQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 59
Charger_TaFT3-D1            METSAADPLVV-HVIQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 59
Badger_TaFT3-D1             METSAADPLVV-HVIQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 59
Avalon_TaFT3-D1             METSAADPLVV-HVIQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 59
A_tauschii_TaFT3-D1         METSAADPLVV-HVIQDVLDPFTSTVPLRIAYNNRLVLAGAELRPSAIVSKPRVDIGGSD 59
                            *********** ** ***************************************** ***

                                                                  Mutation    !
Spark_TaFT3-B1              METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFSQELVVYERPEPRSG 120
Eroica_TaFT3-B1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFSQELVVYERPEPRSG 120
Prokhorovka_TaFT3-B1        METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFSQELVVYERPEPRSG 120
CS_TaFT3-B1                 METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFGQELVVYERPEPRSG 120
Rialto_TaFT3-B1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFGQELVVYERPEPRSG 120
Badger_TaFT3-B1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFGQELVVYERPEPRSG 120
Cadenza_TaFT3-B1            METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFGQELVVYERPEPRSG 120
Banco_TaFT3-B1              METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFGQELVVYERPEPRSG 120
William_TaFT3-B1            METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFGQELVVYERPEPRSG 120
Solid_TaFT3-B1              METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTSGSFGQELVVYERPEPRSG 120
CS_TaFT3-A1                 METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPATTGASFGQELVVYERPEPRSG 120
Spark_TaFT3-A1              METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPATTGASFGQELVVYERPEPRSG 120
Rialto_TaFT3-A1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPATTGASFGQELVVYERPEPRSG 120
Charger_TaFT3-A1            METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPATTGASFGQELVVYERPEPRSG 120
Badger_TaFT3-A1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPATTGASFGQELVVYERPEPRSG 120
Avalon_TaFT3-A1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPATTGASFGQELVVYERPEPRSG 120
Cadenza_TaFT3-A1            METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPATTGASFGQELVVYERPEPRSG 120
urartu_TaFT3-A1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPATTGASFGQELVVYERPEPRSG 120
Spark_TaFT3-D1              METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTGASFGQELLVYERPEPRSG 119
Cadenza_TaFT3-D1            METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTGASFGQELLVYERPEPRSG 119
Rialto_TaFT3-D1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTGASFGQELLVYERPEPRSG 119
CS_TaFT3-D1                 METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTGASFGQELLVYERPEPRSG 119
Charger_TaFT3-D1            METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTGASFGQELLVYERPEPRSG 119
Badger_TaFT3-D1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTGASFGQELLVYERPEPRSG 119
Avalon_TaFT3-D1             METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTGASFGQELLVYERPEPRSG 119
A_tauschii_TaFT3-D1         METRVLYTLILVDPDAPSPSHPSLREYLHWMETVSDIPGTTGASFGQELLVYERPEPRSG 119
                            ************************************** **  ** *** **********
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```
Spark_TaFT3-B1            IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
Eroica_TaFT3-B1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
Prokhorovka_TaFT3-B1      IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
CS_TaFT3-B1               IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
Rialto_TaFT3-B1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
Badger_TaFT3-B1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
Cadenza_TaFT3-B1          IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
Banco_TaFT3-B1            IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
William_TaFT3-B1          IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
Solid_TaFT3-B1            IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQYHLNIVAASYFNCQREGGSGGRRF 180
CS_TaFT3-A1               IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAVSYFNCQREGGSGGRRF 180
Spark_TaFT3-A1            IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAVSYFNCQREGGSGGRRF 180
Rialto_TaFT3-A1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAVSYFNCQREGGSGGRRF 180
Charger_TaFT3-A1          IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAVSYFNCQREGGSGGRRF 180
Badger_TaFT3-A1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAVSYFNCQREGGSGGRRF 180
Avalon_TaFT3-A1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAVSYFNCQREGGSGGRRF 180
Cadenza_TaFT3-A1          IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAVSYFNCQREGGSGGRRF 180
urartu_TaFT3-A1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAVSYFNCQREGGSGGRRF 180
Spark_TaFT3-D1            IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAASYFNCQREGGSGGRRF 179
Cadenza_TaFT3-D1          IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAASYFNCQREGGSGGRRF 179
Rialto_TaFT3-D1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAASYFNCQREGGSGGRRF 179
CS_TaFT3-D1               IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAASYFNCQREGGSGGRRF 179
Charger_TaFT3-D1          IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAASYFNCQREGGSGGRRF 179
Badger_TaFT3-D1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAASYFNCQREGGSGGRRF 179
Avalon_TaFT3-D1           IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAASYFNCQREGGSGGRRF 179
A_tauschii_TaFT3-D1       IHRMETVFVLFQQLGRGTVFAPDVRHNFSCRNFARQHHLNIVAASYFNCQREGGSGGRRF 179
                          ************************************ ****** ****************

Spark_TaFT3-B1            RPESSQGESTOP 192
Eroica_TaFT3-B1           RPESSQGESTOP 192
Prokhorovka_TaFT3-B1      RPESSQGESTOP 192
CS_TaFT3-B1               RPESSQGESTOP 192
Rialto_TaFT3-B1           RPESSQGESTOP 192
Badger_TaFT3-B1           RPESSQGESTOP 192
Cadenza_TaFT3-B1          RPESSQGESTOP 192
Banco_TaFT3-B1            RPESSQGESTOP 192
William_TaFT3-B1          RPESSQGESTOP 192
Solid_TaFT3-B1            RPESSQGESTOP 192
CS_TaFT3-A1               RPESSQGESTOP 192
Spark_TaFT3-A1            RPESSQGESTOP 192
Rialto_TaFT3-A1           RPESSQGESTOP 192
Charger_TaFT3-A1          RPESSQGESTOP 192
Badger_TaFT3-A1           RPESSQGESTOP 192
Avalon_TaFT3-A1           RPESSQGESTOP 192
Cadenza_TaFT3-A1          RPESSQGESTOP 192
urartu_TaFT3-A1           RPESSQGESTOP 192
Spark_TaFT3-D1            RPESSQGESTOP 191
Cadenza_TaFT3-D1          RPESSQGESTOP 191
Rialto_TaFT3-D1           RPESSQGESTOP 191
CS_TaFT3-D1               RPESSQGESTOP 191
Charger_TaFT3-D1          RPESSQGESTOP 191
Badger_TaFT3-D1           RPESSQGESTOP 191
Avalon_TaFT3-D1           RPESSQGESTOP 191
A_tauschii_TaFT3-D1       RPESSQGESTOP 191
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Appendix 6.3 *TaFT3-B1* compared with Chinese Spring ABD.

pink shows exons yellow shows unique *TaFT3-B1* sequences, red are common A and D *TaFT3*

```
                                                                                   1    2
Solid_TaFT3-B1           AAAGCGCGTCGCAGTCAACTTTGTAAAGTTTCTATAAAACTTTCCATATGTCATACAAAT 60
Banco_TaFT3-B1           AAAGCGCGTCGCAGTCAACTTTGTAAAGTTTCTATAAAACTTTCCATATGTCATACAAAT 60
William_TaFT3-B1         ------------------------------------AAACTTTCCATATGTCATACAAAT 24
Rialto_TaFT3-B1          ------------------------------------AAACTTTCCATATGTCATACAAAT 24
Bagder_TaFT3-B1          ------------------------------------AAACTTTCCATATGTCATACAAAT 24
Cadenza_TaFT3-B1         ------------------------------------AAACTTTCCATATGTCATACAAAT 24
Eroica_TaFT3-B1          ------------------------------------AAACTTTCCATATGTCATACAAAT 24
Prokhorovka_TaFT3-B1     ------------------------------------AAACTTTCCATATGTCATACAAAT 24
Paragon_TaFT3-B1         ------------------------------------AAACTTTCCATATGTCATACAAAT 24
Spark_TaFT3-B1           ------------------------------------AAACTTTCCATATGTCATACAAAT 24
CS_TaFT3-B1              ------------------------------------AAACTTTCCATATGTCATACAAAT 24
CS_TaFt3_D               ------------------------------------AAACTTTCCATATGCCATATAAAT 24
CS_TaFT3-A1              ------------------------------------AAACTTTCCATATGCCATATAAAT 24
                                                             ************** **** ****

                                  3          4     5                           6
Solid_TaFT3-B1           AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 114
Banco_TaFT3-B1           AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 114
William_TaFT3-B1         AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
Rialto_TaFT3-B1          AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
Bagder_TaFT3-B1          AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
Cadenza_TaFT3-B1         AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
Eroica_TaFT3-B1          AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
Prokhorovka_TaFT3-B1     AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
Paragon_TaFT3-B1         AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
Spark_TaFT3-B1           AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
CS_TaFT3-B1              AATATCCGC------TTCAGAACTTGTGGTATAGTCCTGTAGGGATGCAAGTCAGCAAGT 78
CS_TaFT3-D1              AATACCCGCAGGTAGTTCAGAAATTGTGCTACAGTCCTGTAGGGATGCAAGT-------- 76
CS_TaFT3-A1              AATATCCGCAGGTAGTTCAGAAATCGTGCTATAGTCCTGTAGGGATGCAAGT-------- 76
                         **** ****      ******* * *** ** *******************
                           7       8             9                             10
Solid_TaFT3-B1           GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 174
Banco_TaFT3-B1           GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 174
William_TaFT3-B1         GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
Rialto_TaFT3-B1          GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
Bagder_TaFT3-B1          GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
Cadenza_TaFT3-B1         GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
Eroica_TaFT3-B1          GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
Prokhorovka_TaFT3-B1     GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
Paragon_TaFT3-B1         GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
Spark_TaFT3-B1           GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
CS_TaFT3-B1              GGATGGACCCATGGGCTGTTTTATCCAACTAATGGTATACTTCTACTTAGCTGATAATTC 138
CS_TaFT3-D1              GGACGAACCCGCGGGCTGTTTTATCTAACTAATGGTATACTTCTACTTAGCTGATACTTC 136
CS_TaFT3-A1              GAACGGACCCACGGGCTGTTTTATCTAACTAATGGTATACTTCTACTTAGCTGATACTTC 136
                         * * * ****  ************* ***************************** ***

                                                                         11
Solid_TaFT3-B1           TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 233
Banco_TaFT3-B1           TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 233
William_TaFT3-B1         TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
Rialto_TaFT3-B1          TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
Bagder_TaFT3-B1          TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
Cadenza_TaFT3-B1         TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
Eroica_TaFT3-B1          TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
Prokhorovka_TaFT3-B1     TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
Paragon_TaFT3-B1         TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
Spark_TaFT3-B1           TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
CS_TaFT3-B1              TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTGGATGGGTTGTT 197
CS_TaFT3-D1              TGCAGGTACCTAACCAATAGTTTACTTTGTGCACA-TAGCAAATAGCTAGATGAGTTGTT 195
CS_TaFT3-A1              TGCAGGTACCTAACCAATAGTTTACTTTGTGCACAATAGCAAATAGCTAGATGGGTTGTT 196
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Solid_TaFT3-B1          GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 293
Banco_TaFT3-B1          GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 293
William_TaFT3-B1        GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
Rialto_TaFT3-B1         GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
Bagder_TaFT3-B1         GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
Cadenza_TaFT3-B1        GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
Eroica_TaFT3-B1         GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
Prokhorovka_TaFT3-B1    GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
Paragon_TaFT3-B1        GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
Spark_TaFT3-B1          GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
CS_TaFT3-B1             GCGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 257
CS_TaFT3-D1             GGGTTGGCCCAATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 255
CS_TaFT3-A1             GG-TTGGCC--ATCAGCCCAAACTTGCATCCTTATGTATGGATAGGCGAGCCTATCGAAT 253
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                                                12                        13
Solid_TaFT3-B1          AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 353
Banco_TaFT3-B1          AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 353
William_TaFT3-B1        AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
Rialto_TaFT3-B1         AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
Bagder_TaFT3-B1         AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
Cadenza_TaFT3-B1        AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
Eroica_TaFT3-B1         AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
Prokhorovka_TaFT3-B1    AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
Paragon_TaFT3-B1        AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
Spark_TaFT3-B1          AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
CS_TaFT3-B1             AAAACTGAATGGTTCCACTAGAAAAAAGAATATAACAGAATTGTATTGTAGAGAACTGGC 317
CS_TaFT3-D1             AAAACTGAATGGTTCTACTAGAAAAA-GA-TATAACAGAATTGTATTGTAGAAAACTGGC 313
CS_TaFT3-A1             AAAACTGAATGGTTCCACTAGAAAAA-GAATATAACAGAATTGTATTGTAGAAAACTGGC 312
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                          14 15/16    17  18           19           20  21 22
Solid_TaFT3-B1          AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 409
Banco_TaFT3-B1          AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 409
William_TaFT3-B1        AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
Rialto_TaFT3-B1         AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
Bagder_TaFT3-B1         AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
Cadenza_TaFT3-B1        AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
Eroica_TaFT3-B1         AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
Prokhorovka_TaFT3-B1    AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
Paragon_TaFT3-B1        AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
Spark_TaFT3-B1          AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
CS_TaFT3-B1             AAAAAAAAC-CTAAAACACACGATGGCCTGCTGGGCTGGATAACTACT---AACGCACGG 373
CS_TaFT3-D1             AAAAGAAATACTACAATACATGATGGCCTGCTGCGCTGGATAACTATTTTTAAGGCACGG 373
CS_TaFT3-A1             AAAAGAAATACTAAAATACATGATGGCCTACTGCGCTGGATAACTATTTTTAAGGCACGG 372
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                            23                     24/25                         26
Solid_TaFT3-B1          TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 468
Banco_TaFT3-B1          TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 468
William_TaFT3-B1        TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
Rialto_TaFT3-B1         TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
Bagder_TaFT3-B1         TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
Cadenza_TaFT3-B1        TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
Eroica_TaFT3-B1         TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
Prokhorovka_TaFT3-B1    TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
Paragon_TaFT3-B1        TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
Spark_TaFT3-B1          TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
CS_TaFT3-B1             TTAAAACTAAAGCCAACA-CAAAAGCAGATTGCCTTAAATAAGCAATATCAGCAACACAA 432
CS_TaFT3-D1             TTAAAAATAAAGCCAACAACAAAAGCAAACTACCTTAAATAAGCAACATCAGCAACAAAG 433
CS_TaFT3-A1             TTAAAAATAAAGCCAACA-CAAAAGCAAACTACCTTAAATAAGCAATATCAGCAACACAG 431
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                            27           28              29                  30
Solid_TaFT3-B1          TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 526
Banco_TaFT3-B1          TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 526
William_TaFT3-B1        TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
Rialto_TaFT3-B1         TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
Bagder_TaFT3-B1         TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
Cadenza_TaFT3-B1        TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
Eroica_TaFT3-B1         TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
Prokhorovka_TaFT3-B1    TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
Paragon_TaFT3-B1        TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
Spark_TaFT3-B1          TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
CS_TaFT3-B1             TGAAGATATGCAATGATTAGGCTAGTGCTAGTCTA--TAAACTACCTTAGATCTTAGCTA 490
CS_TaFT3-D1             TGAAGAGATGCAATGATTAAGCTAGTGCTACTCTAGACAAACTACCTTAGATCTTTGCTA 493
CS_TaFT3-A1             TGAAGAGATGCAATGATTAAGCTAGTGCTAGTCTAGACAAACTACCTTAGATCTTTGCTA 491
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                                                31

Solid_TaFT3-B1         AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 586
Banco_TaFT3-B1         AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 586
William_TaFT3-B1       AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
Rialto_TaFT3-B1        AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
Bagder_TaFT3-B1        AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
Cadenza_TaFT3-B1       AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
Eroica_TaFT3-B1        AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
Prokhorovka_TaFT3-B1   AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
Paragon_TaFT3-B1       AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
Spark_TaFT3-B1         AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
CS_TaFT3-B1            AAAGTTGCACAGAACAAAGAACATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 550
CS_TaFT3-D1            AAAGTTGCACAGAA-------CATAACAATGGCTTCAAGAAGATGCATGCAGCTCACTTT 546
CS_TaFT3-A1            AAAGTTGCACAGAA-------CATAACAGTGGCTTCAAGAAGATGCATGCAGCTCATTTT 544
                       **************       ******* *************************** ***

                       32/33            34     35                         36/37
Solid_TaFT3-B1         TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 641
Banco_TaFT3-B1         TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 641
William_TaFT3-B1       TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
Rialto_TaFT3-B1        TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
Bagder_TaFT3-B1        TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
Cadenza_TaFT3-B1       TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
Eroica_TaFT3-B1        TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
Prokhorovka_TaFT3-B1   TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
Paragon_TaFT3-B1       TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
Spark_TaFT3-B1         TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
CS_TaFT3-B1            TC--GC-ATAAACAGAAG--TGATGACCCTGTTCCAACATAGAGTAGCGTTGCAACTTGG 605
CS_TaFT3-D1            TTCGGTGATAAACAGAAGAGTGATGGCTCTGTTCCAACATAGAGTATCGCTGCAACTTGG 606
CS_TaFT3-A1            TTCGGCAATAAGTAGAAGAGTGATGGCCCTGTTCCAACATAGAGTATTGCTGCAACTTGG 604
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                                           38                   39
Solid_TaFT3-B1         CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 686
Banco_TaFT3-B1         CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 686
William_TaFT3-B1       CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
Rialto_TaFT3-B1        CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
Bagder_TaFT3-B1        CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
Cadenza_TaFT3-B1       CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
Eroica_TaFT3-B1        CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
Prokhorovka_TaFT3-B1   CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
Paragon_TaFT3-B1       CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
Spark_TaFT3-B1         CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
CS_TaFT3-B1            CAGGTCACAGTAGAAAAAATCCACTTTGTAAACAACAGTAAT--------GCT------- 650
CS_TaFT3-D1            CAGGTCACAGTAGAAAAAGTTCACTTTGGAAACAACAGTAATGTCACCAGGCTCCTGCCC 666
CS_TaFT3-A1            CAGGTCACAGTAGAAAAAATTCACTTTGTAAACAACAGTGACATGAGCAGGCTCCTGGCC 664
                       ****************** * ******* ********** *         ***

                            40                                41   42              43
Solid_TaFT3-B1         ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 742
Banco_TaFT3-B1         ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 742
William_TaFT3-B1       ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
Rialto_TaFT3-B1        ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
Bagder_TaFT3-B1        ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
Cadenza_TaFT3-B1       ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
Eroica_TaFT3-B1        ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
Prokhorovka_TaFT3-B1   ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
Paragon_TaFT3-B1       ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
Spark_TaFT3-B1         ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
CS_TaFT3-B1            ----TGCGATTAAGTGGGTTGCAAGCATATGTTTCTCATTTCTACTAGTCCATTTTATGC 706
CS_TaFT3-D1            TGAGTGCAATTAAGTGGGTTGCAAGCATATGTGTTCCATTCCTGCTAGCCCATTTTATGT 726
CS_TaFT3-A1            TGAGTGCAATTAAGTGGGTTGCAAGCATATGTTTTCCATTCCTACTAGTCCATTTTATGT 724
                           *** ************************ *  **** ** **** **********

                                                 44
Solid_TaFT3-B1         AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 802
Banco_TaFT3-B1         AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 802
William_TaFT3-B1       AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
Rialto_TaFT3-B1        AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
Bagder_TaFT3-B1        AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
Cadenza_TaFT3-B1       AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
Eroica_TaFT3-B1        AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
Prokhorovka_TaFT3-B1   AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
Paragon_TaFT3-B1       AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
Spark_TaFT3-B1         AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
CS_TaFT3-B1            AATCCCTGAATTTGAATAAAATAATGGCCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 766
CS_TaFT3-D1            AATCCCTGAATTTGAATAAAATAATGACCCTAGGCTATAAGGAGTATGAGTTTTCAGAAG 786
CS_TaFT3-A1            AATCCCTGATTTTGAATAAAATAATGACCCTAAGCTATAAGGAATATGAGTTTTCAGAAG 784
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                                            45    46          47                        48
Solid_TaFT3-B1            GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 861
Banco_TaFT3-B1            GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 861
William_TaFT3-B1          GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
Rialto_TaFT3-B1           GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
Bagder_TaFT3-B1           GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
Cadenza_TaFT3-B1          GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
Eroica_TaFT3-B1           GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
Prokhorovka_TaFT3-B1      GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
Paragon_TaFT3-B1          GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
Spark_TaFT3-B1            GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
CS_TaFT3-B1               GGAAA-ACATCTTCTAATGTTGTGCAAATGTGTTACATGCCAACAAGAAAACAACATCAG 825
CS_TaFT3-D1               GGAAACAATCTTTTAATGCTATGCAAATGCATTACATGCCAACAATAAAACAATATCAG 846
CS_TaFT3-A1               GGAAA-AAATCTTTTAATGCTGTGCAAATGCATTACATGCCAACAAGAAAACAATGTCAG 843
                          ***** * ***** ***** * ********  ************** *******  ****

Solid_TaFT3-B1            CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 921
Banco_TaFT3-B1            CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 921
William_TaFT3-B1          CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
Rialto_TaFT3-B1           CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
Bagder_TaFT3-B1           CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
Cadenza_TaFT3-B1          CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
Eroica_TaFT3-B1           CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
Prokhorovka_TaFT3-B1      CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
Paragon_TaFT3-B1          CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
Spark_TaFT3-B1            CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
CS_TaFT3-B1               CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 885
CS_TaFT3-D1               CAGATATCTCAAAAAAGTACAAGGGGAAGTACTTAATACCACTAAGCATGCAGTTGAAAT 906
CS_TaFT3-A1               CAGATATCTAAAAAAAATACAAGGGAAAGTACTTAATACCAGTAAGCATGCAGTTGAAAT 903
                          ********* ****** ******** *************** *****************
                                             49                    50  51                52
Solid_TaFT3-B1            GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 981
Banco_TaFT3-B1            GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 981
William_TaFT3-B1          GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
Rialto_TaFT3-B1           GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
Bagder_TaFT3-B1           GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
Cadenza_TaFT3-B1          GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
Eroica_TaFT3-B1           GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
Prokhorovka_TaFT3-B1      GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
Paragon_TaFT3-B1          GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
Spark_TaFT3-B1            GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
CS_TaFT3-B1               GAAGAACCTAAGTACGTAAAGTACAACTACATGTTTAGCTTCACTACATTGTTAATTAGG 945
CS_TaFT3-D1               GAAGAACCTAAGAACGTTAAGTACATCTACATGTTCAGCGTCACTACATTGTTA----GG 962
CS_TaFT3-A1               GAAGAACCTAAGCATGTTAAGTACACCTACATGTTCAGCGTCACTACATTGTTA----GG 959
                          *** ******** * ** ******* ********* *** **************     **
                                                  53   54         55          56
Solid_TaFT3-B1           TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1041
Banco_TaFT3-B1           TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1041
William_TaFT3-B1         TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
Rialto_TaFT3-B1          TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
Bagder_TaFT3-B1          TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
Cadenza_TaFT3-B1         TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
Eroica_TaFT3-B1          TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
Prokhorovka_TaFT3-B1     TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
Paragon_TaFT3-B1         TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
Spark_TaFT3-B1           TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
CS_TaFT3-B1              TTCAGAAATATGGTACCCATTATTTCCATAGAGGTTGTGATCTAAGGAATGCACTAACTA 1005
CS_TaFT3-D1              TTCAGAAATATGGTACCTATTATCTCCAAAGAGGTTGTGACCGAAGGAATGCGCTAACTA 1022
CS_TaFT3-A1              TTCAGAAATATGGTACCCATTATCTCCAAAGAGGTTGTGACCAAAGGAATGCGCTAACTA 1019
                         ***************** ***** **** *********** *  ********* *******
                                                                         57
Solid_TaFT3-B1           TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1101
Banco_TaFT3-B1           TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1101
William_TaFT3-B1         TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
Rialto_TaFT3-B1          TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
Bagder_TaFT3-B1          TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
Cadenza_TaFT3-B1         TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
Eroica_TaFT3-B1          TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
Prokhorovka_TaFT3-B1     TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
Paragon_TaFT3-B1         TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
Spark_TaFT3-B1           TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
CS_TaFT3-B1              TCGCCCACAATTCACAAGCTTGTTCCAGTATACCACAGCCATGCTAATGATCGGATGGCT 1065
CS_TaFT3-D1              TCGCCCACAATTCACAAGTTTGTTCCAGTATACCACAGCCATGGTAATAATCGGATGGCT 1082
CS_TaFT3-A1              TCGTTTACAATTCACAAGCTCGTCCCAGTATACCACAGCCATGCTAATAATAGGATGGCT 1079
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Solid_TaFT3-B1        TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1161
Banco_TaFT3-B1        TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1161
William_TaFT3-B1      TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
Rialto_TaFT3-B1       TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
Bagder_TaFT3-B1       TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
Cadenza_TaFT3-B1      TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
Eroica_TaFT3-B1       TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
Prokhorovka_TaFT3-B1  TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
Paragon_TaFT3-B1      TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
Spark_TaFT3-B1        TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
CS_TaFT3-B1           TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1125
CS_TaFT3-D1           TAAGCATGCATGTCGAAATATCTACGGCCCGACTACTCCATAAAGTTCAGGATCTAATCG 1142
CS_TaFT3-A1           TTAGCATGCATGTCAAAATATCTACGGCCCGACCACTCCATAAAGTACAGGATCTAATCG 1139
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                        58        59                      60/61
Solid_TaFT3-B1        ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1221
Banco_TaFT3-B1        ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1221
William_TaFT3-B1      ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
Rialto_TaFT3-B1       ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
Bagder_TaFT3-B1       ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
Cadenza_TaFT3-B1      ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
Eroica_TaFT3-B1       ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
Prokhorovka_TaFT3-B1  ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
Paragon_TaFT3-B1      ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
Spark_TaFT3-B1        ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
CS_TaFT3-B1           ACGAATATCAAAGACGTTACGTGTATACAGGTGACACAGAACATGACGCTAGTATCAAAA 1185
CS_TaFT3-D1           ACAAATATCAATGATGTAACGAGTATACAGGTGACGCACGACATGACGCTAGTATCAAAA 1202
CS_TaFT3-A1           ACAAATATCAATGACGTTACG----TACAGGTGACGCACAACATGACGCTAGTATCAAAA 1195
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Solid_TaFT3-B1        CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1281
Banco_TaFT3-B1        CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1281
William_TaFT3-B1      CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
Rialto_TaFT3-B1       CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
Bagder_TaFT3-B1       CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
Cadenza_TaFT3-B1      CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
Eroica_TaFT3-B1       CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
Prokhorovka_TaFT3-B1  CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
Paragon_TaFT3-B1      CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
Spark_TaFT3-B1        CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
CS_TaFT3-B1           CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1245
CS_TaFT3-D1           CTTTTGAAAGGTGAATAAGACAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGT 1262
CS_TaFT3-A1           CTTTTGAAAGGTGAATAAGACAACCCTCATCGCACAATACAAGTAGTTCGTGCAAGTAGG 1255
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                                     62             63            a 64      65
Solid_TaFT3-B1        TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1341
Banco_TaFT3-B1        TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1341
William_TaFT3-B1      TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
Rialto_TaFT3-B1       TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
Bagder_TaFT3-B1       TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
Cadenza_TaFT3-B1      TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
Eroica_TaFT3-B1       TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
Prokhorovka_TaFT3-B1  TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
Paragon_TaFT3-B1      TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
Spark_TaFT3-B1        TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
CS_TaFT3-B1           TCATACATAGACACAGTTTGTTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGAC 1305
CS_TaFT3-D1           TCCTGCATAGACACAACTGGTTTCAGGTCTGTAGAGAGCTAGGTTATCACAATAACAGAC 1322
CS_TaFT3-A1           TCATACATAGACACAATTTGTTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGAC 1311
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                           66      67             b 68 Start!
Solid_TaFT3-B1        AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1400
Banco_TaFT3-B1        AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1400
William_TaFT3-B1      AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
Rialto_TaFT3-B1       AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
Bagder_TaFT3-B1       AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
Cadenza_TaFT3-B1      AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
Eroica_TaFT3-B1       AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
Prokhorovka_TaFT3-B1  AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
Paragon_TaFT3-B1      AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
Spark_TaFT3-B1        AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
CS_TaFT3-B1           AA-GGACAAGGCTATTAATTGGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTG 1364
CS_TaFT3-D1           AA-GGCTAAGGCTGTTAATTGGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTG 1381
CS_TaFT3-A1           AAAGGCTAAGGCTGTTAACTGGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTG 1368
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Solid_TaFT3-B1        GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1460
Banco_TaFT3-B1        GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1460
William_TaFT3-B1      GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
Rialto_TaFT3-B1       GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
Bagder_TaFT3-B1       GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
Cadenza_TaFT3-B1      GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
Eroica_TaFT3-B1       GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
Prokhorovka_TaFT3-B1  GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
Paragon_TaFT3-B1      GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
Spark_TaFT3-B1        GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
CS_TaFT3-B1           GTTGTGGCTCATGTTTTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGG 1424
CS_TaFT3-D1           GTTGTG---CATGTTATACAAGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGG 1438
CS_TaFT3-A1           GTTGTGGCCCATGTTCTACAAGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGG 1428
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Solid_TaFT3-B1        ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1520
Banco_TaFT3-B1        ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1520
William_TaFT3-B1      ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
Rialto_TaFT3-B1       ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
Bagder_TaFT3-B1       ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
Cadenza_TaFT3-B1      ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
Eroica_TaFT3-B1       ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
Prokhorovka_TaFT3-B1  ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
Paragon_TaFT3-B1      ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
Spark_TaFT3-B1        ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
CS_TaFT3-B1           ATAGCCTACAACAATAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1484
CS_TaFT3-D1           ATAGCCTACAACAACAGGCTAGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1498
CS_TaFT3-A1           ATAGCTTACAACAATAGGCTAGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTA 1488
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Solid_TaFT3-B1        AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1580
Banco_TaFT3-B1        AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1580
William_TaFT3-B1      AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
Rialto_TaFT3-B1       AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
Bagder_TaFT3-B1       AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
Cadenza_TaFT3-B1      AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
Eroica_TaFT3-B1       AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
Prokhorovka_TaFT3-B1  AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
Paragon_TaFT3-B1      AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
Spark_TaFT3-B1        AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
CS_TaFT3-B1           AGCAAGCCACGAGTTGATATCGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGC 1544
CS_TaFT3-D1           AGCAAGCCGCGAGTTGATATCGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGC 1558
CS_TaFT3-A1           AGCAAGCCACGAGTTGATATCAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGC 1548
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Solid_TaFT3-B1        TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1640
Banco_TaFT3-B1        TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1640
William_TaFT3-B1      TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
Rialto_TaFT3-B1       TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
Bagder_TaFT3-B1       TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
Cadenza_TaFT3-B1      TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
Eroica_TaFT3-B1       TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
Prokhorovka_TaFT3-B1  TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
Paragon_TaFT3-B1      TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
Spark_TaFT3-B1        TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
CS_TaFT3-B1           TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTG 1604
CS_TaFT3-D1           TTCTAACTCTAGTAGTGGACAATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTG 1618
CS_TaFT3-A1           TTCTAACTCTAGTAGTGGACAATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTG 1608
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Solid_TaFT3-B1        ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1700
Banco_TaFT3-B1        ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1700
William_TaFT3-B1      ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
Rialto_TaFT3-B1       ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
Bagder_TaFT3-B1       ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
Cadenza_TaFT3-B1      ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
Eroica_TaFT3-B1       ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
Prokhorovka_TaFT3-B1  ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
Paragon_TaFT3-B1      ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
Spark_TaFT3-B1        ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
CS_TaFT3-B1           ATTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAAT 1664
CS_TaFT3-D1           GGTTGTTAGTATAATTGTGAAGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAAT 1678
CS_TaFT3-A1           GTTTGTTAGTATAACTGTGAAGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGT 1668
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Solid_TaFT3-B1        TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1760
Banco_TaFT3-B1        TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1760
William_TaFT3-B1      TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
Rialto_TaFT3-B1       TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
Bagder_TaFT3-B1       TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
Cadenza_TaFT3-B1      TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
Eroica_TaFT3-B1       TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
Prokhorovka_TaFT3-B1  TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
Paragon_TaFT3-B1      TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
Spark_TaFT3-B1        TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
CS_TaFT3-B1           TTACTCCTAGCAAGCTCAAATGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTC 1724
CS_TaFT3-D1           TTACTCCTAGCAAACTCAAACGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTC 1738
CS_TaFT3-A1           TTACTCCTAGCAAACTCAAACGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTC 1728
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Solid_TaFT3-B1        AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1820
Banco_TaFT3-B1        AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1820
William_TaFT3-B1      AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
Rialto_TaFT3-B1       AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
Bagder_TaFT3-B1       AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
Cadenza_TaFT3-B1      AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
Eroica_TaFT3-B1       AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
Prokhorovka_TaFT3-B1  AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
Paragon_TaFT3-B1      AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
Spark_TaFT3-B1        AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
CS_TaFT3-B1           AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1784
CS_TaFT3-D1           AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1798
CS_TaFT3-A1           AAAAGATATTGGTGGATCCAGACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACT 1788
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Solid_TaFT3-B1        TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1878
Banco_TaFT3-B1        TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1878
William_TaFT3-B1      TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
Rialto_TaFT3-B1       TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
Bagder_TaFT3-B1       TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
Cadenza_TaFT3-B1      TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
Eroica_TaFT3-B1       TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
Prokhorovka_TaFT3-B1  TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
Paragon_TaFT3-B1      TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
Spark_TaFT3-B1        TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
CS_TaFT3-B1           TGCACTGGTAAATCAAATGCAA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TC 1842
CS_TaFT3-D1           TGCACTGGTAAATCAAATGCAAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTC 1858
CS_TaFT3-A1           TGCACTGGTAAATCAAATGCAA-CATGTTCT--TTCTCGCTAATTCGATTCCAAACCCTC 1845
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Solid_TaFT3-B1        CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1938
Banco_TaFT3-B1        CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1938
William_TaFT3-B1      CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
Rialto_TaFT3-B1       CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
Bagder_TaFT3-B1       CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
Cadenza_TaFT3-B1      CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
Eroica_TaFT3-B1       CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
Prokhorovka_TaFT3-B1  CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
Paragon_TaFT3-B1      CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
Spark_TaFT3-B1        CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
CS_TaFT3-B1           CACCCATCTGTTTTCTGCCCCCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTG 1902
CS_TaFT3-D1           GACCCATCTGTTTTCTGCCAT-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTA 1917
CS_TaFT3-A1           CACCCATCTGTTTTCTGCCCC-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTG 1904
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Solid_TaFT3-B1        ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1998
Banco_TaFT3-B1        ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1998
William_TaFT3-B1      ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
Rialto_TaFT3-B1       ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
Bagder_TaFT3-B1       ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
Cadenza_TaFT3-B1      ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
Eroica_TaFT3-B1       ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
Prokhorovka_TaFT3-B1  ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
Paragon_TaFT3-B1      ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
Spark_TaFT3-B1        ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
CS_TaFT3-B1           ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTG 1962
CS_TaFT3-D1           ATTATGATATATCTCCACTCCTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTG 1977
CS_TaFT3-A1           ATTACGATATATCTCCACTCCTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTG 1964
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Solid_TaFT3-B1          GCAGCTTCGGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2058
Banco_TaFT3-B1          GCAGCTTCGGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2058
William_TaFT3-B1        GCAGCTTCGGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
Rialto_TaFT3-B1         GCAGCTTCGGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
Bagder_TaFT3-B1         GCAGCTTCGGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
Cadenza_TaFT3-B1        GCAGCTTCGGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
Eroica_TaFT3-B1         GCAGCTTCAGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
Prokhorovka_TaFT3-B1    GCAGCTTCAGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
Paragon_TaFT3-B1        GCAGCTTCAGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
Spark_TaFT3-B1          GCAGCTTCAGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
CS_TaFT3-B1             GCAGCTTCGGTATGATGTCATGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTG 2022
CS_TaFT3-D1             CCAGCTTCGGTATGATGCCATGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTG 2037
CS_TaFT3-A1             CCAGCTTTGGTATGATGTCATGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTG 2024
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Solid_TaFT3-B1          AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2118
Banco_TaFT3-B1          AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2118
William_TaFT3-B1        AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
Rialto_TaFT3-B1         AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
Bagder_TaFT3-B1         AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
Cadenza_TaFT3-B1        AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
Eroica_TaFT3-B1         AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
Prokhorovka_TaFT3-B1    AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
Paragon_TaFT3-B1        AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
Spark_TaFT3-B1          AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
CS_TaFT3-B1             AATTTTGCAGATGCATAAATCAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2082
CS_TaFT3-D1             AATTTTGTGGACGCAGAAATCAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACA 2097
CS_TaFT3-A1             AATTTTGTGGATGCAGAAATCAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACA 2084
                        *******  ** *** ******** *********************** ***** *****

Solid_TaFT3-B1          AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2178
Banco_TaFT3-B1          AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2178
William_TaFT3-B1        AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
Rialto_TaFT3-B1         AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
Bagder_TaFT3-B1         AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
Cadenza_TaFT3-B1        AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
Eroica_TaFT3-B1         AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
Prokhorovka_TaFT3-B1    AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
Paragon_TaFT3-B1        AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
Spark_TaFT3-B1          AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
CS_TaFT3-B1             AGCTAATTCCAATATAGTCCATCATTAACACCAAGATATCTTAAACCATGACAAAGAATA 2142
CS_TaFT3-D1             AGTTAATTCCAATATAGCCCATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATA 2157
CS_TaFT3-A1             AGTTAATTCTAATATAGCCCATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATA 2144
                        ** ****** ******* ***** ************ ***** *****************

Solid_TaFT3-B1          AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2210
Banco_TaFT3-B1          AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2210
William_TaFT3-B1        AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
Rialto_TaFT3-B1         AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
Bagder_TaFT3-B1         AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
Cadenza_TaFT3-B1        AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
Eroica_TaFT3-B1         AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
Prokhorovka_TaFT3-B1    AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
Paragon_TaFT3-B1        AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
Spark_TaFT3-B1          AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
CS_TaFT3-B1             AATCTAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2174
CS_TaFT3-D1             ACAATAAACAGCGTAAAATGACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGA 2217
CS_TaFT3-A1             ACTATAAACAGGGTAAAATGACATTTGTATGT---------------------------- 2176
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Solid_TaFT3-B1          ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2257
Banco_TaFT3-B1          ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2257
William_TaFT3-B1        ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
Rialto_TaFT3-B1         ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
Bagder_TaFT3-B1         ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
Cadenza_TaFT3-B1        ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
Eroica_TaFT3-B1         ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
Prokhorovka_TaFT3-B1    ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
Paragon_TaFT3-B1        ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
Spark_TaFT3-B1          ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
CS_TaFT3-B1             ------------ACAGCCTAAAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAAT 2221
CS_TaFT3-D1             CAAGGCCACTGTACAGCCTAAAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAAT 2277
CS_TaFT3-A1             ------------ACAGCCTAAAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAAT 2223
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Solid_TaFT3-B1        TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2315
Banco_TaFT3-B1        TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2315
William_TaFT3-B1      TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
Rialto_TaFT3-B1       TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
Bagder_TaFT3-B1       TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
Cadenza_TaFT3-B1      TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
Eroica_TaFT3-B1       TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
Prokhorovka_TaFT3-B1  TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
Paragon_TaFT3-B1      TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
Spark_TaFT3-B1        TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
CS_TaFT3-B1           TTCCTTTTTCTATCTAC--TATTTATACTTGATTTATTTTGCATATGTACAAACACAAAA 2279
CS_TaFT3-D1           TTCCTTTTTCAATCTAC--TATTTATACTTTATTT-----CCACATGTACAAACACAAAA 2330
CS_TaFT3-A1           TTCCTTTTTCTATCTATAATATTTATACTTGATTTATTTTTCACGTGTACAAACACAAAA 2283
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Solid_TaFT3-B1        TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2375
Banco_TaFT3-B1        TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2375
William_TaFT3-B1      TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
Rialto_TaFT3-B1       TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
Bagder_TaFT3-B1       TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
Cadenza_TaFT3-B1      TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
Eroica_TaFT3-B1       TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
Prokhorovka_TaFT3-B1  TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
Paragon_TaFT3-B1      TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
Spark_TaFT3-B1        TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
CS_TaFT3-B1           TTCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACA 2339
CS_TaFT3-D1           TCCATGCAATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATA 2390
CS_TaFT3-A1           TTCATGCGATCAATTAATATCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATA 2343
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Solid_TaFT3-B1        CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2401
Banco_TaFT3-B1        CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2401
William_TaFT3-B1      CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
Rialto_TaFT3-B1       CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
Bagder_TaFT3-B1       CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
Cadenza_TaFT3-B1      CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
Eroica_TaFT3-B1       CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
Prokhorovka_TaFT3-B1  CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
Paragon_TaFT3-B1      CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
Spark_TaFT3-B1        CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
CS_TaFT3-B1           CTCC-CTAT------ACATATACAGCAGA---------------------------TTAT 2365
CS_TaFT3-D1           TTGTGCTAGCAACTAACATATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTAT 2449
CS_TaFT3-A1           TTTTTCTACCAACTAACATATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTAT 2403
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Solid_TaFT3-B1        ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2461
Banco_TaFT3-B1        ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2461
William_TaFT3-B1      ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
Rialto_TaFT3-B1       ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
Bagder_TaFT3-B1       ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
Cadenza_TaFT3-B1      ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
Eroica_TaFT3-B1       ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
Prokhorovka_TaFT3-B1  ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
Paragon_TaFT3-B1      ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
Spark_TaFT3-B1        ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
CS_TaFT3-B1           ATTAGAAGACTCCTTTTTGCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGAC 2425
CS_TaFT3-D1           ATTAGAA---------TTACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGAC 2499
CS_TaFT3-A1           ATTAGAAGACACCTATTTGCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAAC 2463
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Solid_TaFT3-B1        TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2515
Banco_TaFT3-B1        TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2515
William_TaFT3-B1      TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
Rialto_TaFT3-B1       TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
Bagder_TaFT3-B1       TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
Cadenza_TaFT3-B1      TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
Eroica_TaFT3-B1       TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
Prokhorovka_TaFT3-B1  TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
Paragon_TaFT3-B1      TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
Spark_TaFT3-B1        TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
CS_TaFT3-B1           TAAAT------GTTTCCACCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTA 2479
CS_TaFT3-D1           TAGATTGGTATGTTTCCACCAAGTTGAATTACTCTTTAAATTCTTAACT----------- 2548
CS_TaFT3-A1           TAGAT------ATTTCCACCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTA 2517
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Solid_TaFT3-B1             GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2575
Banco_TaFT3-B1             GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2575
William_TaFT3-B1           GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
Rialto_TaFT3-B1            GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
Bagder_TaFT3-B1            GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
Cadenza_TaFT3-B1           GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
Eroica_TaFT3-B1            GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
Prokhorovka_TaFT3-B1       GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
Paragon_TaFT3-B1           GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
Spark_TaFT3-B1             GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
CS_TaFT3-B1                GGGTGCTCTCGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2539
CS_TaFT3-D1                -GGTGCTCTTGCAGGCCAAGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTAT 2607
CS_TaFT3-A1                GGGTGCTCTTGCAGGCCAAGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTAT 2577
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Solid_TaFT3-B1             TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2635
Banco_TaFT3-B1             TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2635
William_TaFT3-B1           TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
Rialto_TaFT3-B1            TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
Bagder_TaFT3-B1            TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
Cadenza_TaFT3-B1           TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
Eroica_TaFT3-B1            TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
Prokhorovka_TaFT3-B1       TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
Paragon_TaFT3-B1           TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
Spark_TaFT3-B1             TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
CS_TaFT3-B1                TCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGA 2599
CS_TaFT3-D1                CCACCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGA 2667
CS_TaFT3-A1                CCATCGGATGGTATTTGTGCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGA 2637
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Solid_TaFT3-B1             TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2695
Banco_TaFT3-B1             TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2695
William_TaFT3-B1           TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
Rialto_TaFT3-B1            TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
Bagder_TaFT3-B1            TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
Cadenza_TaFT3-B1           TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
Eroica_TaFT3-B1            TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
Prokhorovka_TaFT3-B1       TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
Paragon_TaFT3-B1           TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
Spark_TaFT3-B1             TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
CS_TaFT3-B1                TGTGCGACACAATTTCAGCTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGC 2659
CS_TaFT3-D1                TGTGCGACACAACTTCAGCTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGC 2727
CS_TaFT3-A1                CGTGCGACACAACTTCAGCTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGC 2697
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Solid_TaFT3-B1             TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2755
Banco_TaFT3-B1             TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2755
William_TaFT3-B1           TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
Rialto_TaFT3-B1            TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
Bagder_TaFT3-B1            TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
Cadenza_TaFT3-B1           TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
Eroica_TaFT3-B1            TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
Prokhorovka_TaFT3-B1       TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
Paragon_TaFT3-B1           TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
Spark_TaFT3-B1             TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
CS_TaFT3-B1                TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGA 2719
CS_TaFT3-D1                TGCCTCATATTTCAACTGTCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGA 2787
CS_TaFT3-A1                TGTCTCATATTTCAACTGTCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGA 2757
                           ** ********************************* ** ********************

Solid_TaFT3-B1             AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2815
Banco_TaFT3-B1             AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2815
William_TaFT3-B1           AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
Rialto_TaFT3-B1            AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
Bagder_TaFT3-B1            AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
Cadenza_TaFT3-B1           AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
Eroica_TaFT3-B1            AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
Prokhorovka_TaFT3-B1       AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
Paragon_TaFT3-B1           AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
Spark_TaFT3-B1             AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
CS_TaFT3-B1                AAGTTCTCAAGGGGAGTAGAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACT 2779
CS_TaFT3-D1                AAGTTCTCAAGGGGAGTAGGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACT 2847
CS_TaFT3-A1                AAGTTCTCAAGGGGAGTAGAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACC 2817
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Solid_TaFT3-B1          GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2875
Banco_TaFT3-B1          GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2875
William_TaFT3-B1        GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
Rialto_TaFT3-B1         GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
Bagder_TaFT3-B1         GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
Cadenza_TaFT3-B1        GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
Eroica_TaFT3-B1         GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
Prokhorovka_TaFT3-B1    GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
Paragon_TaFT3-B1        GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
Spark_TaFT3-B1          GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
CS_TaFT3-B1             GTAGTGTTGTACCACAAATAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGC 2839
CS_TaFT3-D1             GTAGTGCTGCATCACAAATAATGTGCAGTACATAGAATGTCTTGTGTCACCTAAATATGC 2907
CS_TaFT3-A1             GTAGTGTTGCATCACAAATAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGC 2877
                        ****** ** * ************* ** * *******  * *** *** **********


Solid_TaFT3-B1          AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCAT------ 2929
Banco_TaFT3-B1          AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCAT------ 2929
William_TaFT3-B1        AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCAT------ 2893
Rialto_TaFT3-B1         AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCATT----- 2894
Bagder_TaFT3-B1         AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCATTAG--- 2896
Cadenza_TaFT3-B1        AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCATTAG--- 2896
Eroica_TaFT3-B1         AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCAT------ 2893
Prokhorovka_TaFT3-B1    AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCAT------ 2893
Paragon_TaFT3-B1        AGCATTATATGTATCT-CAGCTATGATAAGCT---------------------------- 2870
Spark_TaFT3-B1          AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCATT----- 2894
CS_TaFT3-B1             AGCATTATATGTATCTTCAGCTATGATAAGCTTGATGGAATATATCTCAATCATTAGTTA 2899
CS_TaFT3-D1             AGCATTATATGCGTCTTCAGCTATGATGAGCTTGATGGGATATATCTCAGTCATTAGTTA 2967
CS_TaFT3-A1             AGCATTATATGCATCTTCAGCTATGATGAGCTTGATGGGATATATCTCAGTCATTTGTTA 2937
                        ***********  *** ********** ****
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Appendix 6.4 *TaFT3-A*BD the exons are shown in purple

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Claire_TaFT3-A1          -------------------------GTTCGTGCAAGTAGGTCATACATAGACACAATTTG 35
Hereward_TaFT3-A1        -------------------------GTTCGTGCAAGTAGGTCATACATAGACACAATTTG 35
StarkeII_TaFT3-A1        -------------------------GTTCGTGCAAGTAGGTCATACATAGACACAATTTG 35
Malacca_TaFT3-A1         -------------------------GTTCGTGCAAGTAGGTCATACATAGACACAATTTG 35
Paragon_TaFT3-A1         -------------------------GTTCGTGCAAGTAGGTCATACATAGACACAATTTG 35
Rialto_TaFT3-A1          -------------------------GTTCGTGCAAGTAGGTCATACATAGACACAATTTG 35
Badger_TaFT3-A1          ---------------------------TCGTGCAAGTAGGTCATACATAGACACAATTTG 33
Avalon_TaFT3-A1          ---------------------------TCGTGCAAGTAGGTCATACATAGACACAATTTG 33
Cadenza_TaFT3-A1         ---------------------------TCGTGCAAGTAGGTCATACATAGACACAATTTG 33
Charger_TaFT3-A1         --------------------------TTCGTGCAAGTAGGTCATACATAGACACAATTTG 34
Spark_TaFT3-A1           -----------------------TAGTTCGTGCAAGTAGGTCATACATAGACACAATTTG 37
Urartu_TaFT3-A1           CCACC-TCATCGCACAATACAAGTAGTTCGTGCAAGTAGGTCATACATAGACACAATTCG 70
Claire_TaFT3-D1          ------------------------------------------------------------
Spark_TaFT3-D1           ------------------------------------------------------------
Paragon_TaFT3-D1         ------------------------------------------------------------
Rialto_TaFT3-D1          ------------------------------------------------------------
Malacca_TaFT3-D1         ------------------------------------------------------------
Hereward_TaFT3-D1        ------------------------------------------------------------
StarkeII_TaFT3-D1        ------------------------------------------------------------
Cadenza_TaFT3-D1         ------------------------------------------CTGCATAGACACAACTGG 18
Avalon_TaFT3-D1          ----------------------------------------TCCTGCATAGACACAACTGG 20
Badger_TaFT3-D1          ------------------------------------------CTGCATAGACACAACTGG 18
Charger_TaFT3-D1         ----------------------------------------TCCTGCATAGACACAACTGG 20
Atauschii_TaFT3-D1       ------------------------------------------CTGCATAGACACAACTGG 18
Malacca_TaFT3-B1         CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 111
Paragon_TaFT3-B1         CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 111
Rialto_TaFT3-B1          CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 120
Spark_TaFT3-B1           CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 110
Eroica_TaFT3-B1          CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 109
Prokhorovka_B            CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 109
Banco_TaFT3-B1           CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 109
William_TaFT3-B1         CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 109
Solid_TaFT3-B1           CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 109
Cadenza_TaFT3-B1         CAACCCTCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 110
Bagder_TaFT3-B1          CAACC-TCATCGCGCAATACAAGTAGTTCGTGCAAGTAGTTCATACATAGACACAGTTTG 109


Claire_TaFT3-A1          TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 91
Hereward_TaFT3-A1        TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 91
StarkeII_TaFT3-A1        TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 91
Malacca_TaFT3-A1         TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 91
Paragon_TaFT3-A1         TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 91
Rialto_TaFT3-A1          TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 91
Badger_TaFT3-A1          TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 89
Avalon_TaFT3-A1          TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 89
Cadenza_TaFT3-A1         TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 89
Charger_TaFT3-A1         TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 90
Spark_TaFT3-A1           TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 93
Urartu_TaFT3-A1          TTTCAGGTCTGTAGAGAGCTAGG----CACAATAACAGACAAAGGCTAAGGCTGTTAACT 126
Claire_TaFT3-D1          -----GGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 54
Spark_TaFT3-D1           ---------------GAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 44
Paragon_TaFT3-D1         -----GGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 54
Rialto_TaFT3-D1          ---------------GAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 44
Malacca_TaFT3-D1         -----GGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 54
Hereward_TaFT3-D1        -----GGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 54
StarkeII_TaFT3-D1        -----GGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 54
Cadenza_TaFT3-D1         TTTCAGGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 77
Avalon_TaFT3-D1          TTTCAGGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 79
Badger_TaFT3-D1          TTTCAGGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 77
Charger_TaFT3-D1         TTTCAGGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 79
Atauschii_TaFT3-D1       TTTCAGGTCTGTAGAGAGCTAGGTTATCACAATAACAGACAA-GGCTAAGGCTGTTAATT 77
Malacca_TaFT3-B1         TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 170
Paragon_TaFT3-B1         TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 170
Rialto_TaFT3-B1          TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 179
Spark_TaFT3-B1           TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 169
Eroica_TaFT3-B1          TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 168
Prokhorovka_B            TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 168
Banco_TaFT3-B1           TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 168
William_TaFT3-B1         TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 168
Solid_TaFT3-B1           TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 168
Cadenza_TaFT3-B1         TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 169
Bagder_TaFT3-B1          TTTCAGGTCTCTAGAGAGCTAGGTTAACACAATAGCAGACAA-GGACAAGGCTATTAATT 168
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Claire_TaFT3-A1        GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 148
Hereward_TaFT3-A1      GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 148
StarkeII_TaFT3-A1      GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 148
Malacca_TaFT3-A1       GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 148
Paragon_TaFT3-A1       GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 148
Rialto_TaFT3-A1        GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 148
Badger_TaFT3-A1        GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 146
Avalon_TaFT3-A1        GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 146
Cadenza_TaFT3-A1       GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 146
Charger_TaFT3-A1       GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 147
Spark_TaFT3-A1         GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 150
Urartu_TaFT3-A1        GGTAGTCCTCC---AGTATATGTCGGCAGCGGATCCATTGGTTGTGGCCCATGTTCTACA 183
Claire_TaFT3-D1        GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 111
Spark_TaFT3-D1         GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 101
Paragon_TaFT3-D1       GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 111
Rialto_TaFT3-D1        GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 101
Malacca_TaFT3-D1       GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 111
Hereward_TaFT3-D1      GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 111
StarkeII_TaFT3-D1      GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 111
Cadenza_TaFT3-D1       GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 134
Avalon_TaFT3-D1        GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 136
Badger_TaFT3-D1        GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 134
Charger_TaFT3-D1       GGTAGTCCTCCTCTAGTATATGTCGGCAGCGGATCCATTGGTTGTG---CATGTTATACA 136
Atauschii_TaFT3-D1     GGTAGTCCTCCTCTAGTATATGTCGGCTGCGGATCCATTGGTTGTG---CATGTTATACA 134
Malacca_TaFT3-B1       GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 230
Paragon_TaFT3-B1       GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 230
Rialto_TaFT3-B1        GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 239
Spark_TaFT3-B1         GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 229
Eroica_TaFT3-B1        GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 228
Prokhorovka_B          GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 228
Banco_TaFT3-B1         GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 228
William_TaFT3-B1       GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 228
Solid_TaFT3-B1         GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 228
Cadenza_TaFT3-B1       GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 229
Bagder_TaFT3-B1        GGTAGTCCTCCTCCAGTATATGTCGGCAGCGGATCCATTGGTTGTGGCTCATGTTTTACA 228
                       ***********   ************* ******************   ****** ****

Claire_TaFT3-A1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 208
Hereward_TaFT3-A1      AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 208
StarkeII_TaFT3-A1      AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 208
Malacca_TaFT3-A1       AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 208
Paragon_TaFT3-A1       AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 208
Rialto_TaFT3-A1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 208
Badger_TaFT3-A1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 206
Avalon_TaFT3-A1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 206
Cadenza_TaFT3-A1       AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 206
Charger_TaFT3-A1       AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 207
Spark_TaFT3-A1         AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 210
Urartu_TaFT3-A1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCTTACAACAATAGGCT 243
Claire_TaFT3-D1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 171
Spark_TaFT3-D1         AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 161
Paragon_TaFT3-D1       AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 171
Rialto_TaFT3-D1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 161
Malacca_TaFT3-D1       AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 171
Hereward_TaFT3-D1      AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 171
StarkeII_TaFT3-D1      AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 171
Cadenza_TaFT3-D1       AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 194
Avalon_TaFT3-D1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 196
Badger_TaFT3-D1        AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 194
Charger_TaFT3-D1       AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAACAGGCT 196
Atauschii_TaFT3-D1     AGATGTGCTTGATCCATTTACATCAACTGTTCCACTCAGGATAGCCTACAACAATAGGCT 194
Malacca_TaFT3-B1       AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 290
Paragon_TaFT3-B1       AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 290
Rialto_TaFT3-B1        AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 299
Spark_TaFT3-B1         AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 289
Eroica_TaFT3-B1        AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 288
Prokhorovka_B          AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 288
Banco_TaFT3-B1         AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 288
William_TaFT3-B1       AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 288
Solid_TaFT3-B1         AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 288
Cadenza_TaFT3-B1       AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 289
Bagder_TaFT3-B1        AGATGTGCTTGATCCATTTACATCAACTGTTCCGCTCAGGATAGCCTACAACAATAGGCT 288
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Claire_TaFT3-A1         AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 268
Hereward_TaFT3-A1       AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 268
StarkeII_TaFT3-A1       AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 268
Malacca_TaFT3-A1        AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 268
Paragon_TaFT3-A1        AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 268
Rialto_TaFT3-A1         AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 268
Badger_TaFT3-A1         AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 266
Avalon_TaFT3-A1         AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 266
Cadenza_TaFT3-A1        AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 266
Charger_TaFT3-A1        AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 267
Spark_TaFT3-A1          AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 270
Urartu_TaFT3-A1         AGTCCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 303
Claire_TaFT3-D1         AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 231
Spark_TaFT3-D1          AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 221
Paragon_TaFT3-D1        AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 231
Rialto_TaFT3-D1         AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 221
Malacca_TaFT3-D1        AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 231
Hereward_TaFT3-D1       AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 231
StarkeII_TaFT3-D1       AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 231
Cadenza_TaFT3-D1        AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 254
Avalon_TaFT3-D1         AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 256
Badger_TaFT3-D1         AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 254
Charger_TaFT3-D1        AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 256
Atauschii_TaFT3-D1      AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCGCGAGTTGATAT 254
Malacca_TaFT3-B1        AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 350
Paragon_TaFT3-B1        AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 350
Rialto_TaFT3-B1         AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 359
Spark_TaFT3-B1          AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 349
Eroica_TaFT3-B1         AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 348
Prokhorovka_B           AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 348
Banco_TaFT3-B1          AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 348
William_TaFT3-B1        AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 348
Solid_TaFT3-B1          AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 348
Cadenza_TaFT3-B1        AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 349
Bagder_TaFT3-B1         AGTTCTGGCAGGTGCTGAGCTAAGACCATCTGCAATTGTAAGCAAGCCACGAGTTGATAT 348
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Claire_TaFT3-A1         CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 328
Hereward_TaFT3-A1       CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 328
StarkeII_TaFT3-A1       CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 328
Malacca_TaFT3-A1        CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 328
Paragon_TaFT3-A1        CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 328
Rialto_TaFT3-A1         CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 328
Badger_TaFT3-A1         CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 326
Avalon_TaFT3-A1         CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 326
Cadenza_TaFT3-A1        CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 326
Charger_TaFT3-A1        CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 327
Spark_TaFT3-A1          CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 330
Urartu_TaFT3-A1         CAGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 363
Claire_TaFT3-D1         CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 291
Spark_TaFT3-D1          CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 281
Paragon_TaFT3-D1        CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 291
Rialto_TaFT3-D1         CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 281
Malacca_TaFT3-D1        CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 291
Hereward_TaFT3-D1       CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 291
StarkeII_TaFT3-D1       CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 291
Cadenza_TaFT3-D1        CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 314
Avalon_TaFT3-D1         CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 316
Badger_TaFT3-D1         CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 314
Charger_TaFT3-D1        CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 316
Atauschii_TaFT3-D1      CGGTGGCAGTGACATGAGAGTTCTCTACACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 314
Malacca_TaFT3-B1        CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 410
Paragon_TaFT3-B1        CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 410
Rialto_TaFT3-B1         CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 419
Spark_TaFT3-B1          CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 409
Eroica_TaFT3-B1         CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 408
Prokhorovka_B           CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 408
Banco_TaFT3-B1          CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 408
William_TaFT3-B1        CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 408
Solid_TaFT3-B1          CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 408
Cadenza_TaFT3-B1        CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 409
Bagder_TaFT3-B1         CGGTGGCAGTGACATGAGAGTCCTCTATACCCTGGTAAGCTTCTAACTCTAGTAGTGGAC 408
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Claire_TaFT3-A1         AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 388
Hereward_TaFT3-A1       AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 388
StarkeII_TaFT3-A1       AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 388
Malacca_TaFT3-A1        AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 388
Paragon_TaFT3-A1        AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 388
Rialto_TaFT3-A1         AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 388
Badger_TaFT3-A1         AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 386
Avalon_TaFT3-A1         AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 386
Cadenza_TaFT3-A1        AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 386
Charger_TaFT3-A1        AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 387
Spark_TaFT3-A1          AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 390
Urartu_TaFT3-A1         AATATATGCAAATCCTTTGGTTATTTCACTCTTTTACGTGGTTTGTTAGTATAACTGTGA 423
Claire_TaFT3-D1         AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 351
Spark_TaFT3-D1          AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 341
Paragon_TaFT3-D1        AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 351
Rialto_TaFT3-D1         AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 341
Malacca_TaFT3-D1        AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 351
Hereward_TaFT3-D1       AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 351
StarkeII_TaFT3-D1       AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 351
Cadenza_TaFT3-D1        AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 374
Avalon_TaFT3-D1         AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 376
Badger_TaFT3-D1         AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 374
Charger_TaFT3-D1        AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 376
Atauschii_TaFT3-D1      AATATATGCAAATACTTTGGTTATTTCACTCTTTTACGTGGGTTGTTAGTATAATTGTGA 374
Malacca_TaFT3-B1        AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 470
Paragon_TaFT3-B1        AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 470
Rialto_TaFT3-B1         AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 479
Spark_TaFT3-B1          AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 469
Eroica_TaFT3-B1         AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 468
Prokhorovka_B           AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 468
Banco_TaFT3-B1          AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 468
William_TaFT3-B1        AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 468
Solid_TaFT3-B1          AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 468
Cadenza_TaFT3-B1        AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 469
Bagder_TaFT3-B1         AATATATGCAAATCCTTTGGTTATTTCACTCTTTTATGTGATTTGTTAGTATAATTGTGA 468
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Claire_TaFT3-A1         AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 448
Hereward_TaFT3-A1       AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 448
StarkeII_TaFT3-A1       AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 448
Malacca_TaFT3-A1        AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 448
Paragon_TaFT3-A1        AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 448
Rialto_TaFT3-A1         AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 448
Badger_TaFT3-A1         AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 446
Avalon_TaFT3-A1         AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 446
Cadenza_TaFT3-A1        AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 446
Charger_TaFT3-A1        AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 447
Spark_TaFT3-A1          AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 450
Urartu_TaFT3-A1         AGGAAGTCCATAGAAGGAAAATGTCTCATAGATGATTAGTTTACTCCTAGCAAACTCAAA 483
Claire_TaFT3-D1         AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 411
Spark_TaFT3-D1          AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 401
Paragon_TaFT3-D1        AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 411
Rialto_TaFT3-D1         AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 401
Malacca_TaFT3-D1        AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 411
Hereward_TaFT3-D1       AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 411
StarkeII_TaFT3-D1       AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 411
Cadenza_TaFT3-D1        AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 434
Avalon_TaFT3-D1         AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 436
Badger_TaFT3-D1         AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 434
Charger_TaFT3-D1        AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 436
Atauschii_TaFT3-D1      AGGAATTCCATAGAAGGAAAAGGTCTCATAGATGATTAATTTACTCCTAGCAAACTCAAA 434
Malacca_TaFT3-B1        AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 530
Paragon_TaFT3-B1        AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 530
Rialto_TaFT3-B1         AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 539
Spark_TaFT3-B1          AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 529
Eroica_TaFT3-B1         AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 528
Prokhorovka_B           AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 528
Banco_TaFT3-B1          AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 528
William_TaFT3-B1        AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 528
Solid_TaFT3-B1          AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 528
Cadenza_TaFT3-B1        AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 529
Bagder_TaFT3-B1         AGGAATTCCATAGAAGAAAAATGTCTCATAGATGATTAATTTACTCCTAGCAAGCTCAAA 528
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Claire_TaFT3-A1          CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 508
Hereward_TaFT3-A1        CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 508
StarkeII_TaFT3-A1        CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 508
Malacca_TaFT3-A1         CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 508
Paragon_TaFT3-A1         CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 508
Rialto_TaFT3-A1          CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 508
Badger_TaFT3-A1          CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 506
Avalon_TaFT3-A1          CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 506
Cadenza_TaFT3-A1         CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 506
Charger_TaFT3-A1         CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 507
Spark_TaFT3-A1           CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 510
Urartu_TaFT3-A1          CGAATCATATGTTAACTTTTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 543
Claire_TaFT3-D1          CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 471
Spark_TaFT3-D1           CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 461
Paragon_TaFT3-D1         CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 471
Rialto_TaFT3-D1          CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 461
Malacca_TaFT3-D1         CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 471
Hereward_TaFT3-D1        CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 471
StarkeII_TaFT3-D1        CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 471
Cadenza_TaFT3-D1         CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 494
Avalon_TaFT3-D1          CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 496
Badger_TaFT3-D1          CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 494
Charger_TaFT3-D1         CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 496
Atauschii_TaFT3-D1       CGAATCATATGTTAACTGGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 494
Malacca_TaFT3-B1         TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 590
Paragon_TaFT3-B1         TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 590
Rialto_TaFT3-B1          TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 599
Spark_TaFT3-B1           TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 589
Eroica_TaFT3-B1          TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 588
Prokhorovka_B            TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 588
Banco_TaFT3-B1           TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 588
William_TaFT3-B1         TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 588
Solid_TaFT3-B1           TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 588
Cadenza_TaFT3-B1         TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 589
Bagder_TaFT3-B1          TGGATCATATGTTAACTTGTTTGAGTTTGTCTTTGACTTCAAAAGATATTGGTGGATCCA 588
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Claire_TaFT3-A1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 568
Hereward_TaFT3-A1        GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 568
StarkeII_TaFT3-A1        GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 568
Malacca_TaFT3-A1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 568
Paragon_TaFT3-A1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 568
Rialto_TaFT3-A1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 568
Badger_TaFT3-A1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 566
Avalon_TaFT3-A1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 566
Cadenza_TaFT3-A1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 566
Charger_TaFT3-A1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 567
Spark_TaFT3-A1           GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 570
Urartu_TaFT3-A1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 603
Claire_TaFT3-D1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 531
Spark_TaFT3-D1           GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 521
Paragon_TaFT3-D1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 531
Rialto_TaFT3-D1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 521
Malacca_TaFT3-D1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 531
Hereward_TaFT3-D1        GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 531
StarkeII_TaFT3-D1        GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 531
Cadenza_TaFT3-D1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 554
Avalon_TaFT3-D1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 556
Badger_TaFT3-D1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 554
Charger_TaFT3-D1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 556
Atauschii_TaFT3-D1       GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 554
Malacca_TaFT3-B1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 650
Paragon_TaFT3-B1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 650
Rialto_TaFT3-B1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 659
Spark_TaFT3-B1           GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 649
Eroica_TaFT3-B1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 648
Prokhorovka_B            GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 648
Banco_TaFT3-B1           GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 648
William_TaFT3-B1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 648
Solid_TaFT3-B1           GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 648
Cadenza_TaFT3-B1         GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 649
Bagder_TaFT3-B1          GACGCCCCAAGCCCAAGTCACCCATCACTAAGGGAGTACTTGCACTGGTAAATCAAATGC 648
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Claire_TaFT3-A1         AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCATCCACCCATCTGTTTTCTGCCC 625
Hereward_TaFT3-A1       AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCATCCACCCATCTGTTTTCTGCCC 625
StarkeII_TaFT3-A1       AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCCTCCACCCATCTGTTTTCTGCCC 625
Malacca_TaFT3-A1        AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCCTCCACCCATCTGTTTTCTGCCC 625
Paragon_TaFT3-A1        AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCCTCCACCCATCTGTTTTCTGCCC 625
Rialto_TaFT3-A1         AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCCTCCACCCATCTGTTTTCTGCCC 625
Badger_TaFT3-A1         AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCCTCCACCCATCTGTTTTCTGCCC 623
Avalon_TaFT3-A1         AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCCTCCACCCATCTGTTTTCTGCCC 623
Cadenza_TaFT3-A1        AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCCTCCACCCATCTGTTTTCTGCCC 623
Charger_TaFT3-A1        AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCATCCACCCATCTGTTTTCTGCCC 624
Spark_TaFT3-A1          AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCATCCACCCATCTGTTTTCTGCCC 627
Urartu_TaFT3-A1         AA-CATGTTCTT--TCTCGCTAATTCGATTCCAAACCCTCCACCCATCTGTTTTCTGCCC 660
Claire_TaFT3-D1         AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 591
Spark_TaFT3-D1          AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 581
Paragon_TaFT3-D1        AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 591
Rialto_TaFT3-D1         AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 581
Malacca_TaFT3-D1        AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 591
Hereward_TaFT3-D1       AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 591
StarkeII_TaFT3-D1       AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 591
Cadenza_TaFT3-D1        AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 614
Avalon_TaFT3-D1         AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 616
Badger_TaFT3-D1         AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 614
Charger_TaFT3-D1        AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 616
Atauschii_TaFT3-D1      AAACATGTTCTTATTCTCACCAATACGATTCCAAACCCTCGACCCATCTGTTTTCTGCCA 614
Malacca_TaFT3-B1        AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 708
Paragon_TaFT3-B1        AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 708
Rialto_TaFT3-B1         AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 717
Spark_TaFT3-B1          AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 707
Eroica_TaFT3-B1         AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 706
Prokhorovka_B           AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 706
Banco_TaFT3-B1          AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 706
William_TaFT3-B1        AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 706
Solid_TaFT3-B1          AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 706
Cadenza_TaFT3-B1        AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 707
Bagder_TaFT3-B1         AA-CATGTTCTTATTCTCGCCAATACGATCCCAAACC-TCCACCCATCTGTTTTCTGCCC 706
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Claire_TaFT3-A1         C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 684
Hereward_TaFT3-A1       C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 684
StarkeII_TaFT3-A1       C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 684
Malacca_TaFT3-A1        C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 684
Paragon_TaFT3-A1        C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 684
Rialto_TaFT3-A1         C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 684
Badger_TaFT3-A1         C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 682
Avalon_TaFT3-A1         C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 682
Cadenza_TaFT3-A1        C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 682
Charger_TaFT3-A1        C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 683
Spark_TaFT3-A1          C-GAAACTTTTGATATATGCTTCCTATTTAAGTTGCCCTGATTACGATATATCTCCACTC 686
Urartu_TaFT3-A1         C-GAAACTTTTGATATATGCTTCCTATTTAATTTGCCCTGATTACGATATATCTCCACTC 719
Claire_TaFT3-D1         T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 650
Spark_TaFT3-D1          T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 640
Paragon_TaFT3-D1        T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 650
Rialto_TaFT3-D1         T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 640
Malacca_TaFT3-D1        T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 650
Hereward_TaFT3-D1       T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 650
StarkeII_TaFT3-D1       T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 650
Cadenza_TaFT3-D1        T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 673
Avalon_TaFT3-D1         T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 675
Badger_TaFT3-D1         T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 673
Charger_TaFT3-D1        T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 675
Atauschii_TaFT3-D1      T-GAAACTTTAGATGTATGTTCCATACTTAATTTGCTCTAATTATGATATATCTCCACTC 673
Malacca_TaFT3-B1        CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 768
Paragon_TaFT3-B1        CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 768
Rialto_TaFT3-B1         CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 777
Spark_TaFT3-B1          CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 767
Eroica_TaFT3-B1         CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 766
Prokhorovka_B           CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 766
Banco_TaFT3-B1          CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 766
William_TaFT3-B1        CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 766
Solid_TaFT3-B1          CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 766
Cadenza_TaFT3-B1        CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 767
Bagder_TaFT3-B1         CCGAAACTTTTGATATATGCTTCCTATTTAATAGGATCTGATTATGATATATCTCCACTC 766
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Claire_TaFT3-A1          CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 744
Hereward_TaFT3-A1        CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 744
StarkeII_TaFT3-A1        CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 744
Malacca_TaFT3-A1         CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 744
Paragon_TaFT3-A1         CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 744
Rialto_TaFT3-A1          CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 744
Badger_TaFT3-A1          CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 742
Avalon_TaFT3-A1          CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 742
Cadenza_TaFT3-A1         CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 742
Charger_TaFT3-A1         CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 743
Spark_TaFT3-A1           CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 746
Urartu_TaFT3-A1          CTGTGTAGGATGGTGTCAGACATCCCTGCAACAACTGGTGCCAGCTTTGGTATGATGTCA 779
Claire_TaFT3-D1          CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 710
Spark_TaFT3-D1           CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 700
Paragon_TaFT3-D1         CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 710
Rialto_TaFT3-D1          CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 700
Malacca_TaFT3-D1         CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 710
Hereward_TaFT3-D1        CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 710
StarkeII_TaFT3-D1        CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 710
Cadenza_TaFT3-D1         CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 733
Avalon_TaFT3-D1          CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 735
Badger_TaFT3-D1          CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 733
Charger_TaFT3-D1         CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 735
Atauschii_TaFT3-D1       CTGTGTAGGATGGTGTCAGACATCCCTGGAACAACTGGTGCCAGCTTCGGTATGATGCCA 733
Malacca_TaFT3-B1         CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGTATGATGTCA 828
Paragon_TaFT3-B1         CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCAGTATGATGTCA 828
Rialto_TaFT3-B1          CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGTATGATGTCA 837
Spark_TaFT3-B1           CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCAGTATGATGTCA 827
Eroica_TaFT3-B1          CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCAGTATGATGTCA 826
Prokhorovka_B            CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCAGTATGATGTCA 826
Banco_TaFT3-B1           CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGTATGATGTCA 826
William_TaFT3-B1         CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGTATGATGTCA 826
Solid_TaFT3-B1           CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGTATGATGTCA 826
Cadenza_TaFT3-B1         CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGTATGATGTCA 827
Bagder_TaFT3-B1          CTGTGTAGGATGGTGTCCGACATCCCTGGAACAACTAGTGGCAGCTTCGGTATGATGTCA 826
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Claire_TaFT3-A1          TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 804
Hereward_TaFT3-A1        TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 804
StarkeII_TaFT3-A1        TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 804
Malacca_TaFT3-A1         TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 804
Paragon_TaFT3-A1         TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 804
Rialto_TaFT3-A1          TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 804
Badger_TaFT3-A1          TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 802
Avalon_TaFT3-A1          TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 802
Cadenza_TaFT3-A1         TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 802
Charger_TaFT3-A1         TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 803
Spark_TaFT3-A1           TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 806
Urartu_TaFT3-A1          TGCATAACAATTTGTTCAATGTGATTTTTGGTTTTAGCTGAATTTTGTGGATGCAGAAAT 839
Claire_TaFT3-D1          TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 770
Spark_TaFT3-D1           TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 760
Paragon_TaFT3-D1         TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 770
Rialto_TaFT3-D1          TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 760
Malacca_TaFT3-D1         TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 770
Hereward_TaFT3-D1        TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 770
StarkeII_TaFT3-D1        TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 770
Cadenza_TaFT3-D1         TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 793
Avalon_TaFT3-D1          TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 795
Badger_TaFT3-D1          TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 793
Charger_TaFT3-D1         TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 795
Atauschii_TaFT3-D1       TGCATAACAATTTGTTCAATGTGATTTTTTGTTTTAGCTGAATTTTGTGGACGCAGAAAT 793
Malacca_TaFT3-B1         TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 888
Paragon_TaFT3-B1         TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 888
Rialto_TaFT3-B1          TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 897
Spark_TaFT3-B1           TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 887
Eroica_TaFT3-B1          TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 886
Prokhorovka_B            TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 886
Banco_TaFT3-B1           TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 886
William_TaFT3-B1         TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 886
Solid_TaFT3-B1           TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 886
Cadenza_TaFT3-B1         TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 887
Bagder_TaFT3-B1          TGCATAACAATTTGTTCAATGTTATTTTTGGTTTTAGCTGAATTTTGCAGATGCATAAAT 886
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Claire_TaFT3-A1         CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 864
Hereward_TaFT3-A1       CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 864
StarkeII_TaFT3-A1       CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 864
Malacca_TaFT3-A1        CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 864
Paragon_TaFT3-A1        CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 864
Rialto_TaFT3-A1         CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 864
Badger_TaFT3-A1         CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 862
Avalon_TaFT3-A1         CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 862
Cadenza_TaFT3-A1        CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 862
Charger_TaFT3-A1        CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 863
Spark_TaFT3-A1          CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 866
Urartu_TaFT3-A1         CAGGCCATGTTAAGTTCTTTCCCTCAAATGACTCCATACAAGTTAATTCTAATATAGCCC 899
Claire_TaFT3-D1         CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 830
Spark_TaFT3-D1          CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 820
Paragon_TaFT3-D1        CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 830
Rialto_TaFT3-D1         CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 820
Malacca_TaFT3-D1        CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 830
Hereward_TaFT3-D1       CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 830
StarkeII_TaFT3-D1       CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 830
Cadenza_TaFT3-D1        CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 853
Avalon_TaFT3-D1         CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 855
Badger_TaFT3-D1         CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 853
Charger_TaFT3-D1        CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 855
Atauschii_TaFT3-D1      CAGGCCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGTTAATTCCAATATAGCCC 853
Malacca_TaFT3-B1        CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 948
Paragon_TaFT3-B1        CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 948
Rialto_TaFT3-B1         CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 957
Spark_TaFT3-B1          CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 947
Eroica_TaFT3-B1         CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 946
Prokhorovka_B           CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 946
Banco_TaFT3-B1          CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 946
William_TaFT3-B1        CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 946
Solid_TaFT3-B1          CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 946
Cadenza_TaFT3-B1        CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 947
Bagder_TaFT3-B1         CAGGTCATGTTAAGTTCTTTCCCTCAAACGACTCGATACAAGCTAATTCCAATATAGTCC 946
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Claire_TaFT3-A1         ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 924
Hereward_TaFT3-A1       ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 924
StarkeII_TaFT3-A1       ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 924
Malacca_TaFT3-A1        ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 924
Paragon_TaFT3-A1        ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 924
Rialto_TaFT3-A1         ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 924
Badger_TaFT3-A1         ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 922
Avalon_TaFT3-A1         ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 922
Cadenza_TaFT3-A1        ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 922
Charger_TaFT3-A1        ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 923
Spark_TaFT3-A1          ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 926
Urartu_TaFT3-A1         ATCGTTAACACCAAGATATCTTAAACCATGACAAAGAATAACTATAAACAGGGTAAAATG 959
Claire_TaFT3-D1         ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 890
Spark_TaFT3-D1          ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 880
Paragon_TaFT3-D1        ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 890
Rialto_TaFT3-D1         ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 880
Malacca_TaFT3-D1        ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 890
Hereward_TaFT3-D1       ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 890
StarkeII_TaFT3-D1       ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 890
Cadenza_TaFT3-D1        ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 913
Avalon_TaFT3-D1         ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 915
Badger_TaFT3-D1         ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 913
Charger_TaFT3-D1        ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 915
Atauschii_TaFT3-D1      ATCGTTAACACCAAGACATCTTGAACCATGACAAAGAATAACAATAAACAGCGTAAAATG 913
Malacca_TaFT3-B1        ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1008
Paragon_TaFT3-B1        ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1008
Rialto_TaFT3-B1         ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1017
Spark_TaFT3-B1          ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1007
Eroica_TaFT3-B1         ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1006
Prokhorovka_B           ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1006
Banco_TaFT3-B1          ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1006
William_TaFT3-B1        ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1006
Solid_TaFT3-B1          ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1006
Cadenza_TaFT3-B1        ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1007
Bagder_TaFT3-B1         ATCATTAACACCAAGATATCTTAAACCATGACAAAGAATAAATCTAAACAGGGTAAAATG 1006
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Claire_TaFT3-A1         ACATTTGTATGT----------------------------------------ACAGCCTA 944
Hereward_TaFT3-A1       ACATTTGTATGT----------------------------------------ACAGCCTA 944
StarkeII_TaFT3-A1       ACATTTGTATGT----------------------------------------ACAGCCTA 944
Malacca_TaFT3-A1        ACATTTGTATGT----------------------------------------ACAGCCTA 944
Paragon_TaFT3-A1        ACATTTGTATGT----------------------------------------ACAGCCTA 944
Rialto_TaFT3-A1         ACATTTGTATGT----------------------------------------ACAGCCTA 944
Badger_TaFT3-A1         ACATTTGTATGT----------------------------------------ACAGCCTA 942
Avalon_TaFT3-A1         ACATTTGTATGT----------------------------------------ACAGCCTA 942
Cadenza_TaFT3-A1        ACATTTGTATGT----------------------------------------ACAGCCTA 942
Charger_TaFT3-A1        ACATTTGTATGT----------------------------------------ACAGCCTA 943
Spark_TaFT3-A1          ACATTTGTATGT----------------------------------------ACAGCCTA 946
Urartu_TaFT3-A1         ACATTTGTATGT----------------------------------------ACAGCCTA 979
Claire_TaFT3-D1         ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 950
Spark_TaFT3-D1          ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 940
Paragon_TaFT3-D1        ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 950
Rialto_TaFT3-D1         ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 940
Malacca_TaFT3-D1        ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 950
Hereward_TaFT3-D1       ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 950
StarkeII_TaFT3-D1       ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 950
Cadenza_TaFT3-D1        ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 973
Avalon_TaFT3-D1         ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 975
Badger_TaFT3-D1         ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 973
Charger_TaFT3-D1        ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 975
Atauschii_TaFT3-D1      ACATTAGTATGTTTTGCAAATGAAATGGAAAACATTAAGACAAGGCCACTGTACAGCCTA 973
Malacca_TaFT3-B1        ACATTTGTATGT----------------------------------------ACAGCCTA 1028
Paragon_TaFT3-B1        ACATTTGTATGT----------------------------------------ACAGCCTA 1028
Rialto_TaFT3-B1         ACATTTGTATGT----------------------------------------ACAGCCTA 1037
Spark_TaFT3-B1          ACATTTGTATGT----------------------------------------ACAGCCTA 1027
Eroica_TaFT3-B1         ACATTTGTATGT----------------------------------------ACAGCCTA 1026
Prokhorovka_B           ACATTTGTATGT----------------------------------------ACAGCCTA 1026
Banco_TaFT3-B1          ACATTTGTATGT----------------------------------------ACAGCCTA 1026
William_TaFT3-B1        ACATTTGTATGT----------------------------------------ACAGCCTA 1026
Solid_TaFT3-B1          ACATTTGTATGT----------------------------------------ACAGCCTA 1026
Cadenza_TaFT3-B1        ACATTTGTATGT----------------------------------------ACAGCCTA 1027
Bagder_TaFT3-B1         ACATTTGTATGT----------------------------------------ACAGCCTA 1026
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Claire_TaFT3-A1         AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1003
Hereward_TaFT3-A1       AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1003
StarkeII_TaFT3-A1       AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1003
Malacca_TaFT3-A1        AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1003
Paragon_TaFT3-A1        AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1003
Rialto_TaFT3-A1         AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1003
Badger_TaFT3-A1         AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1001
Avalon_TaFT3-A1         AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1001
Cadenza_TaFT3-A1        AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1001
Charger_TaFT3-A1        AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1002
Spark_TaFT3-A1          AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1005
Urartu_TaFT3-A1         AAGAAGCAAGAACTCTTAAA-CAGTGGTATACTCATGAATTTCCTTTTTCTATCTATACT 1038
Claire_TaFT3-D1         AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1008
Spark_TaFT3-D1          AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 998
Paragon_TaFT3-D1        AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1008
Rialto_TaFT3-D1         AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 998
Malacca_TaFT3-D1        AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1008
Hereward_TaFT3-D1       AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1008
StarkeII_TaFT3-D1       AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1008
Cadenza_TaFT3-D1        AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1031
Avalon_TaFT3-D1         AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1033
Badger_TaFT3-D1         AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1031
Charger_TaFT3-D1        AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1033
Atauschii_TaFT3-D1      AAGAAGCAAGAACTCTTAAAACAGTGGTATACTTAAGAATTTCCTTTTTCAATCT--ACT 1031
Malacca_TaFT3-B1        AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1085
Paragon_TaFT3-B1        AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1085
Rialto_TaFT3-B1         AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1094
Spark_TaFT3-B1          AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1084
Eroica_TaFT3-B1         AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1083
Prokhorovka_B           AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1083
Banco_TaFT3-B1          AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1083
William_TaFT3-B1        AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1083
Solid_TaFT3-B1          AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1083
Cadenza_TaFT3-B1        AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1084
Bagder_TaFT3-B1         AAGAAGAAAGAACTCTTAAAGCAGTG-TGTACTTAAGAATTTCCTTTTTCTATCT--ACT 1083
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Claire_TaFT3-A1        ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1062
Hereward_TaFT3-A1      ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1062
StarkeII_TaFT3-A1      ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1062
Malacca_TaFT3-A1       ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1062
Paragon_TaFT3-A1       ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1062
Rialto_TaFT3-A1        ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1062
Badger_TaFT3-A1        ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1060
Avalon_TaFT3-A1        ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1060
Cadenza_TaFT3-A1       ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1060
Charger_TaFT3-A1       ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1061
Spark_TaFT3-A1         ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1064
Urartu_TaFT3-A1        ATTTATACTTGATTTATTTTTCACGTGTACAAA-CACAAAATTCATGCGATCAATTAATA 1097
Claire_TaFT3-D1        ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1062
Spark_TaFT3-D1         ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1052
Paragon_TaFT3-D1       ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1062
Rialto_TaFT3-D1        ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1052
Malacca_TaFT3-D1       ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1062
Hereward_TaFT3-D1      ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1062
StarkeII_TaFT3-D1      ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1062
Cadenza_TaFT3-D1       ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1085
Avalon_TaFT3-D1        ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1087
Badger_TaFT3-D1        ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1085
Charger_TaFT3-D1       ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1087
Atauschii_TaFT3-D1     ATTTATACTTTATTT-----CCACATGTACAAA-CACAAAATCCATGCAATCAATTAATA 1085
Malacca_TaFT3-B1       ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1144
Paragon_TaFT3-B1       ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1144
Rialto_TaFT3-B1        ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1153
Spark_TaFT3-B1         ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1143
Eroica_TaFT3-B1        ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1142
Prokhorovka_B          ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1142
Banco_TaFT3-B1         ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1142
William_TaFT3-B1       ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1142
Solid_TaFT3-B1         ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1142
Cadenza_TaFT3-B1       ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1143
Bagder_TaFT3-B1        ATTTATACTTGATTTATTTTGCATATGTACAAA-CACAAAATTCATGCAATCAATTAATA 1142
                       ********** ****      **  ******** ******** ***** ***********

Claire_TaFT3-A1        TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1121
Hereward_TaFT3-A1      TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1121
StarkeII_TaFT3-A1      TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1121
Malacca_TaFT3-A1       TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1121
Paragon_TaFT3-A1       TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1121
Rialto_TaFT3-A1        TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1121
Badger_TaFT3-A1        TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1119
Avalon_TaFT3-A1        TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1119
Cadenza_TaFT3-A1       TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1119
Charger_TaFT3-A1       TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1120
Spark_TaFT3-A1         TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1123
Urartu_TaFT3-A1        TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGATATATTTTTCTACCAACTAACA 1156
Claire_TaFT3-D1        TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1121
Spark_TaFT3-D1         TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1111
Paragon_TaFT3-D1       TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1121
Rialto_TaFT3-D1        TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1111
Malacca_TaFT3-D1       TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1121
Hereward_TaFT3-D1      TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1121
StarkeII_TaFT3-D1      TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1121
Cadenza_TaFT3-D1       TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1144
Avalon_TaFT3-D1        TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1146
Badger_TaFT3-D1        TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1144
Charger_TaFT3-D1       TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1146
Atauschii_TaFT3-D1     TCATTCAATCTTATACTGGTTTTGAAGACTTTTATGATATATTGTGCTAGCAACTAACA 1144
Malacca_TaFT3-B1       TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1196
Paragon_TaFT3-B1       TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1196
Rialto_TaFT3-B1        TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1205
Spark_TaFT3-B1         TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1195
Eroica_TaFT3-B1        TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1194
Prokhorovka_B          TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1194
Banco_TaFT3-B1         TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1194
William_TaFT3-B1       TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1194
Solid_TaFT3-B1         TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1194
Cadenza_TaFT3-B1       TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1195
Bagder_TaFT3-B1        TCATTCAATCTTATACTGGTTTTGAAGAGTTTTATGGTACACT-CCCTAT------ACA 1194
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Claire_TaFT3-A1         TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1181
Hereward_TaFT3-A1       TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1181
StarkeII_TaFT3-A1       TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1181
Malacca_TaFT3-A1        TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1181
Paragon_TaFT3-A1        TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1181
Rialto_TaFT3-A1         TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1181
Badger_TaFT3-A1         TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1179
Avalon_TaFT3-A1         TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1179
Cadenza_TaFT3-A1        TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1179
Charger_TaFT3-A1        TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1180
Spark_TaFT3-A1          TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1183
Urartu_TaFT3-A1         TATACAGCAGAACAAAGGTTACCCCCTATACATGAAGATTATATTAGAAGACACCTATTT 1216
Claire_TaFT3-D1         TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1171
Spark_TaFT3-D1          TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1161
Paragon_TaFT3-D1        TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1171
Rialto_TaFT3-D1         TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1161
Malacca_TaFT3-D1        TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1171
Hereward_TaFT3-D1       TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1171
StarkeII_TaFT3-D1       TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1171
Cadenza_TaFT3-D1        TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1194
Avalon_TaFT3-D1         TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1196
Badger_TaFT3-D1         TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1194
Charger_TaFT3-D1        TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1196
Atauschii_TaFT3-D1      TATACAGCAGAACAAAGGTTACCCC-TATACATGAAGATTATATTAGAA---------TT 1194
Malacca_TaFT3-B1        TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1229
Paragon_TaFT3-B1        TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1229
Rialto_TaFT3-B1         TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1238
Spark_TaFT3-B1          TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1228
Eroica_TaFT3-B1         TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1227
Prokhorovka_B           TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1227
Banco_TaFT3-B1          TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1227
William_TaFT3-B1        TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1227
Solid_TaFT3-B1          TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1227
Cadenza_TaFT3-B1        TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1228
Bagder_TaFT3-B1         TATACAGC---------------------------AGATTATATTAGAAGACTCCTTTTT 1227
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Claire_TaFT3-A1         GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1235
Hereward_TaFT3-A1       GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1235
StarkeII_TaFT3-A1       GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1235
Malacca_TaFT3-A1        GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1235
Paragon_TaFT3-A1        GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1235
Rialto_TaFT3-A1         GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1235
Badger_TaFT3-A1         GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1233
Avalon_TaFT3-A1         GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1233
Cadenza_TaFT3-A1        GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1233
Charger_TaFT3-A1        GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1234
Spark_TaFT3-A1          GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1237
Urartu_TaFT3-A1         GCCTAGAACTGAACAAAGTAGACTACGTTGCAGATAAATAACTAGAT------ATTTCCA 1270
Claire_TaFT3-D1         ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1230
Spark_TaFT3-D1          ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1220
Paragon_TaFT3-D1        ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1230
Rialto_TaFT3-D1         ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1220
Malacca_TaFT3-D1        ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1230
Hereward_TaFT3-D1       ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1230
StarkeII_TaFT3-D1       ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1230
Cadenza_TaFT3-D1        ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1253
Avalon_TaFT3-D1         ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1255
Badger_TaFT3-D1         ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1253
Charger_TaFT3-D1        ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1255
Atauschii_TaFT3-D1      ACCTAGAAC-AAACAAAGTAGACTACGTTGCAGATAAATGACTAGATTGGTATGTTTCCA 1253
Malacca_TaFT3-B1        GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1283
Paragon_TaFT3-B1        GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1283
Rialto_TaFT3-B1         GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1292
Spark_TaFT3-B1          GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1282
Eroica_TaFT3-B1         GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1281
Prokhorovka_B           GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1281
Banco_TaFT3-B1          GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1281
William_TaFT3-B1        GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1281
Solid_TaFT3-B1          GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1281
Cadenza_TaFT3-B1        GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1282
Bagder_TaFT3-B1         GCCTAGAACTGAACAAAGTAGACCACATCGCAGATAAATGACTAAAT------GTTTCCA 1281
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Claire_TaFT3-A1        CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1295
Hereward_TaFT3-A1      CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1295
StarkeII_TaFT3-A1      CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1295
Malacca_TaFT3-A1       CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1295
Paragon_TaFT3-A1       CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1295
Rialto_TaFT3-A1        CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1295
Badger_TaFT3-A1        CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1293
Avalon_TaFT3-A1        CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1293
Cadenza_TaFT3-A1       CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1293
Charger_TaFT3-A1       CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1294
Spark_TaFT3-A1         CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1297
Urartu_TaFT3-A1        CCAAGTTGAATTACTTTTGAAACTCTAAACTAATTAATATTAGGGTGCTCTTGCAGGCCA 1330
Claire_TaFT3-D1        CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1278
Spark_TaFT3-D1         CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1268
Paragon_TaFT3-D1       CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1278
Rialto_TaFT3-D1        CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1268
Malacca_TaFT3-D1       CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1278
Hereward_TaFT3-D1      CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1278
StarkeII_TaFT3-D1      CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1278
Cadenza_TaFT3-D1       CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1301
Avalon_TaFT3-D1        CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1303
Badger_TaFT3-D1        CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1301
Charger_TaFT3-D1       CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1303
Atauschii_TaFT3-D1     CCAAGTTGAATTACTCTTTAAATTCTTAACT------------GGTGCTCTTGCAGGCCA 1301
Malacca_TaFT3-B1       CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1343
Paragon_TaFT3-B1       CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1343
Rialto_TaFT3-B1        CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1352
Spark_TaFT3-B1         CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1342
Eroica_TaFT3-B1        CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1341
Prokhorovka_B          CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1341
Banco_TaFT3-B1         CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1341
William_TaFT3-B1       CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1341
Solid_TaFT3-B1         CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1341
Cadenza_TaFT3-B1       CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1342
Bagder_TaFT3-B1        CCAAGTTGAATTACTCTTTAAATTCTAAACTAATTAATACTAGGGTGCTCTCGCAGGCCA 1341
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Claire_TaFT3-A1        AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1355
Hereward_TaFT3-A1      AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1355
StarkeII_TaFT3-A1      AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1355
Malacca_TaFT3-A1       AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1355
Paragon_TaFT3-A1       AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1355
Rialto_TaFT3-A1        AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1355
Badger_TaFT3-A1        AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1353
Avalon_TaFT3-A1        AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1353
Cadenza_TaFT3-A1       AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1353
Charger_TaFT3-A1       AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1354
Spark_TaFT3-A1         AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1357
Urartu_TaFT3-A1        AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATCCATCGGATGGTATTTGT 1390
Claire_TaFT3-D1        AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1338
Spark_TaFT3-D1         AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1328
Paragon_TaFT3-D1       AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1338
Rialto_TaFT3-D1        AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1328
Malacca_TaFT3-D1       AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1338
Hereward_TaFT3-D1      AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1338
StarkeII_TaFT3-D1      AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1338
Cadenza_TaFT3-D1       AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1361
Avalon_TaFT3-D1        AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1363
Badger_TaFT3-D1        AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1361
Charger_TaFT3-D1       AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1363
Atauschii_TaFT3-D1     AGAGCTTTTAGTTTATGAAAGGCCAGAACCAAGATCTGGTATCCACCGGATGGTATTTGT 1361
Malacca_TaFT3-B1       AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1403
Paragon_TaFT3-B1       AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1403
Rialto_TaFT3-B1        AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1412
Spark_TaFT3-B1         AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1402
Eroica_TaFT3-B1        AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1401
Prokhorovka_B          AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1401
Banco_TaFT3-B1         AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1401
William_TaFT3-B1       AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1401
Solid_TaFT3-B1         AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1401
Cadenza_TaFT3-B1       AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1402
Bagder_TaFT3-B1        AGAGCTTGTAGTTTATGAAAGACCAGAACCCAGATCTGGTATTCACCGGATGGTATTTGT 1401
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Claire_TaFT3-A1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1415
Hereward_TaFT3-A1        GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1415
StarkeII_TaFT3-A1        GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1415
Malacca_TaFT3-A1         GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1415
Paragon_TaFT3-A1         GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1415
Rialto_TaFT3-A1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1415
Badger_TaFT3-A1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1413
Avalon_TaFT3-A1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1413
Cadenza_TaFT3-A1         GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1413
Charger_TaFT3-A1         GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1414
Spark_TaFT3-A1           GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1417
Urartu_TaFT3-A1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1450
Claire_TaFT3-D1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1398
Spark_TaFT3-D1           GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1388
Paragon_TaFT3-D1         GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1398
Rialto_TaFT3-D1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1388
Malacca_TaFT3-D1         GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1398
Hereward_TaFT3-D1        GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1398
StarkeII_TaFT3-D1        GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1398
Cadenza_TaFT3-D1         GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1421
Avalon_TaFT3-D1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1423
Badger_TaFT3-D1          GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1421
Charger_TaFT3-D1         GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGATGTGCGACACAACTTCAG 1423
Atauschii_TaFT3-D1       GCTGTTCCAGCAACTAGGCAGGGGTACAGTTTTTGCACCAGACGTGCGACACAACTTCAG 1421
Malacca_TaFT3-B1         GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1463
Paragon_TaFT3-B1         GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1463
Rialto_TaFT3-B1          GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1472
Spark_TaFT3-B1           GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1462
Eroica_TaFT3-B1          GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1461
Prokhorovka_B            GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1461
Banco_TaFT3-B1           GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1461
William_TaFT3-B1         GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1461
Solid_TaFT3-B1           GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1461
Cadenza_TaFT3-B1         GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1462
Bagder_TaFT3-B1          GCTGTTCCAGCAACTAGGCAGGGGAACAGTTTTTGCACCAGATGTGCGACACAATTTCAG 1461
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Claire_TaFT3-A1          CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1475
Hereward_TaFT3-A1        CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1475
StarkeII_TaFT3-A1        CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1475
Malacca_TaFT3-A1         CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1475
Paragon_TaFT3-A1         CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1475
Rialto_TaFT3-A1          CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1475
Badger_TaFT3-A1          CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1473
Avalon_TaFT3-A1          CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1473
Cadenza_TaFT3-A1         CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1473
Charger_TaFT3-A1         CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1474
Spark_TaFT3-A1           CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATATTTCAACTG 1477
Urartu_TaFT3-A1          CTGCAGGAACTTTGCACGGCAGCACCACCTCAATATTGTGGCTGTCTCATA--------- 1501
Claire_TaFT3-D1          CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1458
Spark_TaFT3-D1           CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1448
Paragon_TaFT3-D1         CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1458
Rialto_TaFT3-D1          CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1448
Malacca_TaFT3-D1         CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1458
Hereward_TaFT3-D1        CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1458
StarkeII_TaFT3-D1        CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1458
Cadenza_TaFT3-D1         CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1481
Avalon_TaFT3-D1          CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1483
Badger_TaFT3-D1          CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1481
Charger_TaFT3-D1         CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1483
Atauschii_TaFT3-D1       CTGCAGGAACTTTGCACGACAGCACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1481
Malacca_TaFT3-B1         CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1523
Paragon_TaFT3-B1         CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1523
Rialto_TaFT3-B1          CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1532
Spark_TaFT3-B1           CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1522
Eroica_TaFT3-B1          CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1521
Prokhorovka_B            CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1521
Banco_TaFT3-B1           CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1521
William_TaFT3-B1         CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1521
Solid_TaFT3-B1           CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1521
Cadenza_TaFT3-B1         CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1522
Bagder_TaFT3-B1          CTGCAGAAACTTTGCACGGCAGTACCACCTCAACATTGTGGCTGCCTCATATTTCAACTG 1521
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Claire_TaFT3-A1          TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1535
Hereward_TaFT3-A1        TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1535
StarkeII_TaFT3-A1        TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1535
Malacca_TaFT3-A1         TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1535
Paragon_TaFT3-A1         TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1535
Rialto_TaFT3-A1          TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1535
Badger_TaFT3-A1          TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1533
Avalon_TaFT3-A1          TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAA-------- 1525
Cadenza_TaFT3-A1         TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1533
Charger_TaFT3-A1         TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1534
Spark_TaFT3-A1           TCAAAGGGAAGGTGGATCAGGTGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1537
Urartu_TaFT3-A1          ------------------------------------------------------------
Claire_TaFT3-D1          TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGACCAGAAAGTTCTCAAGGGGAGTA 1518
Spark_TaFT3-D1           TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGACCAGAAAGTTCTCAAGGGGAGTA 1508
Paragon_TaFT3-D1         TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGACCAGAAAGTTCTCAAGGGGAGTA 1518
Rialto_TaFT3-D1          TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1508
Malacca_TaFT3-D1         TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1518
Hereward_TaFT3-D1        TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1518
StarkeII_TaFT3-D1        TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1518
Cadenza_TaFT3-D1         TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGACCAGAAAGTTCTCAAGGGGAGTA 1541
Avalon_TaFT3-D1          TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1543
Badger_TaFT3-D1          TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1541
Charger_TaFT3-D1         TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1543
Atauschii_TaFT3-D1       TCAAAGGGAAGGTGGATCAGGCGGAAGAAGGTTTAGGCCAGAAAGTT------------- 1528
Malacca_TaFT3-B1         TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1583
Paragon_TaFT3-B1         TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1583
Rialto_TaFT3-B1          TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1592
Spark_TaFT3-B1           TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1582
Eroica_TaFT3-B1          TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1581
Prokhorovka_B            TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1581
Banco_TaFT3-B1           TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1581
William_TaFT3-B1         TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1581
Solid_TaFT3-B1           TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1581
Cadenza_TaFT3-B1         TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1582
Bagder_TaFT3-B1          TCAAAGGGAAGGTGGATCTGGCGGAAGAAGGTTTAGGCCAGAAAGTTCTCAAGGGGAGTA 1581
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Claire_TaFT3-A1          GAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACCGTAGTGTTGCATCACAAA 1595
Hereward_TaFT3-A1        GAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACCGTAGTGTTGCATCACAAA 1595
StarkeII_TaFT3-A1        GAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACCGTAGTGTTGCATCACAAA 1595
Malacca_TaFT3-A1         GAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACCGTAGTGTTGCATCACAAA 1595
Paragon_TaFT3-A1         GAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACCGTAGTGTTGCATCACAAA 1595
Rialto_TaFT3-A1          GAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACCGTAGTGTTGCATCACAAA 1595
Badger_TaFT3-A1          GAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACCGTAGTGTTGCATCACAAA 1593
Avalon_TaFT3-A1          ------------------------------------------------------------
Cadenza_TaFT3-A1         GAGATTAGATACTACAGAGTAA-------------------------------------- 1555
Charger_TaFT3-A1         GAGATTAGATACTACAGAGTAAAGACCAT------------------------------- 1563
Spark_TaFT3-A1           GAGATTAGATACTACAGAGTAAAGACCATTGTATGCTGCACCGTAGTGTTGCATCACAAA 1597
Urartu_TaFT3-A1          ------------------------------------------------------------
Claire_TaFT3-D1          GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1578
Spark_TaFT3-D1           GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1568
Paragon_TaFT3-D1         GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1578
Rialto_TaFT3-D1          GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1568
Malacca_TaFT3-D1         GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1578
Hereward_TaFT3-D1        GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1578
StarkeII_TaFT3-D1        GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1578
Cadenza_TaFT3-D1         GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1601
Avalon_TaFT3-D1          GGGACTAGATAGTACAGAGTACTGACCATTGTATGCGGTACTGTAGTGCTGCATCACAAA 1603
Badger_TaFT3-D1          GGGACTAGATAGTACAGAGTACTGACCA-------------------------------- 1569
Charger_TaFT3-D1         GGGACTAGATAGTACAGAGTACTGACCAT------------------------------- 1572
Atauschii_TaFT3-D1       ------------------------------------------------------------
Malacca_TaFT3-B1         GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1643
Paragon_TaFT3-B1         GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1643
Rialto_TaFT3-B1          GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1652
Spark_TaFT3-B1           GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1642
Eroica_TaFT3-B1          GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1641
Prokhorovka_B            GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1641
Banco_TaFT3-B1           GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1641
William_TaFT3-B1         GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1641
Solid_TaFT3-B1           GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1641
Cadenza_TaFT3-B1         GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1642
Bagder_TaFT3-B1          GAGATTAGATAGTACAGAGTAAAGACCATTATATGCTGTACTGTAGTGTTGTACCACAAA 1641
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Claire_TaFT3-A1         TAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGCAGCATTATATGCATCTTC 1655
Hereward_TaFT3-A1       TAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGCAGCATTATATGCATCTTC 1655
StarkeII_TaFT3-A1       TAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGCAGCATTATATGCATCTTC 1655
Malacca_TaFT3-A1        TAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGCAGCATTATATGCATCTTC 1655
Paragon_TaFT3-A1        TAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGCAGCATTATATGCATCTTC 1655
Rialto_TaFT3-A1         TAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGCAGCATTATATGCATCTTC 1655
Badger_TaFT3-A1         TAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGCAGCATTATATGCATCTTC 1653
Avalon_TaFT3-A1         ------------------------------------------------------------
Cadenza_TaFT3-A1        ------------------------------------------------------------
Charger_TaFT3-A1        ------------------------------------------------------------
Spark_TaFT3-A1          TAATGTGTAGCATATAGAATACCCTGTATCATCTAAATATGCAGCATTATATGCATCTTC 1657
Urartu_TaFT3-A1         ------------------------------------------------------------
Claire_TaFT3-D1         TAATGTGCAGTACATAGAATGTCTTGTGTCACCTAAAT---------------------- 1616
Spark_TaFT3-D1          TAATGTGCAGTACATAGAAT---------------------------------------- 1588
Paragon_TaFT3-D1        TAATGTGCAGTACATAGAATGTCTTGTGTCACCTAAAT---------------------- 1616
Rialto_TaFT3-D1         TAATGTGCAGTACATAGAAT---------------------------------------- 1588
Malacca_TaFT3-D1        TAATGTGCAGTACATAGAATGTCTTGTGTCACCTAAAT---------------------- 1616
Hereward_TaFT3-D1       TAATGTGCAGTACATAGAATGTCTTGTGTCACCTAAAT---------------------- 1616
StarkeII_TaFT3-D1       TAATGTGCAGTACATAGAATGTCTTGTGTCACCTAAAT---------------------- 1616
Cadenza_TaFT3-D1        TAATGTGCAGTACATAGAAT---------------------------------------- 1621
Avalon_TaFT3-D1         TAATGTGCAGTACATAGAAT---------------------------------------- 1623
Badger_TaFT3-D1         ------------------------------------------------------------
Charger_TaFT3-D1        ------------------------------------------------------------
Atauschii_TaFT3-D1      ------------------------------------------------------------
Malacca_TaFT3-B1        TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCT-C 1702
Paragon_TaFT3-B1        TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCT-C 1702
Rialto_TaFT3-B1         TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1712
Spark_TaFT3-B1          TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1702
Eroica_TaFT3-B1         TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1701
Prokhorovka_B           TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1701
Banco_TaFT3-B1          TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1701
William_TaFT3-B1        TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1701
Solid_TaFT3-B1          TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1701
Cadenza_TaFT3-B1        TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1702
Bagder_TaFT3-B1         TAATGTGCAGTATATAGAATGTCTTGTATCATCTAAATATGCAGCATTATATGTATCTTC 1701

Claire_TaFT3-A1         AGCTATGATGAGCTTGATGGGATATATCTCAGTCATTTGTTAATCATCTGATCACGGA-- 1713
Hereward_TaFT3-A1       AGCTATGATGAGCTTGATGGGATATATCTCAGTCATTTGTTAATCATCTGATCACGGA-- 1713
StarkeII_TaFT3-A1       AGCTATGATGAGCTTGATGGGATATATCTCAGTCATTTGTTAATCATCTGATCACGGA-- 1713
Malacca_TaFT3-A1        AGCTATGATGAGCTTGATGGGATATATCTCAGTCATTTGTTAATCATCTGATCACGGA-- 1713
Paragon_TaFT3-A1        AGCTATGATGAGCTTGATGGGATATATCTCAGTCATTTGTTAATCATCTGATCACGGA-- 1713
Rialto_TaFT3-A1         AGCTATGATGAGCTTGATGGGATATATCTCAGTCATTTGTTAATCATCTGATCA------ 1709
Badger_TaFT3-A1         AGCTATGATGAGCTTGATGGGATATATCTCAGTCATTTGTTAATCATCTGATCACGGAGA 1713
Avalon_TaFT3-A1         ------------------------------------------------------------
Cadenza_TaFT3-A1        ------------------------------------------------------------
Charger_TaFT3-A1        ------------------------------------------------------------
Spark_TaFT3-A1          AGCTATGATGAGCTTGATGGGATATATCTCAGTCA------------------------- 1692
Urartu_TaFT3-A1         ------------------------------------------------------------
Claire_TaFT3-D1         ------------------------------------------------------------
Spark_TaFT3-D1          ------------------------------------------------------------
Paragon_TaFT3-D1        ------------------------------------------------------------
Rialto_TaFT3-D1         ------------------------------------------------------------
Malacca_TaFT3-D1        ------------------------------------------------------------
Hereward_TaFT3-D1       ------------------------------------------------------------
StarkeII_TaFT3-D1       ------------------------------------------------------------
Cadenza_TaFT3-D1        ------------------------------------------------------------
Avalon_TaFT3-D1         ------------------------------------------------------------
Badger_TaFT3-D1         ------------------------------------------------------------
Charger_TaFT3-D1        ------------------------------------------------------------
Atauschii_TaFT3-D1      ------------------------------------------------------------
Malacca_TaFT3-B1        AGCTATGATAAGCT---------------------------------------------- 1716
Paragon_TaFT3-B1        AGCTATGATAAGCT---------------------------------------------- 1716
Rialto_TaFT3-B1         AGCTATGATAAGCTTGATGGAATATATCTCAATCATT----------------------- 1749
Spark_TaFT3-B1          AGCTATGATAAGCTTGATGGAATATATCTCAATCATT----------------------- 1739
Eroica_TaFT3-B1         AGCTATGATAAGCTTGATGGAATATATCTCAATCAT------------------------ 1737
Prokhorovka_B           AGCTATGATAAGCTTGATGGAATATATCTCAATCAT------------------------ 1737
Banco_TaFT3-B1          AGCTATGATAAGCTTGATGGAATATATCTCAATCAT------------------------ 1737
William_TaFT3-B1        AGCTATGATAAGCTTGATGGAATATATCTCAATCAT------------------------ 1737
Solid_TaFT3-B1          AGCTATGATAAGCTTGATGGAATATATCTCAATCAT------------------------ 1737
Cadenza_TaFT3-B1        AGCTATGATAAGCTTGATGGAATATATCTCAATCATTAG--------------------- 1741
Bagder_TaFT3-B1         AGCTATGATAAGCTTGATGGAATATATCTCAATCATTAG--------------------- 1740
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Appendix 6.5. The GenBank accession numbers of the *TaFT3* genes

Cultivar	Gene Name	GenBank accession number
Claire	*TaFT3-A1*	KJ711527
Hereward	*TaFT3-A1*	KJ711528
Paragon	*TaFT3-A1*	KJ711529
Starke II	*TaFT3-A1*	KJ711530
Malacca	*TaFT3-A1*	KJ711531
Charger	*TaFT3-A1*	KJ711532
Badger	*TaFT3-A1*	KJ711533
Cadenza	*TaFT3-A1*	KJ711534
Avalon	*TaFT3-A1*	KJ711535
Spark	*TaFT3-A1*	KJ711536
Rialto	*TaFT3-A1*	KJ711537
Spark	*TaFT3-B1*	KJ711538
Rialto	*TaFT3-B1*	KJ711539
Badger	*TaFT3-B1*	KJ711540
Cadenza	*TaFT3-B1*	KJ711541
Paragon	*TaFT3-B1*	KJ711542
William	*TaFT3-B1*	KJ711543
Prokhorovka	*TaFT3-B1*	KJ711544
Solid	*TaFT3-B1*	KJ711545
Banco	*TaFT3-B1*	KJ711546
Eroica	*TaFT3-B1*	KJ711547
Malacca	*TaFT3-B1*	KJ711548
Spark	*TaFT3-D1*	KJ661739
Rialto	*TaFT3-D1*	KJ661740
Cadenza	*TaFT3-D1*	KJ676791
Avalon	*TaFT3-D1*	KJ676792
Badger	*TaFT3-D1*	KJ676793
Charger	*TaFT3-D1*	KJ676794
Malacca	*TaFT3-D1*	KJ676795
Hereward	*TaFT3-D1*	KJ676796
Claire	*TaFT3-D1*	KJ676797
Paragon	*TaFT3-D1*	KJ676798
Starke II	*TaFT3-D1*	KJ676799

Work published during the course of the PhD

1.Díaz A, **Zikhali M**, Turner AS, Isaac P, Laurie DA (2012) Copy Number Variation Affecting the *Photoperiod-B1* and *Vernalization-A1* Genes Is Associated with Altered Flowering Time in Wheat (*Triticum aestivum*). *PLoS ONE* **7(3)**: e33234. doi:10.1371/journal.pone.0033234

In this work I contributed to the discovery that copy number variation at *Vernalization –A1* (*Vrn-A1*) was another mutation that causes variation in vernalization response in winter wheat. Increasing copies of *Vrn-A1* resulted in stronger winter alleles. The work was started as a short MSc project and completed during my third rotation of my PhD and jointly published with Aurora Diaz who did work on *Photoperiod-1* and Adrian S. Turner. The abstract is attached.

2. **Meluleki Zikhali**, Michelle Leverington-Waite, Lesley Fish, James Simmonds, Simon Orford, Luzie U. Wingen, Richard Goram, Nick Gosman, Alison Bentley, Simon Griffiths 2014 Validation of a 1DL earliness *per se* (*eps*) flowering QTL in bread wheat (*Triticum aestivum*) Accepted *Molecular Breeding*.
The work published in this journal covers the results in chapter 2 of this thesis

3. **Zikhali M**., Wingen L., Griffiths S., New insights into short day flowering response in bread wheat. Oral presentation at the Second International Symposium: Genetic Variation of Flowering Time Genes and Applications for Crop Improvement, March 24-26, 2014, Bielefeld German. The work presented at this conference covers results in chapter 6 of this thesis. A manuscript is being written for publication in a journal.

4. **Zikhali M**., and Griffiths *et al*., New Insights into earliness *per ser*, flowering adaptation beyond *Ppd-1* and *Vrn-A1* in Bread wheat. Poster presented at the 12th International Wheat Genetics Symposium, Pacifico, Yokohama, Japan 8-14 September 2013.
The work covers results presented in chapters 3, 4 and 5 of this thesis. Two manuscripts are being written for publication in journals.