How do modern varieties and seed systems affect the challenges faced by Ugandan smallholders?

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Abstract

Institutions across Africa encourage the introduction of new farming technologies. These varieties, inputs and practices are posed to bring greater yields and improved resilience to deliver food security and economic growth, despite climate change and rising demand. Such technologies aim to not only change productivity, but also the nature of agriculture across the continent. The Uganda 2040 vision states this vision as an aim to "*transform the agricultural sector from subsistence farmer to commercial agriculture*" (Uganda Vision 2040, 2013, article 102, pp 61). Yet a challenge to these agendas is that the majority of Ugandan smallholders are not choosing new varieties from commercial seed channels. Instead, they are choosing local seed from informal farmer networks.

This research examines the dynamics of seed systems and modern crop varieties in Eastern Uganda, and how these factors affect smallholder decision-making. The thesis combines natural sciences approaches with technographic insights and behavioural choice models to explore formal and informal seed systems and how farmers navigate these systems. It finds that while formal channels and modern varieties promise higher yields and resilience, they also bring inconsistent seed quality, financial barriers and limited agency. Conversely, informal systems offer flexibility, cultural relevance, and a wider variety of crops. Informal systems are also found to be an underappreciated source of modern varieties for smallholders.

The result of this research shows farmer perspectives on modern variety deployment and adoption in Eastern Uganda. It demonstrates the importance of building plurality in seed systems, to leverage the strengths of both formal and informal channels for smallholder' needs. The thesis provides insights into how farmer preferences are shaped by social and environmental affordances, as well as economic utility. These elements explain Ugandan smallholders' adoption of new technologies and highlight gaps and opportunities within seed systems to supply farmers with useful varieties. The findings offer recommendations for policymakers to support more inclusive, resilient, and context-sensitive agricultural policies.

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Chapter 1

Introduction

A common theme in Ugandan agricultural policy is for farmers to replace traditional crops with modern varieties (*Uganda Vision 2040* 2013; Joughin 2014). Doing so is predicted to reduce the risks farmers face, raise yields and improve food security.[1] But this movement away from traditional varieties appears to be stalling. On one side, large crop improvement institutes push for a crop technology shift, and expansions to the seed systems modern varieties proliferate through (Agra 2017). On the other side, farmers appear to favour informal seed systems where modern varieties are absent (McGuire and Sperling 2016). If these modern varieties hold so much potential, why are smallholders reportedly avoiding the interfaces they are sold through?

To plant a seed means the first step of cultivation, but also the inception of an idea. Seeds are symbolic of an origin, and the great potential that can stem from something small. They have been part of the origin story for our societies. Starting 12,000 years ago, humanity shifted from hunter-gatherers to working the land, harvesting crops and selecting seeds (Putterman 2008; Mayet 2016). Crop domestication brought more food to feed growing populations, but also structuring of place and time by growing spaces and seasons. We changed the land around us, and began new cultures. As societies spread globally and met one another, we took seeds with us, we brought seeds back (Dong et al. 2017; Zhou et al. 2020). The influence of this movement on how cultures developed was enormous. It seems unimaginable now to visit Europe without

[1] Food security defined here using the FAO definition as “a situation that exists when all people, at all times, have physical, social and economic access to sufficient and safe nutritious food that meets their daily dietary needs and food preferences for an active and healthy life.” (FAO, 1996)

potatoes, Asia without chili and Africa without maize. These examples are the manifest potential of those first planted seeds. The products of a transcendent shaping of seeds as technology, and the cascading effects through society.

This thesis follows this ongoing journey of crop adoption as it plays out between different communities in Eastern Uganda. If I can plant two seeds here:

1. Technology is not just the material artefact, but also the social milieu of institutions and behaviours that comprise it.
2. The utility a technology offers, moulds and can be moulded by the agency of actors; not necessarily in line with the original design.

We will come back to these thoughts as I explore the question, "how do seed systems and modern varieties affect the challenges faced by Ugandan smallholders?". This thesis investigates how smallholders navigate seed systems and crop adoption for food and economic security at time of climate, population and policy change (Schlenker and Lobell 2010; *Uganda Vision 2040* 2013; Okonya, Syndikus, and Kroschel 2013; Bonny 2021).

As we will explore in this thesis, there are complex institutions and agendas that drive how crops are improved for 'farmers'. These institutions are legitimised on grounds *why* crops should be improved, and *who* they aim to benefit. For example, the Ugandan 2040 vision calls for a specific kind of transformation of Uganda's current seed systems and a certain vision of how this helps smallholders. This national approach aligns with wider continental agendas on agriculture that must change to deliver food security and economic development (Toenniessen, Adesina, and DeVries 2008; Agra 2017; Rege and Sones 2022). Such projects promise great returns, but also carry assumptions with them about how the most vulnerable interact with the changes and how they modify the risks farmers face.

This thesis investigates how technology changes are playing around modern crop varieties and seed systems in Uganda. To critically review the role improved varieties have for farmer risk exposure, I first introduce the wider context of how and why crop technologies and seed systems are developing globally and across sub-Saharan Africa.

A central theme of this thesis is about food security, the production of food and the delivery of technologies designed to raise productivity. It is mostly upon these grounds that farmers are encouraged to adopt new, more productive varieties as seed. We need to produce enough food for the potential to feed global populations, but this is not to say that production alone ensures food security. For instance, this would overlook food availability and accessibility dimensions that determine who is able to eat that food. Raw production alone might also not include nutritional security, demonstrating that it is not just *how much* we eat, but also *what* we consume. There are also arguments that production increases might have a more limited impact on food security when food spoilage and wastage continues to reduce the amount of overall food. Another consideration is the sustainability of food production and how this affects the capacity to achieve food security for future generations.

1.1 Thesis outline

As the aforementioned paragraph suggests, there are complex and interacting arguments as to why and how smallholders might achieve food security. This thesis focuses on the more specific approach of raising production, within a much wider discourse of achieving nutritional, and farm-derived economic security.

In this section of the introduction I provide an overview of the thesis structure, and a brief summary on the contributions of the research to the literature. This summary is followed by a section outlining the thesis research questions. The main research question is "how do seed systems and modern varieties affect the challenges faced by Uganda smallholders?" Answering this overall question requires consideration of a number of secondary questions, which include topics of; how formal and informal systems operate; risks across these systems and; how these systems come to exist.

The research questions are followed by a short reflective section on the impact of COVID-19 upon this PhD. The pandemic was a time of great uncertainty, and this section seeks to show how these events affected the planning and implementation of the research.

The second chapter of this thesis explores the wider arguments around food security, to contextualise how the push to increase Ugandan yields fits within wider realms of helping smallholders, reducing food insecurity and supporting economic prosperity. This foundation allows the chance to explore how crop improvement has been positioned, and competes, as a solution worth investment to address these challenges. The second part of this context chapter provides a background to focus on agricultural developments across sub-Saharan Africa and Uganda. Seed systems will be introduced briefly in the introduction, to be explored in greater detail in the literary review.

The third chapter of this thesis provides a literature review, providing greater detail on the social and natural science aspects of crop improvement and seed systems. Also included in this section is an exploration of the main arguments surrounding seed system developments, and how these systems are expected to change in Uganda.

The fourth chapter outlines the conceptual framework that guides the thesis methodology to investigate smallholder behaviours across seed systems. This thesis takes a mixed methods approach, integrating insights from both natural and social sciences to provide a comprehensive analysis of seed systems and farmer decision-making processes. The aim of this approach is to enable a nuanced understanding of the complex interactions between farmers and their environments. The conceptual framework that guides this research takes a technographic approach, drawing on the theory of affordances, and combines this with discrete choice experiments from utility theory. This section expands on how combining these approaches can offer a more nuanced understanding of how individual and environmental attributes affect where and how Ugandan smallholders source useful seed.

Three research chapters follow the conceptual framework. The order, and rationale for these research chapters is a product of the conceptual framework approach, with each chapter focusing on a complementary area. These are: chapter five: hidden risks in formal seed supply; chapter six: informal seed systems and their role as a conduit for new seed technologies and; chapter seven: discrete choice experiments that show how smallholders value formal maize seed, and the reasons why they make this choice. Each research chapter contains a review of the relevant literature, a list of methods, results and a conclusion.

The three results chapters are followed by a conclusion chapter that considers how the changing environment of modern varieties and formal seed systems affect the challenges faced by Ugandan smallholders. This conclusion shares a number of findings from this study. The first is that the methodological approach offers a dynamic framework for examining how farmers perceive and respond to changes in their agricultural ecosystems. This approach not only highlights the complexities inherent in farmer behaviours and perceptions but also the broader socio-economic impacts of changing seed systems. A core finding of this study demonstrates how farmers navigate through different seed systems to mitigate risks and enhance their livelihoods effectively. The success of proposed Ugandan seed systems changes therefore involves not just consideration of the material seed technologies, but also understanding and supporting the way farmers adapt to these changes.

1.2 Contributions to the literature

This thesis highlights challenges in formal system supply of seed, and that the formal sector faces significant challenges to feasibly replace informal seed systems. A clear challenge is that the Ugandan formal system focuses on a narrow range of high-value crops, largely neglecting the diverse agricultural needs of most smallholders. As also shown in this study, the regulatory environment that governs this system currently over-promises on the quality of products, struggling to enforce standards and ensure the quality of seeds. Further, and paradoxically, I find that these same regulation systems ask farmers to take more risks when investing in certified seed. On one hand, these findings question the ability of formal seed systems to meet the broader agricultural demands of the Ugandan population. On the other, I share evidence to demonstrate the role of informal seed systems for farmer resilience. Despite advocacy to shift to formal seed systems, informal systems continue to play a critical role for Ugandan smallholder farming. These systems are deeply embedded in the local culture and provide a vital source of diverse and adaptable seed varieties. Informal systems offer forms of seed security through their accessibility, affordability, and flexibility; enabling farmers to respond swiftly in a context of changing environment and markets. Moreover, these systems help preserve important cultural crops and biodiversity, which are absent on formal systems.

A surprising discovery of this work was that many farmers already grow modern varieties without buying from agro-dealers. While many proponents frame formal systems as the vehicle to bring modern varieties to farmers, instead I find that the majority of farmers use their agency to access these technologies through informal systems. The developing integrated seed sector is also shown to present an effective way to connect farmers to useful technologies, while also providing an interface for farmers to feedback varietal needs. These initiatives are demonstrated to be particularly important for promoting crops that are less commercially viable but hold significant nutritional and cultural value.

Despite the above, I share evidence that many smallholders in Eastern Uganda are actively transitioning to formal seed systems for maize. This finding is surprising given the body of reports estimating that agro-dealers serve a small minority of farmers. Discrete Choice Experiment (DCE) results suggest that farmers see agro-dealers as the best maize seed channels, and that seed sold at certified prices as the best products. It seems that farmers are changing to purchase from agro-dealers as they perceive them to sell high-quality maize varieties. Conversely, smallholders appear to be reducing maize purchases from informal channels. While informal channels are seen as beneficial on accessibility grounds, farmers are uncertain of maize seed quality across these channels.

These adoption choices of farmers in Uganda reveal a complex landscape of preferences and actions. There are reasons why farmers rely on informal channels, but also why they are drawn to maize seed sold on formal channels. Overall, these findings demonstrate the nuanced in farmer decision-making across seed channels. From a resilience standpoint, I argue for further integrating the strengths of both formal and informal seed systems. Such plurality in seed technology could help farmers to access useful crop technologies, while also reducing the overall risks they face. This demonstrates the value of diversity in seed systems and promotes collaboration across all levels of the seed supply chain. By enhancing understanding and cooperation between different seed system stakeholders, Uganda can better support smallholders to achieve resilient and sustainable futures.

Explanations

While this study comes from the faculty of social sciences, the content regularly draws from natural sciences. To cater for a broad audience, I have included text boxes, such as this one, to add clarity where necessary.

1.3 Research questions

This thesis seeks to understand how farmers navigate seed systems and new crop technologies. It looks at how farmers decide what varieties to grow and why. It investigates how institutional operations change and influence the risks farmers face. Overall, it asks the question:

> *How do seed systems and modern varieties affect the challenges faced by Uganda smallholders?*

Answering this research question relies on the consideration of secondary questions. These are:

1. **How do Ugandan seed systems operate?** This includes considering the composition of actors involved, and how they align or conflict with one another. Reflecting on the range of Ugandan seed systems also presents the opportunity to compare the inter- and intra-connections within and between crop extension systems.

2. **What are the risks that farmers face from different seed systems?** This question considers where the risks might exist across supply chains to seed technology quality. Part answering this question involves understanding how Ugandan farmers perceive seed system risks around them and how these risks affect decision-making.
3. **What are the power relations in the formal and informal seed systems?** Seed systems are comprised of a complex web of social interactions. This question considers how actors and institutions across these networks might have differences in authority, control and decision-making power. More critically with the changing space across Ugandan seed system, this question considers how the growth of formal, commercialised channels affect power dimensions across seed systems
4. **Has historicism and path dependency manifested in seed technology decision-making?** There are a range of seed channel types and processes that exist today as the result of decisions, patterns of actors and their behaviours. This question considers how these inherited practices and pathways continue to affect the ongoing and future changes and ability of seed system actors to change.
5. **What crop technologies do farmers want?** Fundamentally, seed systems provide a mechanism by which actors can reproduce seed technology as a result of their perception, preferences and agency to select. A part of understanding how Ugandan seed systems operate is therefore also to understand what farmers see as preferable for their utility. We seek to understand what farmers believe to be the most valuable crop technologies and how this influences their investment decisions of where and how to acquire these products.

In answering these questions, this thesis seeks to contribute to the crop adoption literature by understanding how farmers navigate changing seed systems to support their livelihoods. Understanding this situation is important to both feed into seed system developments across Uganda and sub-Saharan Africa.

1.4 The impacts of COVID-19

This PhD and research took place during the COVID-19 epidemic. The changing situation with the pandemic influenced the planning and implementation of the work. This section outlines some of the ways the thesis was impacted, and reflects upon the resulting implications on both the research and my development as a researcher.

Concerns around the pandemic meant that I was one of a cohort of four PhD candidates, with many others deciding to delay their placement. It is hard to recall when our cohort first met in person, as the start of the PhD came between a time of quarantines and social distancing. At the time, the entire university had been arranged into a single one-way system, with tape and arrows marking how to navigate between buildings in curiously winding routes. The system would have been impossible under normal occupancy, but the university was empty as a result of lectures being held remotely and staff working from home. When we did meet, it was in large rooms sparsely populated with desks, or on long desks segmented every two metres by Gaffa tape and printed warnings. The picture I recall was my glasses fogging from the masks while we peered at distant lecturers with voices muffled by plastic face protectors.

The overwhelming feeling at that time was uncertainty. Every PhD has a degree of uncertainty but the fieldwork expectations from a development degree were particularly awkward under pandemic restrictions. We were writing plans to travel and meet people when both aims were prohibited. In the first year of lockdowns, the general consensus was that things would soon return to normal. Suggestions of contingency plans had been mentioned from the start, but the reality of these were either conducting the research remotely through calls (impossible for most of our topics) or employing researchers in country to conduct the work (with few having the funds to achieve this). Fundamentally however, each of us wanted to travel to gain the experience. As such, we planned our work as if the pandemic would end. This meant that my original plans included extended fieldwork to Uganda and a shorter trip to Ethiopia.[2]

As the months of the pandemic continued, we moved closer to fieldwork dates and hoped that precautions, vaccines or herd immunity would reduce incidence levels enough for us to travel. As the virus spread across countries, the feasibility of our travel was ultimately decided by the 'UK Red List'. Once a country changed to 'red', insurance became impossible and the travelling individual was expected to return immediately, to spend two weeks in a specialist COVID-19 hotel, at personal expense for an estimated £1600. Having our intended destinations join the red list prior to travel was one concern. A larger concern was that it would change during our fieldwork.

Africa was one of the later continents to see rises in COVID-19 cases, with slower spread and lower case numbers causing many African countries to remain as 'amber', and possible for travel. During the second year of the PhD, this changed, with both Ethiopia and Uganda changing in and out of red. Three of my planned trips were postponed, one only a week before travel. With

[2]For research that was originally planned to be part of the thesis, but was later kept separate.

time pressing on, it became clear that the fieldwork had to commence remotely.

Thankfully the fieldwork for the Ethiopian research came with funding, which I used to hire a research consultancy who had worked with the World Bank. For the Ugandan fieldwork, I managed to obtain a research grant with Manchester University for the sensor studies that comprise chapter five of this thesis. The rest of the Ugandan fieldwork, I funded personally and through assistance from existing connections between The Field Lab Uganda and the University of East Anglia. I was later reimbursed for my personal investment due to the team's acquisition of another research grant that overlapped with my research. While I never travelled to Ethiopia for this research, I did eventually travel to Uganda for a month in the third year of my PhD. I conducted the bulk of the qualitative work for chapters six and seven from this period.

It is difficult to quantify the negative impacts of COVID-19 on the research. The most tragic impact was the death of my collaborator in Uganda due to complications from COVID-19.[3] While I only briefly worked with Professor Noble Banadda of Makerere University, he was instrumental in helping me start the remote planning for the content in chapter five. One of the outputs from this research was the development of a new low-cost sensor to help farmers track risks to seed quality (https://seedsentry.systems/). Prof. Banadda was Chair of the Department of Agricultural and BioSystems Engineering, and I have no doubt that this concept design would have been further developed at Makerere had he survived. More importantly though, he was an impressive and inspiring man. The world is a sadder place for his passing but I am delighted I had the chance to work with him, albeit briefly.

The other major impact to this work was the subsequent reduction in overall fieldwork. Firstly, in time that was lost while rearranging plans in response to the changing pandemic requirements. Secondly, in the reduced overall amount of fieldwork time that was possible with the redistribution of budgeting for remote fieldwork. Had I been able to travel, a greater share of these budgets could have been allocated to field activities. With that said, I am proud of the amount that was achieved in the time that we had. A big part of this is due to the impressive capacity of the local research collaborators.

Another impact from the reduction in overall fieldwork was that I experienced much less time in the field. This meant I missed out on learning more about the context, making more connections and improving my fieldwork skills. Thankfully, as mentioned, I was able to travel to Uganda in the final year of the thesis and this proved to be essential for my understanding. Similarly, while

[3] https://en.wikipedia.org/wiki/Noble_Banadda

I did not travel to Ethiopia for this work, I have worked across the country in previous projects. This ensured I held a basic understanding of the conditions at the study fieldsite.

Stepping back from the fieldwork, another negative impact from the pandemic on the PhD involves how I could interact with the research community. The majority of my PhD was spent working from my kitchen table. The office was empty and conferences all moved online. While I presented my research at one in-person lecture, I visited no new institutes and met few other researchers in person. Thankfully however, the online research community has been extremely welcoming and I have met many new researchers through online events.

There were positives to the pandemic. The major of these was that the experience of managing remote research teams was extremely useful. Originally, I planned to conduct the Ethiopian and Ugandan fieldwork sequentially, as my direct involvement at both locations gave no other choice. By shifting to remote research however, I was able to work simultaneously with both teams, allowing a greater overall volume of work to be achieved. I was also able to develop my management experience. Both research teams were fantastic but required completely different management approaches. Learning to work with these different styles was a fantastic experience and perhaps the major factor in me successfully obtaining a management level job towards the end of the PhD. The pandemic is what led to the opportunity for me to gain these skills.

While COVID-19 was a strange and traumatic time, there were also many wonderful moments over the PhD. When we started, a professor said to our cohort, ‘the key to the next years will not be about the original plan, but how you are able to adapt’. The pandemic changed many of my original plans, and in shifting to find a way forward, I believe I became a better researcher as a result.

Chapter 2

Background context to the research

Now that I have provided the background context of the PhD, this next section provides the wider context surrounding seed technology and how this influences the changing space of seed systems in Uganda. This overview starts with the challenges in agriculture and assumes some understanding of crop varieties and how they come to be made as part of breeding strategies. A more general background on those components however can be found in the appendix.

2.1 Global challenges for agriculture

We need to transform food systems for both people and the planet. This is not to decry the great achievements humanity has already made to feed the 8.1 billion people alive today (von der Goltz et al. 2020). The Green Revolution alone is a striking example of what unified technology, infrastructure and social movements can deliver.[1] It marked a step change in productivity gains, providing sustenance to growing populations. But this production increase has come at great costs to human lives and the natural world. Despite our capacity for production, food has become a major source of ill-health, and a major driver of habitat degradation (Benton et al. 2021; World Health Organisation 2021; Wentworth and Latter 2023; Katsarova and Chahri 2023).

[1] For instance Asian cereal yields tripled between 1960-2000 and undernutrition prevalence decreased by 25% FAO, 2006; Toenniessen et al., 2008

Urgent global action is required to transform food systems, as the problems are getting worse.

2.1.1 Undernutrition and food shortages

Undernutrition is rising globally (FAO et al. 2022). Around 9% of the global population is malnourished and this number has increased by 60 million people since 2014 (FAO et al. 2020). Many of the hungry are children; around 29% of children under five are estimated to be stunted (FAO et al. 2022). Childhood stunting has risen in every region of Africa, despite falling globally since 2000 (Tansey 2013).

The issue is not just a calorie deficit. Approximately half of all children under five suffer from micronutrient deficiencies or 'hidden hunger'. Many of these malnourished children will face lifelong health impacts as a result (Dewey and Begum 2011). The challenge of providing enough food becomes more pressing with future demand predictions. Estimates suggest we need to produce 60% more food globally in the next 26 years (Conway and Shah 2012). This means that by 2050, we will need to produce another planet's worth of food.

The challenge is not just feeding the number of people, but supplying the *composition* of food people want to eat. As countries are becoming wealthier, consumption is increasing for more resource-demanding foods (Stoll-Kleemann and O'Riordan 2015). Examples of this can be found in the rising demand for red meat and dairy products, and the growing ubiquity of meat in meals. These consumption changes however mark another growing food challenge: at the same time as worrying about those not getting enough food, there is growing ill-health from over-consumption.

2.1.2 The avoidable burden of non-communicable disease

Non-communicable diseases (NCDs) have become the leading cause of ill health and deaths globally (Benziger, Roth, and Moran 2016; Bigna and Noubiap 2019).[2] Unhealthy diets are the biggest cause of NCDs, resulting in shorter healthy life and reduced life expectancy. Worldwide, obesity numbers have tripled since 1975 (World Health Organisation 2021; Katsarova and Chahri 2023). Diabetes numbers have almost quadrupled since the 1980s.[3] Approximately 90% of these cases are Type II diabetes (CDCP 2023). Yet the rise of obesity and type II diabetes is an avoidable burden since they are preventable through healthy diets and exercise (Horton 2013).

[2]This is in part also due to global achievements in preventing infectious diseases, but rates of NCDs are rising.

[3]From an estimated 108 million in 1980 to 415 million today. This figure is predicted to rise to 642 million by 2040.

The increase of NCD prevalence also causes financial burdens on health systems. Diabetes treatment in the UK is estimated to cost more than all cancer treatment (Hex et al. 2012; Stedman et al. 2020). Africa is suspected to have the highest number of untreated diabetes cases (Collins Boakye-Agyemang 2023). The high costs related to NCD care are felt most in lower and middle income countries, where hospitals and patients struggle to access treatment. The cost of NCDs also affects the state economy through the rising number unfit for work as a consequence of diet-related NCDs. If current trends continue, diet-related disease costs are projected to exceed $1.3 trillion per year by 2030 (Bommer et al. 2018). A light in the dark is that we know the causes of rising diet-related disease rise (Schwingshackl et al. 2017). We also know which diets raise the likelihood of long, healthy lives.

2.1.3 Meeting the demand for healthy diets

We understand the drivers of both sides of malnutrition and we also know what solutions we need: we need diverse nutritious diets, rich in fibre and whole foods, and we need these diets to be accessible to all members of society. The world therefore now faces the challenge of delivering these healthy, equitable diets to global populations. The question is, '*how* will we produce healthy, accessible diets to feed global populations?'

Some of this food will be found through reducing the annual 1.3 billion tonnes of lost and wasted edible food throughout post-harvest, supply chain and consumer stages (Food and Agriculture Organization of the United Nations (FAO) 2013). Other savings might be achieved through shifting diets to more efficient systems; such as replacing animal proteins with plant-based alternatives (Stoll-Kleemann and O'Riordan 2015; Ritchie 2021). But recovery and efficiency gains are unlikely to meet the need alone. Feeding 10 billion people will also require us to produce more food. When we think about production, we must consider *how* we produce food, and *what* we produce. One way to consider this is looking at how we raised productivity in the past.

Historically we have increased more food by 1. expanding growing areas and 2. increasing the yield from an area. The Green Revolution from the 1960s onward brought a major productivity increase across most of the world (Evenson and Gollin 2003). Prior to the Green Revolution, yield gains mostly come from expanding agricultural areas, rather than efficiency gains. The Green Revolution did cause an expansion of farmed areas, but the most significant gains came from raising yields per area (Stevenson et al. 2013). These efficiency gains came from the development of improved varieties, and higher productivity from chemical fertiliser application.

An example of the difference this made can be seen in American maize yields, which increased from 2.4 tonnes per hectare in 1950 to 10.88 tonnes per hectare today (Ritchie, Rosado, and Roser 2022). Productivity gains were also made by reducing losses to pests and diseases. For example, a major focus of Norman Borlaug's wheat productivity mission was to breed varieties that are resistant to fungal rusts (Borlaug 2000). If these steps worked in the past to raise productivity, why can't we just continue to use them?

2.1.4 A growing challenge for agriculture

The Green Revolution is often used as an example of the world overcoming a food security crisis before. We must however be careful about using this as a comparison to the situation today. Doing so would be an oversimplification, and the context is not the same.

The Green Revolution had one clear target; to raise productivity. The problems we face today are multiple, different, and cannot be solved with the same single-mindedness. Productivity is a part of the puzzle, but the needs today are more nuanced, inter-woven and complex. Some of these contemporary challenges also came about as a result of the Green Revolution. We must learn from the Green Revolution, rather than aim to repeat it. Instead a more holistic view is needed to deliver sustainable food systems. We need a *"food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised"* (Wentworth and Latter 2023, 3).

An intractable challenge we face is to raise agricultural productivity despite the pressures of climate change, without further expanding agricultural area and while lowering carbon emissions (Campbell et al. 2017; Schlenker and Lobell 2010; Tadross et al. 2009; van Ittersum et al. 2016; Kuriachen, Aiswarya, and Aditya 2021; Wentworth and Latter 2023). Climate change affects seasonality, growing areas, post-harvest storage, pests and diseases. These changes, and the associated uncertainty, have reduced yields. It is estimated that global agricultural productivity is 21% lower as a result of climate change (Ortiz-Bobea et al. 2021). Climate change has shifted what we can grow and where. It has reduced the overall area we have for crop production. For example, it is the estimated 23 hectares of land that are lost every minute to desertification (United Nations Environmental Programme 2018). Threats like these reduce food availability and cause knock-on effects to livelihoods and markets. If we are to raise yields, we must also find more resilient ways to farm as we adapt to changing environments. But agricultural transitions do not take place in a bubble and the impacts of farming on the natural world are becoming increasingly apparent.

2.1.5 Agriculture and habitat degradation

Agriculture is a major contributor to climate change through habitat degradation and carbon emissions (Benton et al. 2021; Wentworth and Latter 2023). Farming practices are the main driver of natural habitat loss, destroying ecosystems and releasing carbon emissions (Brondizio et al. 2019). These changes take place through both the fragmentation and degradation of natural habits, with farmland now covering 50% of habitable land surface (Richies 2019). Remote sensing shows that expanding farming areas has driven 90% of deforestation and 68% of this was by small-scale farming (Branthomme et al. 2023). Agriculture is also the main driver for desertification (Zhu, Luo, and Liu 2022). Run-off of agricultural inputs pollute natural systems and repeated cultivation has degraded soil structures. These combined forms of land degradation have driven biodiversity losses into the sixth major extinction event, with an estimated 25% of all species now facing extinction (Brondizio et al. 2019). This destruction is not only an ethical disaster, it destroys the very same ecosystem services that sustain agricultural and human societies. We must prevent further biodiversity losses, and in doing so we can contribute to climate change mitigation (Shin et al. 2022). The question is therefore how we continue to raise productivity, sustainably, when historically we have proffered from the destruction of habitats.

Strategies to reduce agricultural impact on natural habitats fall into two general groupings: land-sharing and land-sparing. Land-sharing approaches integrate farming areas with biodiversity conservation, with agricultural practices coexisting with habitat restoration. Examples include agro-forestry and silvo-pasture. Alternatively, land-sparing approaches separate agricultural and conservation habitats. Advocates argue that larger protected spaces are required exclusively for nature and that intensifying farming gives potential to ‘free up’ space for conservation (Stevenson et al. 2013; Benton et al. 2021). These land-sparing approaches focus on raising the outputs and efficiency of crop and animal products per unit of land. Examples include precision agriculture and modern breeding techniques.

Criticism exists on both sides of the land-sparing vs land-sharing discourse. Land-sharing critics argue that combining farming and conservation risks a no-win middle ground of lower yields and poorer conservation sites. Conversely, land sparing critics argue that efficiency gains have historically not reduced farming areas, and instead have led to further encroachment onto natural habitats unless combined with stringent policy (Hamant 2020). There is however nuance throughout both groupings and neither approach provides a one-size-fits-all option. Rather than suggest which approach is more promising for future food security, it seems likely that a combination of approaches will be required based on the landscape characteristics, farming and social needs.

So far, these debates have covered broader and more general arguments in the food production discourse. The focus of this thesis however is on how arguments around food production are playing out in Ugandan agriculture. From here on in, I focus on the situation in Africa, and how this is influencing Ugandan agricultural strategy.

2.2 African agriculture and food security

Agriculture is a central part of life for many Africans. The sector provides around 52% of all employment and an average of 14% of GDP for African countries (International Labour Organization 2021; Oxford Business Group 2021). For comparison, these same figures respectively for the European Union are 4% and 1.7%; or 2% and 1% for the United States. Contrary also to patterns in other continents, Africans do not appear to be transitioning away from agriculture with economic development (Davis, Di Giuseppe, and Zezza 2017). These figures show the economic importance of food production for African countries.

Perhaps a consequence of the ubiquity of agriculture in Africa, narratives around improving African food productivity are regularly made as integral to livelihood security and poverty eradication strategies. The general argument is that by increasing harvests, farmers experience better economic returns upon which to escape poverty. In practice, this approach is more problematic as widespread harvest increases do not ensure economic returns nor overcome market barriers (Hollinger and Staatz 2015; Bold et al. 2022). For example, there might be lack of demand for products, lack of social access to markets, lack of infrastructure to reach markets and finally the fundamental rules of supply and demand mean that if all farmers produce more, sale prices per unit are likely to fall. Still, one reason such economic claims are regularly made is likely due to the relative poverty of most African farmers who rely on agricultural livelihoods.

Over half of the African agricultural labour force are poor, with 76% of the region's extreme poor relying on agricultural livelihoods (Castañeda et al. 2016). Around 80% of sub-Saharan farmers are smallholders, farming two acres of land or less (Thompson 2012; Lowder, Skoet, and

Raney 2016). Nearly all of these farms are rain-fed, and agricultural input use remains low.

Despite the prevalence of Africans in agriculture, the continent faces rising food insecurity. Sub-Saharan Africa has the highest increasing rate of diet-related ill-health and death (John-Joy Owolade et al. 2022). Around 40% of women at reproductive age are anaemic (Global Nutrition Report 2022). Around a third of African children are stunted and 6% are wasted. At the same time, the prevalence of obesity is increasing. Around 20% of African women are thought to be obese (IBID). Diabetes levels are expected to rise by 129% by 2045, totalling 55 million people (Collins Boakye-Agyemang 2023). The rise of these non-communicable diseases place further pressure on struggling health care infrastructure and African economies (Owino 2019). Overall, there is increasing pressure for African populations to have equitable access to nutritional food.

2.2.1 Rising food pressures in Africa

African food demand is projected to dramatically rise (van Ittersum et al. 2016). Some of this increase in demand is expected due to rising populations across the continent, expected to double by 2050, to around 2.5 billion people. At this number, Africa would account for a quarter of the global population, with Nigeria alone overtaking the US for the third most populous country. This rise in food demand is particularly concerning given that climate change could cause a 43% increase in African food insecurity by 2050 (Schlenker and Lobell 2010).

Food production pressures from climate change come in the form of changing growing seasons and extremes in conditions. When combined with globalised trade and the rise of monoculture cropping, climatic changes have also increased pest and disease pressures (Barzman et al. 2015; Taylor et al. 2018; Mafongoya et al. 2019). Smallholders are aware of these risks but often lack the means to respond.

African food production is particularly vulnerable to climate changes for a number of reasons. The vast majority of farmers live in poor rural areas with limited infrastructure (Lowder, Skoet, and Raney 2016). These farmers depend upon seasonal rains and few have access to irrigation systems. Climate change has altered these rainy periods, increasing seasonal uncertainty and the risk of droughts or floods. Growing prevalence of degraded soils across sub-Saharan Africa is also making crops more vulnerable to these shock events. For instance desertification can both reduce available soil moisture and increase the chance of flash floods (Cornelis, Waweru, and Araya 2019).

The low-income status of many African farmers may restrict local adaptive capacity to build climate change resilience. For instance, smallholders may lack access to pesticides or disease resistant varieties. These farmers may struggle to access climate-smart cropping strategies, or the infrastructure to protect and store crops (Lipper et al. 2014; Acevedo et al. 2020). Low-income farmers who do experience crop failure may lack the economic capacity to absorb the shock, causing further consequences to livelihoods (S. Asfaw et al. 2016; Tenywa et al. 2017). Additionally, it is not always clear how risk-sensitive farmers will respond to increasing prevalence of climate shocks. For instance, they might discourage or encourage investment in new (unknown) or expensive technologies, and how these technologies are used in combination (Holden and Quiggin 2017; Kelvin M. Shikuku et al. 2017; Mukasa 2018; Jin et al. 2020).

Where shocks are felt over widespread areas, food prices can rise dramatically, bringing access as well as availability barriers to food. Farmers are often aware of these climate risks, but often lack access to finance or credit to invest in more resilient systems (Sani and Chalchisa 2016; Clay and Zimmerer 2020).

In conclusion, African farmers face many risks from climate change, which continues to cause knock-on reductions in food productivity. African countries have responded to these shocks previously through increasing food imports, but this comes with significant financial and food sovereignty costs (van Ittersum et al. 2016; Hoije 2023). It is evident that both African crop productivity and resilience need to improve to nourish rising populations. One way that is commonly touted as a path to deliver this food security is that of an African Green Revolution.

2.2.2 The late agricultural revolution in Africa

As described above, a regularly cited reason for food insecurity in Africa is the relatively low productivity many farmers achieve (Evenson and Gollin 2003; Toenniessen, Adesina, and DeVries 2008). While the Green Revolution brought significant productivity increases to much of the world, these returns have been elusive across African countries (Clay and Zimmerer 2020). An example of this can be found in comparing yield gaps between African countries with the rest of the world, see figure 2 (Hillocks 2014). These figures should however be contextualised. Smallholders' fields often contain a diverse selection of crops. As such, it is logical to expect yields per area for a single crop to be lower than those found in monoculture farming. This mixed-cropping might therefore explain part of the reason behind yield gap differences. Regardless, even with ubiquity of maize farming in Africa, yields remain low and have seen little increase in recent decades comparative to much of the world (Toenniessen, Adesina, and DeVries 2008; Odame and Muange 2011).[4] This has led to many calling for greater efforts to deliver the Green Revolution in Africa.

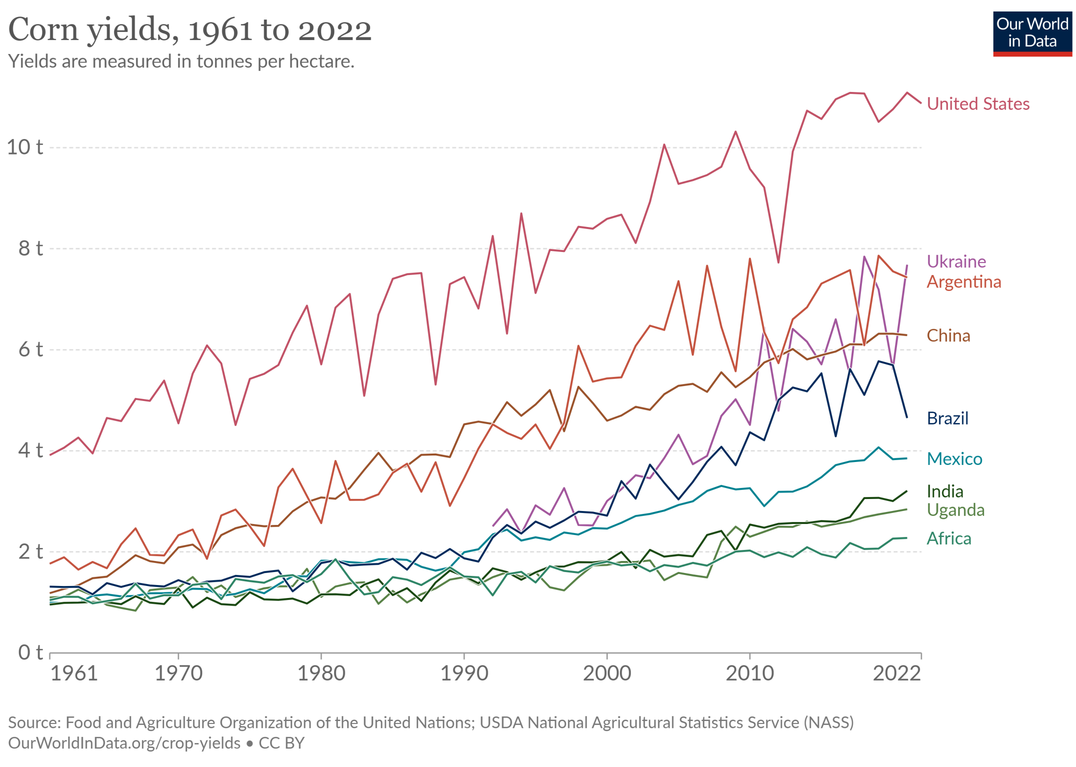

Figure 1: Yield gaps: maize productivity increases globally.

Curiously, despite Africa's reliance on agriculture, the continent has not transitioned through a Green Revolution (Scoones and Thompson 2011; Alliance for a Green Revolution in Africa (AGRA) 2013). Instead, this revolution appears to have started a number of times, but not sustained (Djurfeldt et al. 2006; Scoones and Thompson 2011). Harvests have risen in Africa since the 60s, but approximately 90% of this yield gain was due to agricultural expansion rather than efficiency increases (Toenniessen, Adesina, and DeVries 2008; Scoones and Thompson 2011).

African yield gaps are often explained as a result of relying on traditional varieties, rather than more recent improved varieties (Gaffney et al. 2016). This assumption should be made with caution. A yield gap is the difference between the potential yield and the actual yield. Such

[4] An overview African yield gaps can be explored at the following address: www.yieldgap.org/web/guest/sub-saharan-africa

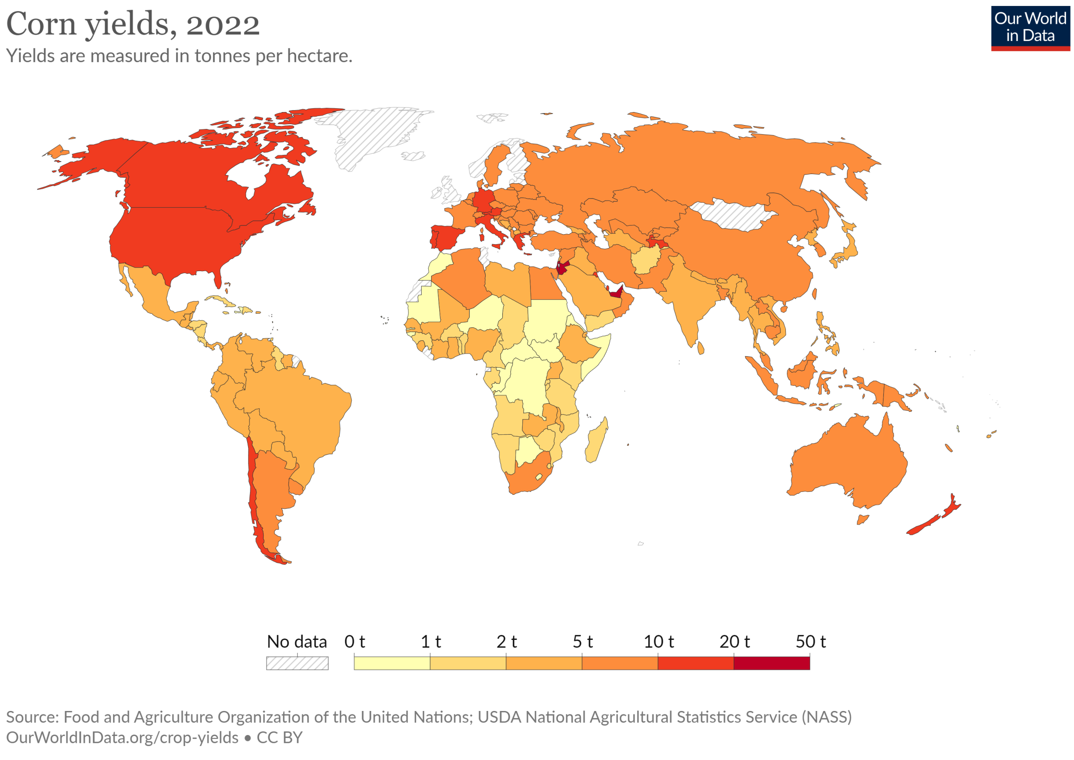

Figure 2: Maize global yield map.

gaps are most likely to occur when crops are grown in sub-optimal conditions, such as under biotic or abiotic stresses (van Ittersum et al. 2013; Nachimuthu and Webb 2017; Lawes et al. 2021). Therefore yield gaps can occur in both modern and traditional varieties. Changing from traditional to modern varieties does not therefore remove yield gaps if the growing conditions remain limiting. It may even increase the yield gap where new varieties are less adapted to local contexts. Still, yield gaps can indicate a shortfall in realised productivity.

Several other arguments are made for why the Green Revolution has not unlocked the same productivity increases in Africa as it has in other parts of the world (Scoones and Thompson 2011; Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019; Mkindi et al. 2020). These can be roughly grouped as follows:

- **African farmers are blocked from adopting modern varieties.** Many smallholders are not growing modern varieties. Financial, physical, knowledge, access and availability barriers are often suggested for this lack of adoption (Shikuku 2019; Mastenbroek, Sirutyte, and Sparrow 2021). The general argument is that farmers do not perceive the benefits of modern varieties, or are somehow unable to acquire them. These barriers make sense given that modern varieties are sold for higher prices and in different, sometimes more distant, locations to local varieties (McGuire and Sperling 2016). In this narrative, adoption is pursued through promoting awareness of modern varieties and improving access to modern varieties. The hope is that if farmers know about modern varieties and can acquire them, sustained adoption will follow based on the continued yield returns. A recent counter to this however found that removing information barriers did not raise investment in modern varieties (Mastenbroek, Sirutyte, and Sparrow 2021). Alternatively, farmers could be blocked by supply barriers, such as under-resourced seed producers or challenges to produce economically sustainable products (Langyintuo et al. 2010; Longley et al. 2021).

- **Modern varieties are performing poorly in African agriculture.** Another suggestion is that farmers are not purchasing improved varieties because they do not deliver the returns they claim. This could be because of poor seed quality in supply (Joughin 2014; Bold et al. 2017; Bagamba et al. 2023). Alternatively, it could be that improved varieties may be poorly adapted to the local growing conditions (Clay and Zimmerer 2020). For example, modern varieties might be bred for specific growing conditions and not the mixed agro-ecologies and pest conditions on farmers' fields (Coromaldi, Pallante, and Savastano 2015). Alternatively, they might depend upon nutrient or water resources that smallholders lack capacity to provide. Where modern varieties perform poorly, farmers may be reluctant to take the risk again (Bold et al. 2017, 2022). Another reason could be that modern varieties do not offer the traits farmers prefer (McGuire 2005). Paradoxically, even high yields might be of limited use to farmers facing capacity challenges with farm labour, storage or market access. In these narratives, adoption projects should aim to find more suited varieties and support mechanisms for farmers needs and preferences.
- **African reliance on different crops to those offered by modern varieties.** Another argument is that modern varieties offer only a partial solution to smallholder cropping needs. Modern varieties tend to focus on a narrow cadre of market focused crops (Mastenbroek, Otim, and Ntare 2021a; Sperling et al. 2020). These improved varieties seldom include lower-value or indigenous crops. Yet many smallholders grow a diverse array of crops. To these farmers, the limited selection of modern varieties can offer only a partial solution. Additionally, Green Revolution farming use of costly agricultural inputs is unlikely to be a viable option for smallholder cultivation of lower market value crops. Projects to overcome

this challenge tend to take one two approaches. The first is to frame modern varieties as a financial approach to obtaining wider nutritional food sources, rather than relying on the crop itself for sustenance. The second is to call for greater breeding attention to a wider range of crops (Bonny 2021; Mastenbroek, Otim, and Ntare 2021a).

These arguments demonstrate that modern varieties *can* offer a greater total factor productivity,[5] but there are numerous reasons why realising these returns has been difficult across sub-Saharan Africa. The situation cannot be considered a product of under-investment. Enormous funding has been paid into African-targeted crop improvement and Green Revolution projects (Mkindi et al. 2020). AGRA sits amongst a broad landscape of pan-Africa development groups and frameworks with central missions to unlock agricultural productivity gains.

The African Union's (AU) New Partnership for Africa's Development (NEPAD) frames agricultural development as a crucial step to sustainable development and poverty reduction. The flagship policy framework of NEPAD is the Comprehensive Africa Agriculture Development Programme (CAADP).

CAADP aims to boost agricultural productivity, improve food security, and reduce poverty in Africa through increased investment in agriculture. The programme promotes country-led agricultural development plans, calling governments to allocate a minimum 10% of budgets to agriculture[6] and meet a target of 6% annual agricultural growth rates (African Union, New Partnership for Africa's Development, and Comprehensive Africa Agriculture Development Programme 2003 ; African Union, New Partnership for Africa's Development, and Comprehensive Africa Agriculture Development Programme 2016). CAADP operates through a four pillar approach, one of which is "improving agriculture research, technology dissemination and adoption". Three quarters of African countries have now committed to CAADP, with 40 developing National Agricultural Investment Plans (NAIPs) which prioritise agriculture.

In addition to CAADP, there are a number of other consortia for African agricultural development. Backed by the African Development Bank, the Africa Food System Forum (AGRF)[7] is a platform bringing together governments, development partners, private sector and civil society for African agricultural development. AGRF hosts the largest African agricultural conferences, which seek to catalyse the transformation of regional agricultural development. The 2022 conference

[5] Total factor productivity calculates the total agricultural output in a ratio with total production inputs. It aims to capture efficiency of yield from resources invested.

[6] As part of the Maputo Agreement.

[7] Still referred to as AGRF as a relic of its brand prior to 2022 as the African Green Revolution Forum.

centred around the African Development Bank's $1.5bn programme, the African Emergency Food Production Facility (AEFPF)[8] (African Development Bank 2022). AEFPF seeks to raise the productivity of 20 million African smallholders through providing certified seed and fertilisers (Alphonso Van Mash 2022). The AEFPF estimates these modern varieties and fertilisers will produce a $12bn increase in food production.

Another major convener for the AGRF is the Alliance for a Green Revolution in Africa (AGRA) (Alliance for a Green Revolution in Africa (AGRA) 2013). AGRA was originally founded in 2006 by the Bill & Melinda Gates Foundation (BMGF) and the Rockefeller Foundation in an effort to 'modernise' African agriculture. AGRA's mission was to use commercial seeds, fertilisers and pesticides to double productivity and incomes by 2020 for 30 million smallholders across 20 countries (Toenniessen, Adesina, and DeVries 2008; Mkindi et al. 2020). Between 2006-2020, AGRA received $1bn in contributions. A further $1bn is estimated to have been put towards AGRA's activities in the form of agricultural subsidies from African Governments (Mkindi et al. 2020).

A core theme of these large-scale initiatives focus on market-led technology adoption as the key to both food and nutritional security. These claims are made despite a growing history of these approaches failing to deliver their promised returns to African smallholders (Clay and Zimmerer 2020; Mkindi et al. 2020). Despite limited impact, these initiatives continue relatively unchanged, backed by research organisations and NGOs, to transform African agriculture.

An additional concern is that sustainability goals appear secondary in priority to Green Revolution transitions. There is a risk that African countries achieve productivity increases, but at the same health and environmental costs that have been well documented globally (Horton 2013; Benziger, Roth, and Moran 2016; Bigna and Noubiap 2019; Benton et al. 2021; Wentworth and Latter 2023). This begs the question as to why these approaches have become so powerful despite questionable returns, and why they appear unable to adapt to changing needs? Uganda offers a good example of this same policy direction and implementation, despite elusive returns.

2.3 Ugandan Agriculture

Uganda has one of the highest population growth rates globally, rising 138% in the last 10 years (World Bank Data 2023). Agriculture accounts for around 24% of Uganda's GDP and comprises

[8]Partly made in response to food import shortages as a result of the Russia-Ukraine war.

around 63% of total employment (IBID). The vast majority of these farmers are smallholders, many of whom are poor, with limited access to farming infrastructure. Despite this prevalence of agriculture in Uganda, around 72.5% of the population experiences moderate to severe food insecurity World Bank Data (2023). This continues a paradox where those producing food struggle to nourish their families. Because of these economic and social pressures, food and food production remains a central part of Ugandan development policy.

2.3.1 Agricultural governance

Ugandan governance exists as a decentralised government system which gives responsibilities to local governments. While policies are set through central government, their implementation is organised through district, sub-district and local government actors. Sub-district agricultural officers are the main actors working to implement agricultural policies with farmers. These agricultural extension agents tend to be locally elected individuals tasked with representing and supporting farmers.

Ugandan national agricultural policies are managed by the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF). MAAIF oversees three departments, the Animal Production Department, Crop Production Department, and Fisheries Department. In addition to the Ugandan 2040 vision, MAAIF launched the National Agricultural Extension Policy (2016) and the National Agricultural Extension Strategy (2016) to achieve the CAADP goals (Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) 2016).

In 2001, MAAIF oversaw the creation and activities of the National Agricultural Advisory Services (NAADS) (Government of Uganda 2001). NAADS agricultural advisers were tasked with improving farmer productivity through improving access to knowledge, information and technology. These advisers worked with district-level officers and agricultural extension services to support farmers. Although intended to operate for seven years, the first phase of NAADS finished in 2010, for a total cost of around $107.93 million (Oluka 2016). Most of this amount was funded by foreign donors, including the Danish International Development Agency, European Union, Global Environment Facility, International Fund for Agricultural Development and World Bank.

The situation becomes more convoluted from this point onward. In 2010, the Agricultural Technology and Agribusiness Advisory Services project (ATAAS) was launched as a successor to NAADS. ATAAS aimed to broaden service provision through more privatisation and demand-led approaches (IFAD 2021). The programme however faced significant restructuring at the 2014 mid-review, causing the total budget to drop from US$665.5 million to US$421 million. NAADS was also given new funding to continue from 2010 for a further five years Ssalongo (2011) and ATAAS was tasked with strengthening NAADS; the programme it was intended to succeed. Tensions continued around NAADS as Ugandan President Museveni blamed the MAAIF minister for mishandling the programme, after the Office of the Auditor General leaked mass farmer dissatisfaction (Oluka 2016).

In 2013, Museveni created Operation Wealth Creation (OWC) to improve food security. OWC is tasked with providing farmers with modern variety seed, agricultural inputs, equipment, and technical advice. Although similar in both goals and implementation, NAADS and OWC were kept as separate bodies. Curiously, OWC was given to the Ugandan Peoples' Defence Forces to implement, rather than MAAIF.[9] This choice of the army has been blamed for the poor quality products distributed by OWC (Monitor Editorial 2021).

In 2014, Museveni announced unexpectedly during a public holiday that NAADS would be terminated, all workers fired and the army would take over management (Oluka 2016). This did not happen and instead NAADS still continues today under the MAAIF (NAADS 2023).

In 2019 alone, OWC donated 3,315 MT of maize seed to just over 660,000 maize-growing households (Mabaya et al. 2021). Today, part of NAADS' mandate is to support OWC, although it has no official management over the programme. NAADS recently hit the news again in August 2023 for spending 7 billion Ugandan Shillings (approximately $1.9 million) without being given a budget (Angurini 2023).

Uganda's main crop research centre is the National Agricultural Research Organization (NARO), funded by the government and development partners. NARO leads agricultural research and the development of new technologies to help drive agricultural development. It operates several agricultural research institutes across the country. MAAIF approves which technologies are developed, to ensure alignment with national agricultural research policy and government priorities. The most recent NARO strategy document is themed ' "Market-Oriented Research Spurring Agro-Industrialization", classified over two areas, technical and institutional research.

[9]There are two main possibilities suggested for this. The first is that the choice was made following the frustration the president felt with MAAIF's handling of NAADS. The second is more political. It is felt that the army is close to Museveni and would side with him should a contender get in. Voting against Museveni thereby caused a risk to ongoing agricultural service extension.

This suggests two themes, firstly that NARO research extends beyond farming, to include supporting industries, and secondly, that the research centre has a market-focused theme, which influences which technologies are prioritised. Crop technologies created by NARO are released to agricultural extension systems and private companies for dissemination to farmers. In practice, this involves a network of seed companies and specialised seed sellers known as agro-dealers (see Box 2). I will explore more into these groups in the following chapters.

Box 2: Ugandan formal seed system actors Adapted from (Mabaya et al. 2021)

Research and breeding: Consultative Group on International Agricultural Research (CGIAR), Makerere University Regional Centre for Crop Improvement (MaRCCI), National Crops Resources Research Institute (NaCCRI), National Semi-Arid Resources Research Institute (NaSARRI)

Variety release and regulation: National Seed Certification Services (NSCS), National Variety Release Committee (NVRC).

Seed production and processing Seed companies (local and foreign owned), private seed laboratories

Education, training, and extension: Seed companies, Uganda Seed Trade Association (USTA), Uganda National Agro-Input Dealers Association (UNADA), Non-Governmental Organizations (NGOs), Department of Agricultural Extension Services

Distribution and sales Seed companies, agro-dealers, National Agricultural Advisory Services (NAADS)

Overall, the actors mentioned in this section work to achieve greater economic and nutritional security through Ugandan agriculture. Their target stakeholders are therefore predominantly smallholder farmers. In the next section, we explore the common farming conditions across Uganda, and the needs smallholders have for new crop technologies.

2.3.2 Ugandan farming conditions

Uganda has a variety of agro-ecological zones ranging from dry lowlands to temperate highlands. Most of the country is on a plateau, ranging between 1,000 to 1,400 metres above sea level with an average temperature of 22.8°C. The majority of Ugandan farmers rely on rain-fed agriculture, with little access to irrigation (Wanyama et al. 2017). Northern Uganda has one rainy season a year, from April to October. Conversely, Central and South Uganda have two rainy seasons a year, with short rains from March to May and long rains between September to November.

Ugandan staple crops are bananas,[10] beans, cassava, maize, rice[11] and sweet potato. Major export crops include, coffee, cocoa beans, raw sugar, tea, tobacco and vanilla, valued at $547m, $92.3m, $59.3m, $24.7m, $34.2m and $25.3m respectively (Observatory of Economic Complexity 2023). Smallholders tend to have limited access to these export markets, which tend to be dominated by larger commercial farmers.

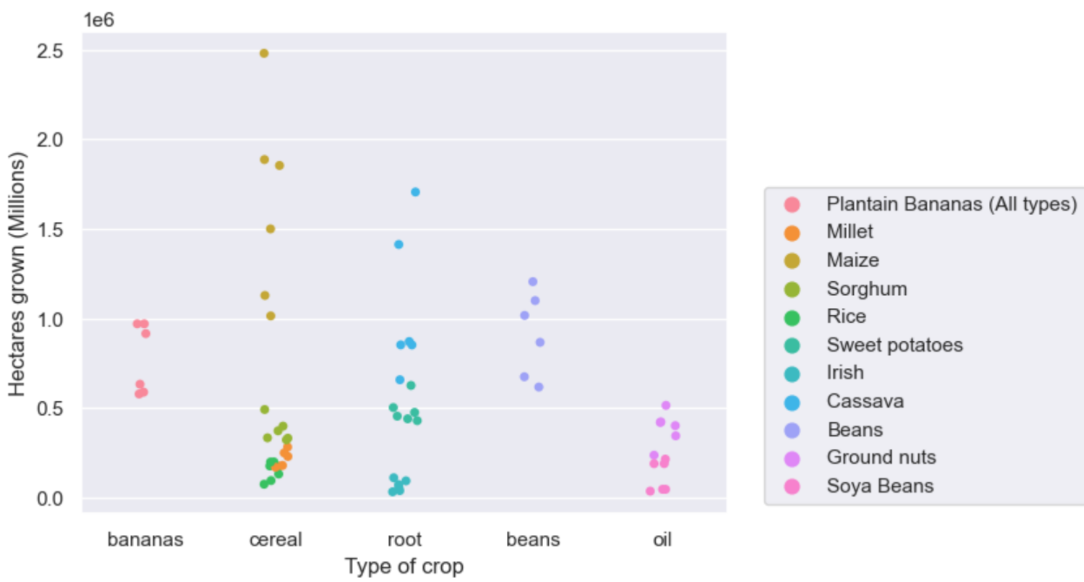

Figure 3: Hectares allocated to crops across Uganda, grouped by crop type.

2.3.3 Threats to productivity

Ugandan agricultural productivity is under threat from a range of pressures. Climate changes are affecting seasonal growing conditions, making them less predictable and increasing incidence

[10]Both sweet and plantain, with Uganda being one of the top banana producers globally (Komarek 2010).
[11]Particularly in lowland areas with suitable conditions for paddy cultivation

of shocks (Osbahr et al. 2011; Kisakye, Akurut, and Van der Bruggen 2018; Nkuba et al. 2021). Ugandan smallholders are aware of these threats, but their dependence on rain-fed systems makes them particularly vulnerable to seasonal changes (Okonya, Syndikus, and Kroschel 2013).

Climate change and international trade has caused increased pest and disease pressures on farms (Hisali, Birungi, and Buyinza 2011; Mubiru et al. 2018; Gno-Solim Ela et al. 2023). Examples of major pests for Ugandan agriculture include: fall armyworm, Banana Bacterial Wilt, Cassava Brown Streak Disease (CBSD), Cassava Mosaic Disease (CMD), Maize Lethal Necrosis Disease (MLND), rust diseases (stem rust, leaf rust, and stripe rust) and Tomato Yellow Leaf Curl Virus (TYLCV).

Another major threat to Ugandan productivity is land degradation (Pender et al. 2004; Tully et al. 2015; Dimkpa et al. 2023). Land degradation through erosion, deforestation and unsustainable management is reducing soil fertility and subsequently productivity. These impacts are particularly threatening to local productivity as many farmers are unable to afford fertilisers (Woniala and Nyombi 2014).

Separate to productivity but worth noting, food spoilage and loss is a major threat to Ugandan food security. A general lack of storage, processing and transport infrastructure prevents Ugandan farmers from reducing post-harvest losses (Costa 2015). The main causes of food spoilage with farmers are due to insects and moulds (IBID). The main way farmers avoid post-harvest losses is to sell their products close to harvest, reducing the availability of household food and the potential price they could attain if sales could be made after the initial harvest boom. Subsequently, productivity increases are likely to have limited returns, if not combined with greater support methods to safely store the resulting harvests.

2.3.4 Plans to improve productivity

So Ugandan agriculture faces a number of pressures to raising productivity and achieving food security. To face these pressures, the Ugandan government adopts the same policy language of CAADP and other initiatives of 'transformations' and 'modernisation' of national agriculture. These terms are used to stress the need to alter current national farming into something else (Mayet 2016). For example:

> *"Uganda aspires to transform the agricultural sector from subsistence farmer to commercial agriculture."*

(Uganda Vision 2040, 2013; article 102, pp 61)

This vision of Uganda is one of modern varieties, applied inputs and agricultural infrastructure. The National Agriculture Extension Strategy describes this as the "government's commitment to realise an agricultural revolution in the country" or to transform Uganda "from a peasant to a modern and prosperous country" (Ministry of Agriculture, Animal Industry and Fisheries, 2016, pp 3 & 9).

The rationale behind these calls is, firstly, that farmers are constrained by the local varieties they grow and secondly, that this production shortfall constrains national development. Replacing these local varieties with modern varieties is proposed to yield greater harvests, increasing food availability and providing increased incomes for poverty alleviation. Modern varieties are proposed to reduce farmer risks through newly introgressed traits that offer greater climate, pest and disease resistance. Yielding the benefits of such varieties is dependent on the increased use of chemical inputs, the costs of which are offset by the greater economic returns that modern varieties are said to offer over traditional varieties.

The challenge to these transformation visions is simple: farmers are not buying from modern variety sellers (McGuire and Sperling 2016). The space appears to not be transforming and contemporary Ugandan smallholders are posed as languishing the agriculture of antiquity.[12]

If modern varieties offer so many benefits, why do smallholders appear to be avoiding them? This observation raises further concerns. Firstly, if farmers are deliberately avoiding modern varieties, what risks might government plans to transform agriculture present to the farmers that comprise it? Much of the narrative around proliferating modern varieties is to reduce risks, but does this mission also bring new risks to smallholders? Further, why has the transformation mission remained largely unchanged despite enormous funding with little results? More research is needed to understand how Ugandan smallholders navigate crop technology risks, and how to reduce the risks farmers face.

[12]Such as Guardian article "Fake seeds force Ugandan farmers to resort to 'bronze age' agriculture" (Toro 2014).

Chapter 3

Literature review

The previous sections have described the wider agricultural setting and developments for this research. As we have seen, Uganda seeks a transformation of its agriculture, with the rationale behind this vision being a path to economic and nutritional security. Modern crop varieties are central in this story. In the following section, we explore what crop varieties are, how they come to be and the pathways through which they reach farmers. This works to serve as a background literature of context and concepts for the conceptual framework at the end of this chapter. Since the three empirical chapters each contribute to a distinct literature, those distinct bodies of research are reviewed in those chapters.

3.1 Uncertainty and risk

Uncertainty and risk are components in life that influence why and how actors make choices. Individuals are subject to risks, and the effects of these risks can affect well-being in various ways. But what do we mean by uncertainty and risk? How do these features interact and, specifically for this thesis, how do they affect farmers? The following section provides a brief literature overview of uncertainty and risk, and how these features affect farmers. I start with the concepts of uncertainty and risk, and move into the ways in which these affect farmers.

There is a large literature on uncertainty and risk, but no agreed definition for these terms (Samson, Reneke, and Wiecek 2009). Instead, the definitions differ with the discipline or context. A general theme, however, is that uncertainty and risk are related. Some even argue that risk *is* uncertainty, although most agree that uncertainty and risk are separate concepts (Samson, Reneke, and Wiecek 2009; Mehr 1966).

Risk is often framed as the chance of loss, an undesirable result of uncertainty with associated negative outcomes as a consequence (Lough et al). Kaplan summarised risk as three questions: what can happen? How likely is that to happen? If so, what are the consequences? In this sense, risk is the "objectified uncertainty" of an unfavourable event (Willett 1901; Samson, Reneke, and Wiecek 2009). Willett argued further that risk is quantifiable, through use of probability arguments. Knight built on this, distinguishing risk as quantifiable uncertainty, and non-quantifiable uncertainty as uncertainty (Knight 1921). While some uncertainties are quantifiable (for example, a coin toss or the weather), there are others that are not quantifiable (e.g. future political instability). Pfeffer brings a perceptual component to distinction, arguing that if risk is measured by probability, then uncertainty is measured by subjective belief (Pfeffer 1956; Samson, Reneke, and Wiecek 2009). Pfeffer posed risk is the state of the world and uncertainty the state of the mind. Here, uncertainty is perceived by an individual depending on their knowledge, whereas risk is objectively present in the world; whether one perceives it or not.

Building on this idea of objective risk, there are three general forms of risk (Fafchamps 2003). The first are high and low frequency risks. Some risks happen frequently, while others are rarer. As to how much these frequencies affect individuals depends on the intensity of the risk. For example, farmers often endure general pest pressures over a season (high frequency, low intensity), but struggle with a shock drought (low frequency, high intensity).

A second kind of risk are auto-correlated or non-stationary risks (Fafchamps 2003). Shocks are not independently distributed over time, and may also affect local resilience to ongoing or future risks (M. R. Carter et al. 2006). Farmers who experience a drought might also face floods, causing food and livelihood consequences that further affect their vulnerability (Trnka et al. 2016; Houston et al. 2021). A risk from one shock can therefore depend on the incidence and lasting effects of other shocks (Bloom 2009; Carter et al. 2006). This lasting effect is the non-stationary component, where a passing shock can lead to a permanent effect. For instance, children who suffer malnutrition during a famine may have lifelong cognitive impacts (Dewey and Begum 2011). A key component here for the lasting effect is whether the risk impacts the income generation of the individual, or their welfare. For instance, a person who loses their job loses their income generation, but their welfare is affected more indirectly as a result of this change. Depending how the shock is felt, informs the latent resilience to further shocks.

Thirdly, there are collective and idiosyncratic aspects to risks (Fafchamps 2003). Shock events and the risks they pose vary by scale and across individuals. For instance, there are risks that affect a single person (such as a fall), or risks that pose collective risks across actors (such as a drought). Similarly, risks that affect a wide number of people might still give the impression of individual safety (Rumar 1988). Note also that the actions of individuals to reduce their risks can cause greater collective risk (Vlek 1996). A classic example of this might be individual fishers overfishing an area in the pursuit of their own interests but risking a tragedy of the commons situation (Santos and Pacheco 2011).

As these reflections on types of risks might suggest, risks affect social groups in different ways. Risks also appear to be greater in poor communities, who generally have less capacity to assets and insurances to face and manage risks (Mosley and Verschoor 2005; Yesuf and Bluffstone 2009; Sinha and Lipton 2001). Examples might be businesses lacking the assets to absorb a shock to sales, or rural communities lacking the means to face climate shocks. Poorer communities tend also to face compounded risks (Perdana 2005; Hay et al. 2007; Law and Morris 1998). For instance, poorer communities may face greater food insecurity while also being in areas of lower sanitation and higher disease pressure (Crimmins, Kim, and Seeman 2009). These same areas might also have higher risk of crime and violence (Buonanno 2003).

The above explanations offer some conceptual groupings of risk, but risks to farmers can also be grouped by the livelihood forms they take. For instance, we can think of:

- **Production risks**: These include risks that affect the ability of farmers to grow, harvest and store food prior to sale or consumption. These might come in the forms of weather variability, pests, diseases, and climate change that affect how the crops grow in the field. Smallholders tend to know about these risks, but lack the capacity to respond (Simotwo, Mikalitsa, and Wambua 2018; Abdul-Razak and Kruse 2017; Jamshidi et al. 2020). There might be risks around the quality of seed, varieties and inputs that farmers source for planting (Bold et al. 2017). For instance counterfeiting in seed and input supply may affect returns from farming. There may also be post-harvest pressures to storing and processing harvests prior to sale or consumption.
- **Market risk:** This includes the risks involved in farmers purchasing or selling farm products. This could be fluctuations in commodity prices and input costs that impact what farmers can purchase and what they are able to sell (Oluwatayo 2019; Cardell and Michelson 2023).

- **Financial risk:** This involves the financial dimensions of what farmers can afford and purchase. It includes access access to credit and interest rate fluctuations (Isaga 2018; Mersha and Ayenew 2018)
- **Institutional risk:** This might be changes in policies or regulations that affect how farms and farming operate. Examples might be regulations around land ownership or subsidies on farming inputs or products. Central to this thesis, these institutional changes could include changes to varietal production or legality around ownership of seed (Tansey 2011; Aistara 2012; Kloppenburg 2017). Some of these themes will be discussed in greater detail throughout this thesis.
- **Personal risk:** These include risks to farmer health or family-related issues that impact their ability to farm. For instance, this could be related to local disease pressures, on or off farm accidents. Some of these pressures might be exacerbated by malnutrition, or the kind of farming that individuals are involved in. For instance, as we will hear later, rice farming also means closer contact with snakes and leeches, which carry health risks with them.

3.1.1 Modelling risk

As we separate these aspects of risk, we are already seeing ways that individuals (or households) might behave to manage risks. This individual approach of how to maximise utility from consumption in the face of risk can be represented as follows (Dercon 2008):

$$u_t = E_t \left[\sum_{\tau=t}^{T} (1+\delta)^{t-\tau} v(c_\tau) \right]$$

Here, u_t represents the expected utility of the individual at time 't'. E_t is the expectation that utility is calculated with information at time t, under uncertainty of future events. This operator is the incorporation of risk, as the future utility is not known but depends on other factors (e.g. seasonality) The summation of future time events is then captured by $\sum_{\tau=t}^{T}$ based on current time, t until a final terminal time of T. $(1+\delta)^{t-\tau}$ then accounts for how future utility is discounted back to the present, where δ shows the rate of time preference and the $t-\tau$ component ensure that future utility is weighted less. This $(1+\delta)^{t-\tau}$ implies that individuals place less value on future consumption, potentially in favour of immediate needs or uncertainty about future conditions; as my be the case with risk adverse individuals. The $v(c_\tau)$ the utility derived from consumption at the current time. As Dercon (2008) mentions, this value is concave, suggesting that small increases in consumption bring utility when the individual is poorer, but less utility when the individual is wealthy.

We can also consider the development of asset use over time, which can be represented by the following (Dercon 2008):

$$A_{t+1} = (1 + r)(A_t + y_t(x_t, A_t) - c_t)$$

Where A_{t+1} represents the individual's assets at the next time period $(t+1)$. $(1+r)$ is the returns on assets since the previous period, growing by a rate of r each time. A_t is the individual's assets at the current time (t). $y_t(x_t, A_t)$ represents the individual's returns at t depending on a choice variable x_t and the level of current assets. The choice variable could be a technology or activity that can influence returns. Finally, c_t is the consumption at t, which is subtracted from the available resources since consumption reduces the overall amount. This equation represents income generated during the current period as a result of investment choices and the individual's current assets. Importantly, this demonstrates that individuals can save or invest assets, rather than consume them, and how income is tied to decisions over assets. We can therefore think of an individual's risk planning as the following steps of (Dercon 2008; Fafchamps 2003; Cervantes-Godoy, Kimura, and Antón 2013):

1. An initial risk.
2. A risk management strategy.
3. An outcome of this approach with either short or long-term effects.
4. A risk 'coping' or 'smoothing' strategy.
5. Another stage of short or long-term outcomes.

Risk management strategies tend to fall into two categories of specialisation or diversification (Goschin 2019; Bodescu et al. 2021; de Roest, Ferrari, and Knickel 2018). An example of specialisation might be something like arid area farmers growing particularly drought-tolerant crops or varieties that are well-suited rain shortfalls. Alternatively, individuals might adopt a diverse range of options, such as growing a range of crops and varieties to reduce the risk of relying on a single option that might fare poorly over the season. For example, growing a range of crops or varieties reduces the risk a disease outbreak poses to the harvest, the complete opposite situation of a monoculture. In equation 2 above, these kinds of choices are the investment decisions (x_t) that influence an individual's income in a world of risk. Fafchamps also shares this process, but takes exception to the wording 'risk management' when referring to impoverished populations as it can suggest a sense of agency to control the risk that communities might not possess (Fafchamps 2003). This is a valid point but indeed any risk management strategy cannot rule out all risks. Doing so would be conceptually difficult, but also practically difficult and likely result in unmanageable costs, that likely become a risk in themselves.

One way for individuals and collectives to protect themselves is through insurance. Insurance is a means to guarantee compensation for loss or damage, in exchange for a pre-made arrangement. Insurance offers high utility, as losses without can be disastrous (Wärneryd 1996). This marks a difference between investment in innovations, as non-investment in innovations is often the safer option, while inaction in obtaining insurance is a riskier choice (Clist, D'Exelle, and Verschoor 2021). In formal insurance arrangements, this insurance is offered by private or state actors in exchange for a financial premium which is based upon the value of the goods and the relative risk (M. Carter et al. 2017). Formal insurance is however relatively rare in rural settings, due to capacity challenges in financial systems and the prohibitive costs of such schemes to smallholders (M. Carter et al. 2017; Hazell 1992; Bramoullé and Kranton 2007). Instead, communities tend to rely instead upon informal, social arrangements to self-insure against risks (Fafchamps 2003; Carter et al. 2017; Bramoullé and Kranton 2007). As such, uninsured risks, such as from climate change, remain a challenge for both investment and resilience to shocks. A more recent development to protect farmers however has been the rise of index insurances which are targeted for rural communities. Index insurances are promising as they separate payouts from the assessment of individual losses, based instead upon triggers correlated with those losses (Carter et al. 2017). Most index insurances are focused on weather shocks, but they may also be adapted to other price shocks or shocks that cause farm losses. These forms of insurance are however still relatively new and, despite increasing policy interventions to encourage insurance, many farmers remain formally uninsured.

Where uninsured individuals do experience an adverse outcome, risk coping or smoothing strategies begin, as the individual takes post-shock action to manage the realised risk in an effort to prevent further risks. Risk coping strategies could be liquidating assets, such as farmers selling livestock or land to meet their immediate needs and prevent further risks (such as providing income to purchase food with to avoid malnutrition and associated risks). As represented in the earlier equation however, the loss of assets is likely to contribute to a sustained or permanent reduction in returns. For example, it's clear to see how a farmer selling their land to meet their immediate needs will face greater challenges to achieve future returns. The other risk coping strategy is therefore not to liquidate assets, but to reduce consumption (Fafchamps 2003).

Another way that individuals might practise risk coping is through risk-sharing approaches (Will et al. 2021; Habtom and Ruys 2007; Ambrus, Chandrasekhar, and Elliott 2014). For example, through family and local networks (Dercon 2008). Examples include marriage arrangements (Stefan Dercon and Krishnan 2000) or village networks (De Weerdt and Dercon 2006). Drawing on these networks after a shock can help individuals to endure the realised shock. It is, however, worth noting that these arrangements may also require investment to maintain, which may in themselves be costly and bring forms of risk (Ambrus, Chandrasekhar, and Elliott 2014).

Regardless of the risk management and coping strategies, shocks appear to be to be always at least partially transferred into outcomes (Dercon 2008). This transference suggests that the ways individuals manage, smooth or share risks are often incomplete. Again, these effects are most commonly felt by the poor, who are themselves both in an environment of relatively higher risk than wealthier communities, as well as having less capacity to face and endure shocks (Fafchamps 2003). It is these kinds of rural communities who are often the target of agricultural development projects. Often the proposed method to help these communities is through the adoption of new practices and technologies.

3.1.2 Risk and investment

Adopting an innovation can be risky, but the potential reward might be higher returns on investment, which could be attractive to even risk-averse individuals (Verschoor, D'Exelle, and Perez-Viana 2016). Adopting new practices and technologies can reduce exposure to risks, such as growing disease-tolerant varieties. A challenge comes in the investment requirement for these innovations, which pose particular barriers to poorer communities. Importantly, the larger the initial investment for the innovation, the likely more limited capacity of the individual to weather realised shocks. For example, a household that places all resources into drought-tolerant crops may reduce the risk of rain shortage, but lower capacity for risk coping. As such, poorer communities might be reluctant to invest their more limited resources, to ensure they maintain liquidity should a shock occur. These factors also relate to how risky the technology decision is for the investor, where communities might favour less effective technologies but have lower risk of failure (Stefan Dercon and Christiaensen 2011). For instance, a farmer might prefer an older crop variety they know works, rather than risk investment in a newer variety that might offer greater returns but with greater up-front costs and uncertainty over performance in the local growing conditions.

The 'less risk - less returns' scenario presents a potential poverty trap, where only the wealthier have sufficient risk-absorbing capacity to adopt profitable new innovations while the more risk-averse avoid the investments that could bring them needed returns (Dercon and Christiaensen 2011; Mosley and Verschoor 2005). Risk aversion here refers to an individual's preference for a more certain outcome versus a prospect with greater uncertainty (Wärneryd 1996). For instance, risk-averse individuals would avoid gains with great uncertainty or losses with low uncertainty (Tversky and Kahneman 1992). Studies have however shown that risk aversion is weakly correlated with income levels, suggesting that these risk attitudes are not a significant driver of poverty traps (Mosley and Verschoor 2005). Risk aversion does however appear to correlate with vulnerability and other social features (Mosley and Verschoor 2005; Outreville 2014). For instance, risk aversion appears to correlate with age, and women generally appear to be slightly more risk averse than men (Outreville 2014). Overall however, these studies demonstrate that poorer communities do indeed remain entrepreneurial, despite the risks that surround them. Encouraging investment decisions more generally will increase the risks these individuals are exposed to but also raises the potential for improved income and welfare. Supporting a diverse range of informal and formal insurance schemes can help risk averse community members in making these investment decisions, while also protecting them against the consequence of shocks. Knowing what they invest in and how they acquire and use it brings us on to concepts of adoption.

3.2 Technology adoption

Differences in technology are often used to explain differences in GDP and income levels across countries (Foster and Rosenzweig 2010). For instance, access to high-yielding crops, irrigation, machinery and electricity. This techno-optimistic view implies that the distribution of technology can explain global inequality, and consequently is used to operationalise the adoption of technology in poor countries to improve welfare (Self and Grabowski 2007).

The conceptualisation of adoption is fundamental to planning, implementing and measuring technical change at both the individual and aggregate level (Glover, Sumberg, and Andersson 2016). In agriculture, adoption is often understood as the acquisition of technical packages of objects and practices, distributed through exchange and instruction (Hermans et al. 2021). While *adoption* focuses on individuals and smaller groups, *diffusion* refers to the more widespread and later stages of technology uptake (Rogers 1962; Glover, Sumberg, and Andersson 2016). Adoption therefore concerns micro level changes, while diffusion concerns macro level trends in how innovations move through firms, communities and populations (Feder and Umali 1993). In this way, adoption and diffusion can theorise and measure how agricultural innovation scales across multiple levels and dimensions, over time (Feder and Umali 1993; Hermans et al. 2021).

We can think of an innovation as the technological component that changes production, combined with the knowledge, perception and know-how of how its acquisition affects the welfare of adopters. Everett Rogers' 1962 'Diffusion of Innovations' remains influential in this area of study, synthesising around 500 studies on the topics of adoption and diffusion (Rogers 1962). Rogers broke down the adoption of innovation as a series of cognitive steps to assess the utility of the innovation (Rogers 1962; Leeuwis and Aarts 2021). These steps are the following:[1]

1. Awareness: of the innovation or policy.
2. Interest: collecting further information.
3. Evaluation: reflecting on the advantages and disadvantages.
4. Trial: testing the innovation / practice on a small scale.
5. Adoption or rejection: applying the technology or behavioural change.

Rogers believed the adoption process is influenced by the experience of the individual and their perception of both the situation and the utility of the innovation (Leeuwis and Aarts 2021). This also includes the advantage that the individual perceives the technology to have over local options, how well it fits with current practice and the ease of operations within the context (Leeuwis and Aarts 2021). While the earliest individuals to adopt a technology are considered innovators or entrepreneurs, actors who acquire the technology during the diffusion stages are considered more late adopters or laggards (Feder and Umali 1993; Rogers 1962). The cognitive elements of Rogers' work inspired a number of adoption models (Leeuwis and Aarts 2021). For instance:

- **Theory of reasoned action:** An individual's behaviour is driven by their intention to perform in a certain way, which is influenced by their attitudes and norm (Fishbein and Ajzen 1975).
- **Technology acceptance model:** Explains technology adoption by focusing on perceived usefulness and ease of use, which influence users' attitudes toward technology and their

[1] Rogers changed the names of these stages in his 1995 edition to: knowledge, persuasion, decision, implementation and confirmation.

intention to use it (Holden and Karsh 2010).

- **Unified theory of Acceptance and use of technology:** Combined models to explain user intentions to adopt technology, with performance expectancy, effort expectancy, social influence, and facilitating conditions as key determinants (Venkatesh, Thong, and Xu 2016).

All of these models demonstrate the importance of both the innovation characteristics and the context in shaping technology uptake and diffusion (Sumberg 2005; Hermans et al. 2021; Whitfield 2015). The innovation needs to address an important need for users, and offers improvements to profits, reliability and usability (Sumberg 2005). It also needs to be suitable to the users across cultural and social dimensions. These contextual elements *determine* the adoption decision and subsequently the idea of 'determinants' of adoption have become central to studying these models.

3.2.1 Determinants of adoption

Many studies focus on the determinants of adoption and diffusion during the uptake of Green Revolution technologies between the 1960 to 1980 (Feder and Umali 1993). A more recent development, to respond to the push for evidence based policy, is the use of impact assessments and randomised control trials to capture drivers and economic impacts of technology adoption (Duflo, Kremer, and Robinson 2008; Glover, Sumberg, and Andersson 2016). A fundamental determinant for adoption is the net gain to the user after all other costs are accounted for, as well as the perception of this by the user prior and during use (Foster and Rosenzweig 2010). This perception includes the effect of, and opportunity for, learning and the reduction of uncertainty (Feder and Umali 1993). There are however challenges with measuring these types of return. For instance, profits might prove difficult to measure in practice, and it is difficult to measure net gains to welfare (Foster and Rosenzweig 2010).

The perceived net gain from the technology, as well as how to access and use it, demonstrates the importance of information to the adoption decision, with studies showing how information can be a barrier to uptake (Pan, Smith, and Sulaiman 2018; Shikuku 2019). For instance, information constraints might come in the form of farmers having incomplete understanding of the challenge, the solutions, how these solutions work, where to get them and how to draw on their advantages (Sumberg 2005). As such, a number of studies have demonstrated that increasing access to information can enable uptake (E. Rogers 2004; Jensen 2007; De Groote et al. 2016). But clearly understanding a challenge and potential solutions does not ensure a user will acquire a technology. Well-informed individuals may still decide not to adopt innovations (Mastenbroek, Sirutyte, and Sparrow 2021).

There are a number of other commonly reported determinants of adoption (Foster and Rosenzweig 2010). For instance, the positive correlation between schooling and adoption suggests a link between cognitive capacity and information with the decision to adopt. Schooling is also associated with another commonly reported determinant for adoption, wealth. Wealthier farmers may have more assets to help them acquire innovations, and may face lower risk to their livelihood should the innovations fail. Wealthier farmers may also be more business focused and active in seeking out innovations, suggesting another cognitive trait to determine adoption. Farmers of course do not live in a bubble, and the adoption of a technology by neighbours also appears to be a determinant of the adoption decision (Richards 2018). This is especially so during diffusion stages of adoption (Rogers 1962). Leeuwis and Aarts further expand on these determinants, show in table 1 (Leeuwis and Aarts 2021)

An issue, however, with identifying these determinants from studies is that it is seldom clear *how* they affect the adoption decision. For instance, does higher educational attainment mean that an individual understands the benefits of a technology more, or are they associated with networks who share useful technologies - or another reason? Further, the same determinants are not consistently important across actors, and vary in relevance across the initial adoption and later diffusion stages (Feder and Umali 1993). For example, the determinant of 'neighbours' adoption' might be insignificant to the first adopters, but instrumental for actors in the diffusion stages. Where these determinants are absent or antagonistic to the adoption decision, they can also be constraints. Through identifying constraints, we can identify measures to address them, such as policies, institutional measures and user support (Sumberg 2005). As described by Sumberg (2005) however, it is important to consider whether these constraints are endogenous or exogenous to adoption decisions:

> "Imagine that somebody decides to sell automobiles in an area where there are neither roads, nor is it possible to purchase fuel. After 24 months without making a single sale, in desperation, the would-be automobile dealer seeks the advice of a consultant. Does it make sense for the consultant to conclude that 'lack of a road network' and 'lack of a fuel network' are constraining automobile sales?" (Sumberg, 2005, p.7)

Identifying determinants can help understand what enables adoption, but it is also important

Table 1: Determinants that influence adoption behaviour, adapted from Leeuwis and Aarts 2021.

Determinant	**Explanation**
Intention (behavioural intention, intention to use)	Many models assume that adoption behaviour is preceded by an overall predisposition to perform the behaviour, as a result of other determinants.
Attitude (perceived usefulness, relative advantage, attitude towards use)	Intention is shaped by the feeling that individuals have towards a behaviour or technology, which can be positive, negative or neutral. Attitude is informed by knowledge and values.
Knowledge (behavioural beliefs, outcomes expectation, performance expectation)	Predictive knowledge and understanding of the actor to adopt the technology. E.g. What happens if one adopts the technology?
Values (outcome evaluation, aspirations, goals)	Influences what actors see as important in a context, in either a positive or negative light.
Social influence (subjective norm)	How individuals perceive the expectations of others. Arises from the sub-variables of norms and motivation.
Normative beliefs	Relates to the perceptions that individuals have with regard to how relevant others would evaluate adoption or non-adoption. E.g would they approve or disapprove it?
Motivation to comply	A sub-component of social influence. Relates to whether or not individuals are inclined to follow wider social expectations.
Ability (perceived self-efficacy, ease of use, effort expectancy, barriers)	How individuals perceive the difficulty of adopting the technology with their own abilities, capacities and self-confidence. Also includes external barriers or actors that enable or restrict action.

to understand how these factors affect the decision to adopt and the context surrounding the actors. This point on ‘the decision to adopt’ touches on a deeper issue in adoption studies.

3.2.2 What adoption involves

What does it mean to have ‘adopted’ something? A challenge for the measurement of adoption in agricultural research is that many studies are restrictively linear and binary in design (Glover, Sumberg, and Andersson 2016). Systematic reviews show that while many papers seek to measure adoption, few define what they mean by it (Loevinsohn et al. 2013; Hermans et al. 2021). Similarly, some studies might report profit gains based on sales versus seed and input costs, but leave out other costs such as farm preparation and labour. The result is a misleading picture of how practices are changing.

Clearly the process of adoption is not just a binary choice. For instance, there is a difference if farmers plant a new crop variety on a small area, versus the majority of the field. We might also think of how long they use the technology for or how consistently they use it (Leeuwis and Aarts 2021). We therefore need to also consider the *intensity* of adoption (Glover, Sumberg, and Andersson 2016). We should also consider that many users do not just adopt a technology or practice, but experiment with it and adapt it to their needs (Whitfield 2015; Hermans et al. 2021). For instance, technologies are not discrete packages that are exchanged in isolation to replace others. Technologies can complement one another, both simultaneously (like fertiliser and modern varieties), or opportunistically under certain conditions (pesticides when under pest pressure). These changes are important, as reporting a technology as simply ‘adopted’ is ambiguous and risks overlooking how the technology has been taken up and how it might have changed to be contextually adapted (Leeuwis and Aarts 2021; Glover, Sumberg, and Andersson 2016). Glover et al. 2016 provide guidelines for adoption concepts to include six criteria, which include:

1. Building on anthropological ideas of change.
2. More nuanced change, such as emergent or incremental change.
3. Alteration of the technology.
4. Ranging complexity.
5. Scale.
6. Cost-effective estimates of investment.

As this list shows, there is a need to find more dynamic modes to understand technology uptake and implementation, drawing on approaches that combine both technical and social components (Jansen and Vellema 2011; Arora and Glover 2017; Leeuwis and Aarts 2021). While earlier adoption models following Rogers include a cognitive component, they often overlook factors such as heuristics and triggers for behaviour or how it changes (Petty and Cacioppo 1986; Baumeister, Vohs, and Tice 2007). Similarly, they can overlook the interdependencies of how technologies, processes and actors are linked (Leeuwis and Aarts 2021). In reality, the actor of one behaviour is often linked with others. These might include components of trust, responsibilities and trade offs. For example, interdependencies might be (Leeuwis and Aarts 2021):

- **Vertical:** where actors are linked to separate actors in different sections of the practice. For example, farmers might depend upon agro-dealers selling varieties, but also processors or markets where the products are sold.
- **Horizontal:** where actors might be enabled or bound by the actions of similar actors. For instance, farmers might see little point in controlling pest pressures unless other farmers are doing the same.
- **Intra-individual:** where uptake of one technology assumes the prior uptake or acceptance of other practices. An example is the expectation for farmers to adopt modern varieties which are designed to work in conditions where nitrogen fertilisers have also been adopted.
- **Temporal:** where the interests of potential adopters depends upon decisions made in the past or future. For instance, farmer interest to adopt modern varieties might be influenced by previous experiences with modern varieties.

These interdependencies add to an emerging theme in recent adoption literature of building on the social aspects of adoption, and closely integrated this with the technical components. This combined approach seeks to more effectively encompass the lived realities of farm life, where the technical dimensions are naturally integrated with social and economic dimensions of how workforces interact and adapt to the market. Yet, despite this well-known reality, there are few approaches that capture all together (Jansen and Vellema 2011). One approach that seeks to combine these elements, and is used within this thesis, is a technographic approach.

I will expand more upon the details of a technographic methodology in the conceptual framework of this thesis, but for here, a technography study combines the human aspects with the machine components (Jansen and Vellema 2011; Glover 2022). It considers *technology* not just as the material artefact, but a term that encompasses the social components of making and coordinating thought and action to achieve the task over task groups and institutions. This approach seeks to capture the overall performance of socio-technical arrangements and the actors involved (Richards 2007; Jansen and Vellema 2011). Doing so offers the potential for a more holistic understanding of the causal mechanisms, the how and why technology change takes place. It therefore makes a promising model for analysing technology change in African agriculture. In this thesis, I draw on this approach to understand how farmers perform and navigate seed technology and the adoption of new varieties.

3.3 Seeds and seed systems

> *"The main limiting factor in [African agriculture] is not a lack of capability. Nor is it a lack of drive among smallholder farmers to increase their yields. Nor is it a preference for traditional methods. It is not even the lack of government extension support. It is the seed.*
>
> *To put it more precisely, the main limiting factor in agricultural productivity growth in Africa has historically been a failure to provide Africa's farmers access to higher-yielding seed, without which little else done to assist them can have much effect. Because in all crop production systems it is primarily the seed that sets the upper limit on what farmers can achieve."*
>
> (Agra 2017, 11)

If varieties are the solution, then seeds are the mechanism and seed system actors are the extension. Seeds are the foundation of agriculture. Seeds and planting materials[2] can be a fast and effective way for farmers to harness varietal innovations (Coomes et al. 2015). Where established seed systems exist, they are the conduit between research and end users. Where seed systems are weak, crop technologies are unlikely to reach end users. Yet a great deal of research focuses on the technology within the seed, rather than the networks that realise it in the field (McGuire and Sperling 2011). Given this role seed systems play, agricultural development and varietal adoption strategies should consider 'seed security', as well as food security (McGuire and Sperling 2011; Scoones and Thompson 2011).

Here, I draw on definitions of *seed security* from across Sperling, Cooper, and Remington (2008), Scoones and Thompson (2011) and Sperling and McGuire (2012), to define it as:

[2]Seeds and planting materials included within 'seeds' from here on for conciseness.

> *"When seed is available, accessible and of sufficient seed and varietal quality. It is the sum of physical, organisational and institutional components, their actions and interactions that determine supply and use in quantitative and qualitative terms."*

A basic component of seed security is the logistics of supply, but also important are the social dimensions of actors, networks and their arrangements (Louwaars and de Boef 2012; Louwaars, de Boef, and Edeme 2013; McGuire and Sperling 2016). Seed system security and resilience is a product of access and availability to quality seed (Biemond 2013; McGuire and Sperling 2013).

Seed quality refers to both the physical condition and genetic purity of the product (McGuire and Sperling 2011; Mulesa et al. 2021; Louwaars and Manicad 2022). High physical quality means that the seed is cleaned of debris and shows no sign of physical damage. Good genetic purity means that a bag of seed is genetically near-identical and true to the traits of the listed variety. Quality also refers to the phytosanitary health of the seed, ensuring that it is free of pests and diseases. Seed that passes all of these quality checks should raise the likelihood that farmers are getting the best potential from the seed they purchase. The travel conditions in seed logistics may also play a role in seed quality, and so do the behaviours of seed producers and sellers.

Seed availability refers to the presence of the seeds within a user's reach (McGuire and Sperling 2011; Mulesa et al. 2021). Supply routes are a part of the seed security picture as they inform the availability of where farmers can obtain seed. Seed availability can differ for farmers depending on their remoteness from towns. For example, rural towns might have different varieties to those that are sold in remote areas. Distance to the seed source is important for farmers as travelling demands financial and time costs. The ability to travel might also be unequally felt across age, gender and faith dimensions (Chebet, Adong, and Ninsiima 2015; McGuire and Sperling 2016). Seed availability also includes a time component of *when* seed is present. To get the best yields for many crops in rain-fed agriculture, seeds must be planted just as the rains start. Missing this start to the growing season can have knock-on yield reductions. It is therefore particularly important for rain-fed farms that seeds are available in time for the planting season (Tadross et al. 2009).

Similarly to food security, seed security includes an access component (McGuire and Sperling 2011; Mulesa et al. 2021). There might be available and high quality seed, but there may still be financial or social reasons why farmers are unable to access the product. For instance, where farmers are unable to provide the finances required for seed, or where seed markets offer difference access across gender dimensions.

Where seed access, availability, and quality meet farmers needs, users are able to rapidly draw on useful crop innovations. Actors in such a system might be considered seed secure, and more resilient to shocks as a result (McGuire and Sperling 2011, 2013; Mulesa et al. 2021). Where a shock does affect an area, seed aid, much like food aid, is administered to restore a sustained recovery for local food security (Sperling, Cooper, and Remington 2008).

Seed systems can be roughly grouped into three different types: the formal, informal and integrated. In reality, these groups are not distinct and permeability exists between each (Coomes et al. 2015). These groups do however help to identify different patterns of operation. In this next section, I explore and note the differences between these seed system groupings.

3.3.1 Formal system

The formal seed system follows a linear breeding approach, with researchers and breeders developing varieties, and private actors tasked with downstream seed marketing and farmer adoption (Cleveland 2001; Mastenbroek and Ntare 2016). This model was proposed as the primary model for rural development that gained popularity during 90s neoliberalisation (Ellis and Biggs 2001; Lynam 2011). The same model is often presented as the path to a Green Revolution in Africa (Toenniessen, Adesina, and DeVries 2008; Scoones and Thompson 2011; Odame and Muange 2011). The aim is to link farmers with the latest crop breeding breakthroughs, packaged in products which are tightly regulated for high quality. The system is maintained by ongoing farmer demand for new varieties, and market competition to drive product improvement. The general production of seed for extension can be broken down as follows:

1. **Breeders or basic seed** is the initial stage of seed production, harvested from breeders plots. It is used by breeders to create the genetic purity for a new variety. Breeders seed is not intended for sale and is produced in relatively low amounts.
2. **Foundation seed** is produced by growing breeders seed under controlled conditions that ensure genetic purity. Foundation seed is the source for seed multiplication to other breeders and producers. As such, it must pass meticulous checks to ensure genetic purity and the absence of any contamination.
3. **Registered seed** is produced from foundation seed. It is used in the multiplication stage, to increase the amount of seed available for sale. It is subject to checks that confirm quality standards.

4. **Certified seed** is the product of the multiplication and conditioning of registered seed. Certified seed is the product that farmers will purchase and as such is treated with chemicals to assist storage and improve germination.

In Uganda, like much of sub-Saharan Africa, this process is coordinated through a linear commercial chain of seed producers, processors, wholesalers, suppliers, agro-dealers and local shops (Bentley, Mele, and Reece 2011; Joughin 2014; McCann 2001; McCann 2011; Odame and Muange 2011). These actors are mainly officiated private businesses, sustained on the continued sales of commercial goods to farmers. The exception to this might be contract farmers who are tasked with multiplying the seed during the final stages of production. Ugandan seed companies mainly obtain basic seed from one of two public bodies, NARO research institutes or NaCCRI (Mabaya et al. 2021). Mabaya (*et al.*, 2021) describe the process to obtain basic seed as the following:

> The general process to obtain the desired quantities of basic seed starts with a seed company making a formal request for basic seed at least one season or six months before the seed collection date. A letter addressed to the Director of the Research Institute should provide details of the parental stock, quantity requested and date of collection. On receiving the letter, the Director notifies the breeder, who engages directly with the seed company to further establish the specific details of the order. Seed companies may also submit their seed production plans/schedules and forecasts to the breeder. The seed company is advised on the costs and payment modalities as established in the NARO Financial Management procedures. The seed company and the institute sign a memorandum of understanding detailing the terms and costs of engagement. Seed companies are required to make a down-payment of 30-40% of the value of the seed."
>
> (Mabaya et al. 2021, 9)

The Ugandan seed market is worth an estimated $7.90bn (Mordor Intelligence 2023). There are somewhere between 20 and 42 seed companies in Uganda, arranged in a highly competitive space with no clear dominant players (Joughin 2014; Mabaya et al. 2021; Mordor Intelligence 2023). These companies rely on around 11 active breeders, who focus on maize, bean, millet, and sorghum (Mabaya et al. 2021). Five of these breeders work specifically on maize. Between 2002 and 2019, these breeders released 139 new varieties, of which 99 varieties were maize, 24 were bean, ten were sorghum and six were millet (Mabaya et al. 2021).

Agro-dealers are the main customer interface for the formal seed sector. These are specialist shops dealing in improved varieties alongside other agricultural inputs and equipment (Toenniessen, Adesina, and DeVries 2008; Alliance for a Green Revolution in Africa (AGRA) 2013; Domínguez et al. 2022). Agro-dealers are trained to be knowledgeable in the varieties they stock and intended as such to provide a source of information for farmers to draw on. Currently, agro-dealers in Uganda are thinly spaced, with a ratio of one agro-dealer per 3400 farmers (Mastenbroek, Otim, and Ntare 2021a).

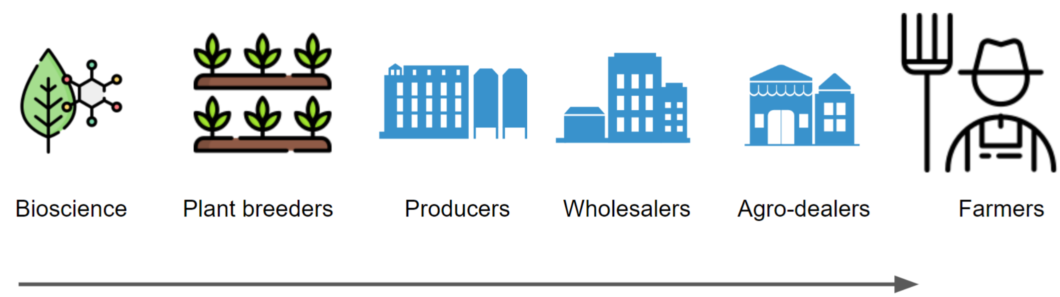

Figure 4: The linear pathway of the formal seed sector.

Ugandan formal seed systems focus on the sale of certified seed (Mastenbroek, Otim, and Ntare 2021a). Certified seed is designed to be of the best condition possible for farmers to purchase. It is the product of quality-focused seed machinery and preservation. It is packaged in sealed bags of uniform size and is often treated. This seed treatment is usually a coating of biological and chemical agents that protect the seed against pests and diseases encountered during storage or initial planting (Muthii 2014; Lamichhane et al. 2020). Seed treatments might also contain substances to aid germination and initiation, such as bacterial inoculants on legumes.[3]

Certified seed is also designed to be fresh when purchased (Longley et al. 2021; Miehe, Sparrow, and Spielman 2023). It has an expiry date on it, with farmers advised to avoid the bag if it exceeds the printed date. To ensure seed is fresh, seed producers deliver seed just before the growing season (Mabaya et al. 2021).[4] A quirk of this delivery timing however is that there can be a narrow time window between seed arriving at agro-dealers in time for the rains, with some seed arriving after the rains have started. As such, this aspiration for quality can affect seed availability.

[3]Treated seed is often dyed to prevent the seed being confused as grain and consumed.
[4]Another reason for this is to prevent counterfeiters, which will explore later.

In Uganda, the ‘certification’ status is a form of regulation awarded at the end point of processing, and a blue seal inscribed on the packaging to indicate this approval to farmers (Joughin 2014; Mabaya et al. 2021; Bagamba et al. 2023). Regulation officers are expected to visit formal seed processors and check seed bags for standards of quality, such as moisture content, germination rates and physical purity of the seed. Should the test bag fail, the entire batch will be void. The aim of certification is to regulate for high-quality seed, preventing sales of low-quality seed that fails to germinate, contains diseases or is not true to the variety type. Regulatory standards also prevent bags from being opened prior to the final user, or sold in smaller denominations. Thus certified seed is sold in set sizes, with the smallest size being a 2kg bag (Barriga and Fiala 2020; Mabaya et al. 2021).

Certified seed is always comprised of modern varieties. Because of the costs in breeding, seed multiplication, processing and marketing, certified seed is sold for a higher price than local seed. Purchasing certified seed should however provide a good return on investment for farmers, provided they are grown in combination with other agricultural inputs (Bold et al. 2017).[5]

The commercial need to recover the high costs of certified seed production and supply means that the formal sector tends to focus on high-value crops. This is in part because smallholders are unlikely to pay the high costs of certified seed production for crops with limited financial returns (Mastenbroek, Otim, and Ntare 2021a). Consequently, the formal seed sector for African smallholders is nearly entirely focused on improved maize, select legumes and a few higher value oil crops and vegetables, like sunflower or tomatoes, rather than the full range of local crop smallholders cultivate (David 2004; Coomes et al. 2015; Mastenbroek, Otim, and Ntare 2021a). The formal sector does also supply closed value chain crops, like tobacco, but these systems rarely involve smallholders. Certified seed is purchased from agro-dealers in cash and this nearly always as an up-front exchange (McGuire and Sperling 2016; Sperling et al. 2020).

In the Ugandan 2040 vision, certified seed sold by agro-dealers is set to replace local seed. The challenge is that Ugandan farmers do not appear to be purchasing from agro-dealers (McGuire and Sperling 2016; Odame and Muange 2011). Instead, they seem to be purchasing from informal systems. In this next section, I will introduce the informal seed system.

[5] Growing seed without inputs does not always result in low yields, but it makes yields more dependent upon soil nutrient status. In areas of degraded soils and continual farming, as is common in Uganda, omission of fertilisers is likely to limit yields.

3.3.2 Informal system

Approximately 90% of the seed sub-Saharan farmers acquire is from informal seed systems (McGuire and Sperling 2016). Some argue that these systems should be called 'farmer seed networks' as the 'informal' label unfairly suggests a casual, unstructured arrangement (Coomes et al. 2015). On the contrary, informal seed systems are comprised of complex networks of actors and social interactions around seed exchange. They enable smallholders with a wide range of cropping strategies and changing needs (Bazile et al. 2005; McGuire 2005; Poudel, Sthapit and Shrestha 2015). This makes them a critical resilience option for subsistence farmers (McGuire and Sperling 2013).

Until 1968, all seed systems in Uganda would be classed as informal (Mastenbroek, Otim, and Ntare 2021a). Informal seed systems are based upon the farmers saving their own seed from previous harvests, and exchanging these seeds with others (McGuire and Sperling 2016; Sperling et al. 2020). Informal system actors might therefore include: farmers, farmer cooperatives, local shops, local markets and mobile traders.

Counter to the formal system's ordered pipeline of officially regulated products, exchanges of seed on informal seed systems are less linear and changeable in both time and space. Sites of exchange might be through local shops and markets, or they could be at the household, through travelling salespeople or farmer cooperative meetings. As such, these systems are prevalent and permeate across rural areas, wherever agriculture is common-place (Coomes et al. 2015). Thus, seed on these systems is readily available, and easy for farmers to access without extensive travel. This can mark a contrast to agro-dealers that tend to be situated in towns or close to the main roads that formal seed companies sell along (Chinsinga 2011; Farrow et al. 2011; Odame and Muange 2011). Informal seed systems are therefore crucial for varietal availability for more remote farmers.

Informal system transactions mostly take place through cash, but payment is often more flexible than agro-dealer arrangements (Sperling et al. 2020). For example, payment might be exchanged after harvest or in smaller repayments. Alternatively, seed might be shared in exchange for labour, commodities, or gifts. The flexibility in these systems means that informal systems can be more accessible to farmers with less finances. Similarly, seed on informal systems is not constrained to set bag sizes, allowing farmers to purchase exact amounts. This flexibility provides farmers with greater accessibility, to trial smaller amounts for a low price.

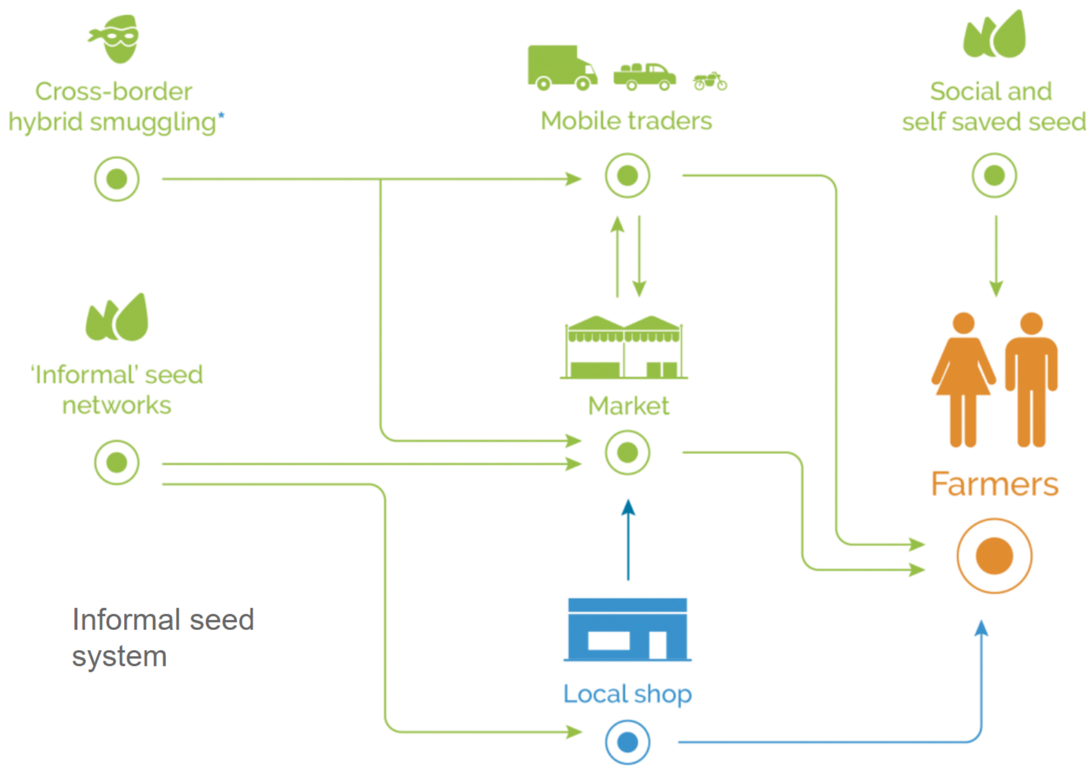

Figure 5: Examples of informal seed network actors.

Informal systems offer a wider selection of crops than formal systems; including cash and non-cash crops, modern and traditional varieties (Coomes et al. 2015; Mastenbroek, Otim, and Ntare 2021a). This holistic selection makes informal systems a vital source for household nutritional security.

Seed on informal networks are a mix of traditional varieties and the saved seed of modern varieties. Where modern varieties are sold, they will be one or more subsequent generations descended from certified seed sources. As mentioned earlier, the genetic diversity in the variety will increase with subsequent generations (Westengen et al. 2014). The rate at which this diversification of genetics and traits takes place depends on the crop species and whether it is a hybrid. Of relevance to Ugandan smallholders, maize plants are wind pollinated and so, depending on their proximity to other maize varieties, have a high potential for out-crossing (Aylor, Schultes, and Shields 2003). The progeny of hybrid plants will also express different traits of the parent lines depending on which genes have been inherited. This combination of factors means that modern varieties sold as saved seed may not be as true to type as that found in certified seed (Westengen et al. 2014). This is generally, but not always, a hindrance to productivity, if more genetic diversity in the field leads to some parts being more adapted or resistant to local contexts (Bellon et al. 2006; Mulumba et al. 2012; Westengen et al. 2014). It could however result in a loss of potential yield versus first generation hybrids, but this reduction might be less noticeable in low input systems.

Certified seed might be sold on informal systems, but it tends to be associated with formal sector agro-dealers. Where certified seed is sold, it can sometimes be the result of smuggling.[6] Seed production and quality is maintained in informal systems through the selection by farmers and sellers. Formal sector advocates argue that this unregulated system is the source of poor quality seed (Toenniessen, Adesina, and DeVries 2008; Bold et al. 2022). Poor quality seed however is also found on formal seed systems despite the regulatory rounds in place (Bold et al. 2017).

A benefit of less stages in seed production is less overheads. Informal systems work through a large network of comparatively small producers, using single generations in multiplication (Coomes et al. 2015). While this leads to a large overall output, the costs for individual producers are low. This means that informal seed can be sold for much lower prices than formal sector products. In Eastern Uganda for example, informal maize seed tends to be a third the price, or less, of certified seed. For subsistence farmers, this lower price point enables the accessibility of

[6]There is a belief in Eastern Uganda that Kenyan maize is better quality. As such some mobile sellers obtain certified seed in Kenya and run it across the border.

seed to farmers.

3.3.3 Integrated seed system

A newer seed system approach is that of the integrated seed sector (Louwaars and de Boef 2012; Louwaars, de Boef, and Edeme 2013; Borman et al. 2020; Bonny 2021; Mastenbroek, Otim, and Ntare 2021a). This system was created to encourage pluralism in seed systems and create more links between formal and informal seed sectors (Louwaars and de Boef 2012). Integrated seed systems draw on the strengths of both formal and informal systems. The integrated seed sector uses participatory breeding approaches to collaborate modern and farmer breeding approaches towards local needs.

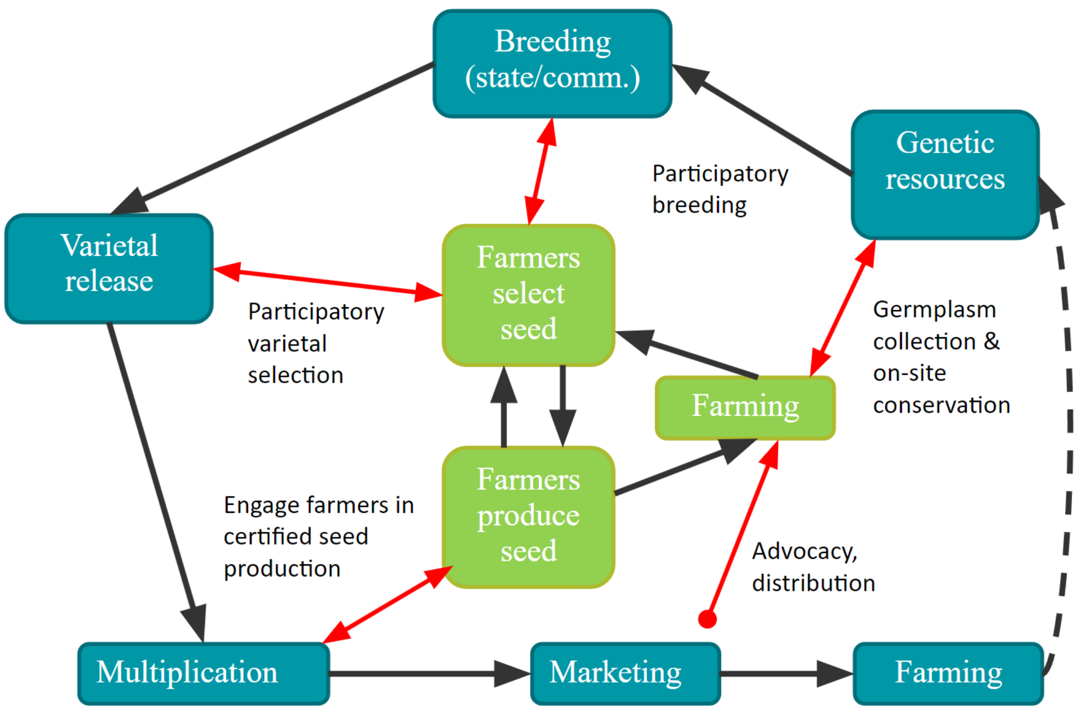

Figure 6: A schematic of the integrated seed sector. Adapted from Louwaars *et al.* 2012.

The integrated seed sector operates through networks of farmers as the primary producers of high-quality seed. These farmer groups are arranged into 'Local Seed Businesses' (LSBs), who are trained in best practices for seed multiplication and quality standards. The resulting seed is known as 'Quality-Declared Seed' (QDS) (Otim 2015; Mastenbroek, Otim, and Ntare 2021a). QDS can be likened to a farmer-produced form of the certified seed produced by the formal sector.

The integrated seed sector is still fairly new, but has grown quickly in Uganda thanks to the Wageningen University supported "Integrated Seed Sector Development programme (ISSD) (Mastenbroek 2015). QDS is now recognised in Ugandan policy as a way to proliferate improved varieties for crops outside of the formal sector's focus (Mastenbroek, Otim, and Ntare 2021a). Consequently, there are over 200 LSBs registered across the country, and this number continues to grow (Bonny 2021).[7]

Quality Declared Seed in Uganda bears some similarity to certified seed but there are some distinctions (Mastenbroek, Otim, and Ntare 2021a). Firstly, QDS includes many formal seed crops but excludes maize and sunflower. QDS is sold directly in communities and, unlike certified seed, is not sold by agro-dealers. Both certified seed and QDS are inspected for quality but QDS inspection takes place by government authorised field inspectors. Both seed types are inspected on the same standards of germination rates, moisture content and seed health.

3.3.4 The 'evolution' of seed systems

Formal seed sector advocates often frame informal seed systems as ineffective and the source of out-dated, low-productivity varieties (Bishaw, Niane, and Devlin 2015; Agra 2017). These groups define seed sector development in evolutionary language, with informal systems framed as a thing of the past that is destined to disappear (Bishaw, Niane, and Devlin 2015; Coomes et al. 2015). Instead, privatisation and the replacement of the informal sector is framed as a natural process of improvement. For example:

> *"Successful seed systems are typically led by the private sector, working in partnership with agricultural researchers and governments. In contrast, the seed systems of many developing countries fail to engage the private sector effectively and therefore fall short of their potential."*
>
> (Bishaw, Niane, and Devlin 2015, 8)

Or

> *"Throughout history and around the world, the intensification of local farms and national food supply systems has been catalysed by the introduction and distribution*

[7]These businesses and their chosen crops can be viewed at the following URL, care of ISSD Uganda: https://tinyurl.com/jmcm5arf

> *of seed of improved, higher-yielding crop varieties. While traditional crop varieties embody a number of traits that allow them to grow reliably under local conditions, they also, with few exceptions, embody very low yield potential."*
>
> (Agra 2017, 20)

This commercialised system promises varietal innovations for farmers, but also brings dense legal frameworks of what these technologies are, and who controls them (Tansey 2011; Ulmer et al. 2014; Agra 2017). The uncontrolled informal sector on the other hand is seen as problematic by the formal sector. It is framed as ineffective and antiquated at best, and constraining farmers at worst (Toenniessen, Adesina, and DeVries 2008; Agra 2017; Bold et al. 2017). But there are major assumptions in these lines of thinking that deserve critically unpacking.

The first major assumption is that the formal sector even offers a feasible replacement to the current situation. The Ugandan formal sector provides a narrow range of crops that offers part of farmers' needs, but lacks the full portfolio of crops that smallholders rely on (Louwaars and de Boef 2012; Mastenbroek, Otim, and Ntare 2021a). Informal systems on the other hand are vital for sharing these crops which are ignored by the formal sector (Coomes et al. 2015; McGuire and Sperling 2016; Sperling et al. 2020). Even within the limited crops the formal sector offers, the overwhelming majority of Ugandan seed comes from informal sources (McGuire and Sperling 2016; Mastenbroek and Menya 2015). In the current commercial model, it is hard to see how the formal sector could offer the non-market focused crops smallholders need. Claims of the utility of the formal sector need to be contextualised with this narrow focus of products in mind. Formal seed systems offer many potential benefits, but only to a small selection of crops and farmers in Uganda currently.

A second assumption is that the proposed rapid transformation does not expose farmers to significant seed security risks (see Box 7) (McGuire and Sperling 2011, 2013). The majority of Ugandan smallholders' seed comes from informal systems (Mastenbroek, Otim, and Ntare 2021a). Many of these farmers are vulnerable to shocks and have few safety nets. Importing of World Trade Organisation ruling has already illegitimised farmer activities in ways these same actors would struggle to contest (Tansey 2011; Ulmer et al. 2014). Shifting to the formal sector brings changes to where, when, and how farmers acquire the seeds for their livelihood. It requires them to work with different purveyors who may not be known, change to new varieties and to trust in regulatory systems different to the ones that have sustained them for generations (Odame and Muange 2011; McGuire and Sperling 2016; Staudacher et al. 2021; Domínguez et al. 2022).

All of these uncertainties bring risks. A shift to certified seed also affects how much time and finances farmers invest in these resources, and the returns they must achieve to profit. This change comes with increased use of inputs and a shift to monocultures, both of which reduce local biodiversity; bringing complex risks to the local habitats and ecosystem services upon which farmers depend. Despite the range of uncertainty associated with shifting seed systems, there appears to be little evidence to confirm that such a change reduces the risks farmers face.

Box 7: Switching to hybrids in Zimbabwe

In the late 60s, South Africa switched to the first African maize hybrids and saw a 46% increase in productivity (McCann 2001). Governments across Africa sought to see similar returns and so provided smallholders with credit to access hybrid seed and fertiliser. Zimbabwe saw a particularly sudden shift to the new hybrid varieties and it is estimated that nearly all smallholders grew hybrids by 1990 (Eicher 1995). Later study however suggested that production increases across the country were mainly due to the expansion of farming area, and that average yields were falling (McCann 2011). As the food supply dipped, prices rose in response (McGuire and Sperling 2013). Price rises particularly affected smallholders, causing many to be unable to afford new seeds and fertiliser inputs. Instead farmers resorted to growing saved hybrid seed despite the expected lower returns in subsequent generations. Farmers however had little choice as the nationwide shift to hybrid varieties had made other traditional varieties scarce. Smallholders struggled as a result of the loss to seed security and resilience that the transition had created (McGuire and Sperling 2013). Only wealthier farmers were able to continue the routine re-purchase of hybrid seed, and supply the plants with the nitrogen inputs they required (McCann 2011).

Another assumption is that informal seed systems are ineffective at spreading varietal innovations and that the formal sector model could do this more effectively. On the contrary, evidence suggests that informal systems are comparatively fast purveyors of useful traits, even across remote and difficult to access rural areas (Coomes et al. 2015). If anything, decades of limited uptake despite enormous funding would suggest that formal systems are facing difficulties to share crop innovations with smallholders (Mkindi et al. 2020).

A third assumption is around quality. Many narratives frame informal seed products as of poor quality, on account of their lack of official regulation, and that this reduces farmers yields (Toenniessen, Adesina, and DeVries 2008; Bishaw, Niane, and Devlin 2015; Bold et al. 2017, 2022). Conversely, formal seed systems and certified seed are exemplified as high quality. 'Quality' is conflated as both the genetic quality of the variety as well as the quality of the seed product. There are two challenges to this. The first is that this claim of poor seed quality in informal systems appears anecdotal (Barriga and Fiala 2020; Dey et al. 2022). Seed quality in informal systems appears to be understudied and there is no clear evidence that the products are of low quality. Further, informal seed systems are regularly used by risk-sensitive farmers as part of resilience strategies (McGuire and Sperling 2013). If it is quality shortfalls that restrict these farmers and the formal sector offered a more reliable product, one might expect to see wider adoption of formal products; but this does not appear to be happening. In fact, most quality concerns in Uganda apply to seed from formal systems (Joughin 2014; Bold et al. 2017; Barriga and Fiala 2020). Thus it would appear that if farmers are concerned about purchasing poor quality goods, they should perhaps be wary of agro-dealers.

Finally, there is an assumption that African informal seed systems are destined to weaken and disappear (Coomes et al. 2015; Bishaw, Niane, and Devlin 2015; Agra 2017). This is expected by the formal system on grounds of the, perceived, better products they offer and increasing legislation to push farmers into buying officiated seed (Wattnem 2016). The challenge is that informal seed systems are much more prevalent than formal systems, and do not appear to be disappearing (Coomes et al. 2015; McGuire and Sperling 2016; Sperling et al. 2020). Instead, it seems formal systems are not meeting the need that informal systems currently meet. This scenario exists despite enormous resourcing to extend the formal sector, compared to no additional investment in the informal sector. Bioscientists using evolutionary language regarding the change of seed systems[8] should perhaps be mindful that survival of the fittest often depends on the most efficient use of resources. Since informal systems appear to thrive without additional support from private and public actors, an evolutionary perspective of the system might instead suggest that it is the resource-demanding formal sector that has an uncertain future. After all, while informal systems persist for all crops, formal systems struggle to survive outside of a narrow group of cash crops that can support these production resource demands.

A challenge with transformation or replacement debates is that either result is a zero sum game

[8]See "The evolution of seed systems" in (Bishaw, Niane, and Devlin 2015).

for smallholders. Farmers seed systems are not a fading anachronism but a constant in a time of instability. Forcing the majority of farmers to change key component of their resilience brings major uncertainties at a time of many other pressures to food production. The priority from a national standpoint should be how to help farmers thrive despite the pressures of climate change and the push for more sustainability production. Smallholders will need access to varietal innovations to raise productivity without expanding agricultural area (Campbell et al. 2017). The technologies of the formal sector offer efficiency and resilience improvements towards this goal, but currently they are out of reach of the most risk-sensitive farmers (Mayet 2016; Pixley et al. 2019). But farmers also find resilience in the diversity of actors and varieties around them, rather than a select sub-group. Part of supporting these farmers will be higher-yielding varieties, but another part is about maintaining the flexible array of seed acquisition methods the vulnerable rely upon. Legal control and profit by a small minority has become a part of the production story in Africa (Louwaars, Tripp, and Eaton 2006; Wattnem 2016). This transformation is justified as a path to achieve development goals, but it also profits the interest of a powerful minority (Tansey 2011; Thompson 2012; Wattnem 2016).

Despite legislative pressures and development initiatives to push agriculture towards a commercial model, informal systems are likely to persist. Rather than push for supremacy of either side, it is worth exploring what pluralism and shared learning could bring to make a better system for all (Mastenbroek and Menya 2015; Borman et al. 2020; Barikore et al. 2022). From this perspective, this thesis considers how modern varieties and seed systems affect the risks faced by farmers. Understanding these risks can inform ways to reduce the risks to farmers, and help build productive and resilient food production systems. In the next section, I share the conceptual framework that guides the thesis approach.

Chapter 4

Conceptual approach

Much of this work so far has introduced how the formal and informal seed systems came to be. Both systems are simultaneously the process and product of different bodies of thought, structured around *providing useful technologies for farmers*. A great many other groups of actors outside of farmers stand to benefit from this mission. For example, agricultural companies, research centres, ministry bodies and beyond agricultural bodies all can gain power and influence by investment.

Investment in the productivity mission is often legitimised on moral grounds, where the intended beneficiaries are vulnerable farmers (Toenniessen, Adesina, and DeVries 2008; Agra 2017; Mkindi et al. 2020). But bodies of actors within the mission have also originated and expanded by focusing on private interests. For example, large institutions, such as AGRA and the CGIAR centres, stand to receive significant funding on the promise of improving smallholder agriculture. Similarly, the number of private seed companies and agro-dealers have dramatically increased in response to profiting from a particular set of seed products and agricultural inputs. Meeting these needs has led to particular structures in how crop improvement is practised, and how resources are allocated to achieve these aims. Such decisions can have lasting effects on which technologies are favoured, and how they might be improved. The question is, as institutions coordinate to meet their own needs, how much these decisions continue to align with the needs of impoverished farmers. Understanding this question is important to perceive how changes in cropping approaches affect the risks farmers face.

4.1 Mapping the institutional landscape

Overall, this study is interested in seed system institutional practices and how these fit with the behaviours of farmers. Critically comparing the arrangement of actors across these systems, and how this influences farmer behaviour, relies upon a methodical analytical approach. Since this study considers arrangements of actors, a conventional starting point is with an overarching institutionalism perspective.

Institutionalism is a social theory that focuses on institutions. Based on a number of influences, I define institutions as (Martin 2004; Bryant and Jary 2007; Kingston and Caballero 2009):

> *A body of actors operating through formal and informal rules that guide norms, and structures of behaviour. These rules, customs and traditions influence individual and collective actions within the group of actors and wider society. They may be hierarchical or egalitarian, with associated structures around power and control of resources; material or social. These structures include a degree of self-preservation and continuity through recurring performance. The stability of this preservation may depend upon enforcement of the guiding rules, through resource allocation or punitive action.*

Institutionalism examines how institutions shape behaviour, set expectations, influence decision-making and the organisation of groups within social systems. It includes the role of power, culture, and historical context in shaping these institutions. The operations of institutions encourage certain interactions, reducing transactional costs for those who cooperate. The legacy of these contexts influences 'the rules of the game' to maintain status quo (Kingston and Caballero 2009). As such, institutions constrain what behaviours and responsibilities are acceptable within societies, informing which behaviours are enabled or constrained. Naturally this makes institutions central in power dynamics, whereby they reinforce power imbalances and influence who benefits or loses within societies. But institutions do not exist in isolation. They might exist in states of cooperation, conflict or varying levels of complementarity. These interactions will be an area that we revisit as we explore the institutional landscape across Ugandan seed supply.

So far we have summarised the dynamics of how institutions operate, but we should also consider their origins. A large amount of institutional theory has sought empirical findings of ongoing processes, but less so on the process by which they originate and alter (Barley and Tolbert 1997).

Including this change component is especially useful given our interest in the transforming space around Ugandan smallholders.

To include analysis of institutional change, I draw on elements from structuration theory. Structuration theory sees social behaviours, such as cultures and traditions, not as exact repeats, but as constantly reconfigured as they are performed by actors. Although actors are restrained by institutions, it is through their agency that social structures are reproduced (Bryant and Jary 2007). With that agency comes the potential for change. An example of how this plays out can be demonstrated through combining the use of the concept of *habitus* (Bourdieu 1995). Habitus refers to the ongoing cultural traditions and practices of actors as they perform social structures. It is a set of culturally inherited dispositions, but ones that change through the contribution of actor agency to the performance. From a structuralist approach, this actor contribution to repeated social performance is what causes the ongoing change in structures (see Box 8 below).

Box 8: A metaphor for habitus and social change

A metaphor for *habitus* could be individuals walking through a woods, guided by well-trodden tracks. As more walk the path, some might take a slightly different route - perhaps noticing a shorter path, or blocked by an obstacle ahead. As they deviate, they form a new path. If others follow, this new route might begin to become the norm in place of the older path. In a similar way, institutions mould and are also moulded by the actors that comprise them. Closely related to this is the ability of institutions to adapt to changing conditions.

A consequence of the inherited norms of institutions is the potential for path dependency and subsequent lock-in; where historically made decisions constrain future decisions. In the case of technology, this lock-in might be the continued focus on a particular technology, due to its historical institutional investment, even when a better innovation arises. The classic example of this is in the continued use of QWERTY keyboards when more efficient options exist (Arthur 1989). Some institutes might even draw on this lock-in to maintain actors in their ecosystem by making it significantly difficult or costly to change. Lock-in can however increase the chance of a network effect; whereby the value of a good is dependent upon the number of actors using it (Draisbach, Widjaja, and Buxmann 2013).

The mention of technology brings us back to the topic of seed systems and technology. While institutionalism provides a foundation for the start of our analysis, a more critical lens would be to frame our approach around the social practice of technology. Here we will do so through the use of a *technographic* lens.

4.1.1 Technographic approach

A technographic approach provides a more holistic method to study the social performance of technology. It draws on traditional ethnographic approaches to study the ongoing habitus of what technology is, and how it changes (Glover et al. 2019).

A technographic approach considers technology as not solely the material object, but also the integrated social behaviours and institutions involved in performing the technology (Jansen and Vellema 2011; Glover 2022). These include: the creation and use of the technology; the actors involved; the organisation of these actors; the required skillsets and know-how; the division of labour; and the hierarchies in decision-making. As should be apparent from this list, a technographic approach follows on from the institutionalism mindset, and sharpens it for our technological focus. Therefore our study of seed technology is not just of the material germplasm, but also the wider arrangement of social structures that shape, share and sustain what is grown, how and why.

The above definition of technology brings an important consideration. A large part of the agricultural technology literature views technology as something users receive, adopt and use. Instead, a technographic viewpoint sees technology as something that is practised, to be made and remade as part of socio-technical interactions (Glover, Sumberg, and Andersson 2016). New technologies do not proliferate as fixed entities (Mica 2013). Instead, they are adjusted and adapted as they are locally translated into practice (Glover et al. 2019). Here, technology change includes the reconfiguration of these social structures, rather than just the introduction of a new material innovation package (Glover et al. 2019). This approach also moves away from the framing of adoption decisions as purely individual and instead offers a model of 'interdependance' whereby the social influence around the individual informs the technology change decision (Leeuwis and Aarts 2020). Technology change in seed systems is not just when one type of seed is swapped for another. That is part of the story, along with the social practice of technology; its incorporation and its influence in reconfiguring institutions.

This study uses a technographic approach to map the different actors, and mechanisms involved in the practice of a technology. This involves studying the life cycles, social networks, and institutional settings of seed technology across seed systems. Inspired by the from the work of Glover (2022) and Jansen & Vellema (2011) this lens includes:

1. **The making:** how are techniques, actors and roles involved in the material transformation? This includes considering the life-cycle of how seeds undergo processes of development, testing, distribution, and post-harvest storage, and identify how these processes are differently managed in formal and informal systems.
2. **Distribution of thought:** how are tasks and communication flows ordered by institutions? This includes consideration of social networks, where we consider how social relations and knowledge exchange influence farmers' seed choices. For instance, how might farmers draw on both community-shared knowledge and corporate or government advice?
3. **Rule construction:** how are rules, protocols and hierarchies organised in the technology practice? For example with seed systems, this includes institutional contexts of the regulatory measures, quality control, and socio-political influence that shape farmers' access to seeds. These might be more structured and regulations, or more fluid and flexible.

These dimensions provide a means to map the institutional landscape of seed technology, and how it operates. We are however also interested in the behaviours of farmers as they navigate seed systems for their own needs. The final step of our analysis needs to include behavioural theory into why farmers make their choices. We will use a combination of utility theory and the theory of affordances as part of a multi-layered model of decision-making.

4.2 Multi-layered model of decision-making

Both the theories of utility and affordances are frameworks to understanding decision-making. Fundamentally, they are both approaches to understand how and why actors make decisions. They differ however in both the intellectual traditions they come from and the different perspectives they offer.

4.2.1 Utility theory

The concept of 'utility' represents the benefits an actor experiences from the consumption of goods or services. Utility theory focuses on how actors make choices to achieve maximum utility. Researchers have drawn on this concept of utility as a form of metric driving choice decisions

(Harsanyi 1953; Fishburn 1968 ; McFadden 1974). This metric component has two conceptual branches. The first is cardinal utility, where utility can be measured numerically. The second is ordinal utility, where actors rank utility, but it is not quantified in a numeric sense (Barnett 2003). A more classical view of utility theory assumes perfect rationality in choice-making, whereas behavioural economists argue this rationality is influenced by cognitive capacity and bias (Stanovich and West 2008; Oechssler, Roider, and Schmitz 2009).

Utility theory research generally draws on mathematical formulae to predict individuals preferences, using statistical models to derive the values for utility functions from observed choices. A focus of much utility theory research is to draw on experimental games to test and improve the precision of formulas predicting decision-making. These games aim to capture specific choice making behaviour in the absence of external influences (Verschoor, D'Exelle, and Perez-Viana 2016). A randomisation element is usually included in these studies to account for assumed random variation across the sample, that is uncorrelated with the tested variable. Using behavioural games allows quantification of decision-making, and the opportunity to compare this with other decisions.

4.2.2 Theory of affordances

The theory of affordances is concerned with how environments present opportunities and constraints that influence choices (see Box 9). The word *affordances* encompasses the opportunities for action based on the actor's capabilities and needs, in space and time. Affordance is defined by the Cambridge Dictionary as, *"a use or purpose that a thing can have, that people notice as part of the way they see or experience it"*. The theory considers the relationship between individuals and their environment, rather than an individual's agency to choose maximum individual utility (Scarantino 2003). This relational component between actor, technology and environment (over time) makes affordance theory accommodating of heuristic decision-making, or disposition, over pure utility maximisation (Glover 2022).

Box 9: Affordances explained

Affordances can be thought of as the actions an object or technology offers to the potential user, within an environment. For example, an actor might be able to sit on a chair, stand on it or even throw it. The *affordances* are the 'sit-on-able' or 'stand-on-able' or 'throw-able' action possibilities perceived by the actor. This range of action possibilities depends on the qualities of the person; their size, capacities and position in space and time. These relational qualities affect which object offers greater affordances for the task at hand. With the chair example, a very tall chair might be less sit-on-able than a normal sized chair, but it might be more stand-on-able for the user seeking greater elevation.

While utility theory uses quantitative measures and statistical formulas to predict behaviour, affordance theory focuses on qualitative methods and models. For our work on seed systems, this might include the following dimensions:

- **Perceived affordances**: What do seed actors and farmers identify as the affordances offered by formal and informal seed systems? For example, how reliable, locally adapted, accessible and profitable are seed choices across sources?
- **Enabling and constraining factors**: What action possibilities does each system afford to farmers? For example, what aspects of seed and seed systems might enable or constrain farmers' cropping strategies.
- **Situational affordances**: What environmental effects influence the perceived affordances different seed systems offer to users? For example, how might seed system affordances change depending on the externalities of user type, climate change, markets or policies? Understanding these situational components can inform the knock-on relativity of 'technology usefulness' to users.

4.3 Combined analytical framework

Combining the above conceptual approaches offers a holistic framework for analysis of seed systems and farmer choice behaviour. It provides an analytical toolkit to assess the institutional and behavioural perspectives that influence seed technology change in Uganda. Integrating the aforementioned theories presents a model to assess farmer reasoning and the environmental factors influencing decision-making. Further, it might clarify how changing environments affect the utility seed technologies offer to users.

The institutionalism lens sets the foundation for comparing formal and informal seed systems, and the crop improvement institutions that support them. These systems exist on the sale of seeds to farmers, but achieve this through different paths. For example, there may be different institutions involved in breeding new varieties, producing seed and regulating for quality goods. With these different practices, may come differences in culture, traditions, drivers, interfaces and transactions. These same elements inform which decisions are made, and future legacy of institutions to change to contemporary pressures. Including this historicism can help us understand differences between institutions in their agency to change.

Our technographic lens builds on this by mapping how institutions shape decisions related to seed selection, production, distribution, and ownership. It provides a chance to investigate the interplay between formal and informal rules, routines and protocols. This sets the context for the layered utility and affordance theory approaches to examine how smallholder farmers make choices to navigate this landscape. The utility theory component models how farmers make choices to maximise their benefit (yield, profit, etc.) from the resources they have. The affordances theory approach complements these numerical estimates by informing how seed technology properties (such as accessibility or knowledge requirements, etc.) enable or constrain farmers' choices.

Combined, this approach offers a potentially comprehensive view of why farmers make certain seed technology choices. It gives an opportunity to triangulate findings, or compare contrasts. It also gives the chance to test the suitability of this combined behavioural analysis approach for future research.

This overall framework is complex in that it combines two forms of decision-making theory in an attempt to consider a more nuanced perspective of seed acquisition choices across actors and environments. For instance, it includes both the decision-making of the individual, but also how those decisions are made in relation to changing environmental and institutional dimensions that afford different potential actions to the individual. In doing so, this approach seeks to also offer a new potential method to shed light on equity, access, and the implications of different institutional arrangements; including the knock-on effects to seed diversity, seed sovereignty, livelihoods and food security. For instance, affordance theory can highlight the environmental aspects of physical, mental and institutional aspects that enable or constrain seed access, which adds great context to the DCEs that capture the perceived benefits of different seed options to farmers relative to their constraints. Environmental features could also include institutional components, such as seed distribution systems, agricultural extension and government programmes for agricultural inputs. Doing so expands the frame of reference beyond an individual and a physical technology object, to include these interconnected physical and social elements of seed technology practice. Expanding this frame of reference allows for understanding of how the choice is made within a wider context, and the influence of these contexts on the choice. For instance, agro-dealers are well-designed and supported to sell cash crops focused for yield, but farmers may also find affordances in varietal diversity or different purchase methods. These affordances are likely to be influenced along social dimensions that dictate access and equity crop technology use.

The interplay between affordances and utility maximisation could also show the broader implications of farmers' decisions. For instance, institutional pressures and market incentives to focus on modern varieties could reduce seed diversity, which in turn affects the affordances local crop diversity offers to farmers; perhaps as resilience or cultural returns. Considering these affordances also touches on concepts of ownership, where modern varieties are legislated as property of actors outside of farmers, compared to the seed sovereignty farmers experience over local varieties.

Here, I test this combined approach, to see what potential it has to inform national agricultural policy on how seed systems might better meet farmers needs.

4.4 Limitations and assumptions

There are some limitations and assumptions to this approach. The first is that this approach risks overlooking facets of seed-user decision-making that is neither technological or affordance-based. For example, there may be traditional beliefs or competing epistemologies that operate on a different decision-making rationale than those assumed by our multi-layered approach, or captured by the instruments we use to measure it. We must therefore be mindful that our results give a window into the decision-making process for users, but should not be taken as the full picture.

The next limitation comes with how generalisable the findings are. This limitation comes in two forms. The first concerns time, the second with space.

The first limitation is that our analytical approach captures a snapshot of a situation at a time of great change (to government, market, climate, food security, etc.). While this snapshot can report on the past and present, it may not fully capture the dynamism of farmer behaviour or institutional changes over time. Our approach captures past and present patterns, but causal predictions for the future should seek triangulation with a broader range of behavioural research.

The section limitation is that our type of analytical approach is specific to the context. The limits of this ‘context’ varies with the conceptual approach. While a technography approach might provide a more generalisable view of Ugandan seed technology, affordances are by their nature highly context specific since they draw on actors in environments. The degree of this contextuality ranges, with less abstraction closer to the studied sample. For example, the affordances of a crop technology may differ between individuals, villages, districts based on the distinct environments.

4.5 Epistemological stance

This section expands upon the epistemological stance of the thesis, drawing on reflections from my journey in taking an interdisciplinary approach to this research.

As is likely already apparent, this thesis draws on both natural and social sciences to answer its central research questions. The natural science elements depend upon positivist methods of seeking and defining empirical evidence to ontological questions. The social science elements are more subjective, relying upon an interpretivist epistemology. The overall thesis takes a pragmatist approach, seeking to combine both positivist and interpretivist mindsets and their findings.

A driver for the interdisciplinary nature of this thesis stems from my previous experience moving between disciplines. My biology undergraduate degree gave me the foundation I needed to move into a research lab developing improved crops for African smallholders. The technology was inspiring but the more I travelled to the field, the more I realised how few crop innovations reach farmers. I also saw how distant many breeding projects are from the fields they intend to reach. This drove me to retrain in social sciences, to understand the needs from farmers’ perspectives and to understand how they navigate crop technologies. This journey is also reflected in the approach and shaping of this thesis.

My move from natural sciences to social sciences brought two phases of discoveries. This first phase was in observing immediate differences in the approaches and arrangements of institutions across disciplines. An obvious major difference was the subject matter, but a more surprising difference was the change in working arrangements. In bioscience, each lab member has their own space, working on projects that, generally, all support the research of the group leader. The group leader is responsible for management of the lab, and obtaining research funding. This arrangement brings with it both an accepted steer on the research of the lab members, and an embedded power hierarchy. My experience in social science teams on the other hand felt more independent, where researchers drove their own research and found their own funding. Perhaps consequently the working environment felt egalitarian and more embracing of emergent ideas. This difference is relevant for the thesis, as the chapters and content were not generally typical of my supervisor's research focus, but my own choosing and subject to subtle shifts as I learnt more. This, however, brings me to my second phase of discovery.

The second phase involves the unconscious and conscious compartmentalising of natural and social science approaches in my own thinking. Perhaps the most pivotal feedback comment in my first year planning was that, *it was clear that I came from natural sciences, as those are the areas I focused my thinking.* With that astute comment I re-read my work and realised that I had subconsciously focused the majority of my thinking on approaches and topics that more closely matched my natural sciences training. While I believed that I was mixing methods and disciplines to create a more nuanced project, my subconscious dispositions led me to reproduce a natural science approach, and to shape the social science elements to emphasise the positivist methods from my previous training. In response, I switched to focusing on social science theories and methods. The result was the other side of the same coin, in forcing the other side, I had created tension rather than complementarity between approaches. Only through time did I manage to find a way to bring balance back to the research, where multiple approaches are each given a chance to shine, and add nuance. The results chapters of this thesis are largely chronological in when they were deployed and written up. I believe some elements of my own journey can be found in their emphasis as I learned to become an interdisciplinary researcher.

> "The thing about being an interdisciplinary researcher is that you work with all groups and yet are home in none of them." - A research colleague during my PhD.

A final lesson I learned in pursuing an interdisciplinary approach was in publication and 'fit' with funding proposals. During the PhD, I tried to publish research from fieldwork in Ethiopia that included both bioscience and discrete choice experiments. While the research went well and produced some interesting findings, I soon discovered the challenge in finding a relevant journal in which this combination would fit. 'Fit' here was both a challenge in finding a suitable journal and then in desk rejections that also saw the research as beyond their scope. Thankfully the paper is now in the second round of review in another journal. I encountered a similar challenge in funding proposals I contributed towards, which called for interdisciplinary research but feedback and successful proposals aligned with the research council they stemmed from. One challenge here could be terminology, as some might consider different fields within, say, biology to be interdisciplinary, e.g. plant science and entomology. Regardless, my discovery as part of this PhD is that although countless papers call for systems thinking and transdisciplinarity, funding and journals seem to hinder these approaches and encourage compartmentalisation. I left the lab because I saw the need for more diverse collaboration. This thesis has helped me learn this approach but more openness to transdisciplinarity is required if we are to achieve the systems level solutions many challenges today call for.

Chapter 5

Hidden risks in formal seed supply

> *"The real enemy of farmers is lousy seeds"*
>
> Simon Groot, 2019 World Food Prize winner, World Food Prize 2019 award ceremony.

The Ugandan government, backed by powerful institutions, calls for agriculture to shift to a formal and commercialised model (*Uganda Vision 2040* 2013). This model operates on a particular organisation of varietal production and deployment. As we have explored, a wealth of literature outlines how this process theoretically takes place. How this conceptual approach is playing out in Uganda however, is less reported. For example, how do seed companies organise what and where they sell? How do agro-dealers prioritise which crops to sell and which farmers to cater to? How does quality regulation, of which the formal is so famed, operate in practice? These kinds of questions are important because something in the system is resulting in reports of farmers buying seed that fails to grow (Joughin 2014; Mennel et al. 2014; Barriga and Fiala 2020).

In this chapter, we investigate how the Ugandan formal seed sector operates in practice. I also provide insights into how formal seed is created, purchased and used. This provides a background on the formal seed sector, which also be used for comparison in later chapters on informal systems, and farmer decision-making. This first research chapter also explores the formal system through the lens of 'delivering quality seed technologies to farmers'.

5.0.1 Seed quality

A major risk to smallholders is investing in something that fails. In Uganda, farmers are reportedly buying seed that fails to germinate (Mennel et al. 2014; Bold et al. 2017). When seed fails to grow, the farmer not only loses out on the seed costs, but also the financial and time costs in preparing and planting the field.[1] Such costs are particularly damaging to subsistence farmers, where household finances are dependent upon the immediate returns from each harvest. In the absence of available household finances, failure to return on pre-harvest investments might require the selling of farm assets; further limiting farming capacity and ability to recover. Since many Ugandan smallholders rely on rain-fed agriculture, failing seed might also cause farmers to miss the start of the growing season. Those who plant late have fewer growing days in the season, raising the likelihood of smaller yields.

The problem of seed failing to grow is often posed as a result of purchasing low-quality seed (Bold et al. 2017, 2022). Quality here refers to the seed health, and subsequently its viability. Where seed quality is good, farmers can rely on seeds to give high germination rates.[2] Reliable seed, with high germination rates, offers farmers greater confidence in the investment. Where germination rates are low, farmers might have to purchase larger volumes of seed, to achieve the same coverage of the field.

Advocates of the formal seed sector argue that poor-quality seed circulates in informal seed systems (Bold et al. 2017). Conversely, seeds in the formal sector are presented as of high-quality, due to the state-led regulation of certified seed by the National Seed Certification Service (NSCS) (Joughin 2014). The NSCS licences seed dealers, crop inspection and official certification of seed bags. It develops rules by which the seed industry operates and monitors the system for compliance. Here, differences in quality are explained by the regulated nature of the formal seed sector and the 'unregulated' nature of the informal sector. The challenge to these arguments is that formal sector products are found to be of poor quality and proposed to contribute towards under-performance in the field (Bold et al. 2017).

Farmers are purchasing certified seed from agro-dealers and experiencing seed that either fails to germinate or performs poorly in the field (Bold et al. 2017; Barriga and Fiala 2020). Approximately 50% of hybrid seed from agro-dealers is suspected to be counterfeit and estimated to deliver a 16% return on investment, compared to an expected 100% investment return for

[1] Such as ploughing, planting labour, use of inputs, etc.

[2] Provided the planting conditions are sufficiently favourable.

genuine products (Bold et al. 2017). Even bags found to be of genuine seed suffer from varying quality, suggested to occur in supply (Barriga and Fiala 2020). These seed quality failures are looked on particularly poorly by farmers on account of the comparatively high prices of formal sector seed.[3] Consequently, failing certified seed is seen as a threat to new variety adoption, as it erodes farmer trust in improved varieties and the formal seed sector (Ashour et al. 2019; Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019). Bold *et al.* (2017) refer to this as a 'market for lemons' situation, whereby asymmetry in product information between buyers and sellers results in buyer distrust and the eventual collapse of the market for quality goods (explained in box 10 below). As Bold *et al.* (2017) argue however, the Ugandan context appears to be in contradiction to the market for lemons phenomenon, as good quality seed is available and is not diminishing. In this instance, both fake and genuine products appear to co-exist on the market.

Box 10: Market for lemons

The 'market for lemons' concept was introduced by George Akerlof in his 1970 paper "The Market for Lemons: Quality Uncertainty and the Market Mechanism". Akerlof suggests that where there is information asymmetry between buyers and sellers, it creates an inevitable exit of quality goods from the market. The concept is based upon the buying and selling of cars, where a good car is a 'peach', and a bad car is a 'lemon'. Sellers have more information about the product and can differentiate between peaches and lemons. Buyers cannot differentiate and therefore they are unwilling to pay above the market average for a car. Sellers of lemons are inclined to sell their products above their worth, and remain in the market. Sellers of peaches are unwilling to sell below their higher market value and so withdraw their products from the market. Sellers with lemons continue to sell. The result is that quality products continue to leave the market, leaving only lemons. The situation assumes that buyers are unable to ascertain true quality products before purchase, and that sellers have correct knowledge of quality goods.

The question is, how can quality-regulated seed apparently be a source of low-quality products? A frequently suggested answer for much of Uganda is counterfeiting or 'fake' seed.

[3] This will vary with the product and location but the pattern is generally the case. For reference, certified maize seed in Eastern Uganda is often around three times the price or more than saved seed prices.

5.0.2 Counterfeit seed

Much debate has focused on counterfeiting as the cause of the seed that fails to grow (Boef et al. 2019, 2019; Bold et al. 2017; Barriga and Fiala 2020). There are two main narratives in these debates. The first is that fake seed doubly impacts food security; once in the immediate losses to the farmer and secondly in the reduced willingness of farmer to purchase improved seed in the future.[4] Another narrative is that counterfeiting is the work of unscrupulous business-people throughout seed supply, profiting at smallholders' expense (Mennel et al. 2014; Boef et al. 2019).

Counterfeiting here refers to selling seed that performs differently to the labelled variety. This could include low germination rates, poor initiation or the development of different traits to the advertised variety. Seed bags can be adulterated by replacing a proportion of the seed with another variety, likely locally saved seed or grain. Bags might also have stones or other foreign materials added to raise the weight. The seed is often dyed to imitate certified seed. Counterfeiters target these products on account of the higher prices that certified seed commands over local seed or grain.

The scale and sources of counterfeiting are not known. Some estimate around 50% of seed at Ugandan agro-dealers is counterfeit (Bold et al. 2017). This threat is seen to be a major barrier to smallholders shifting to modern varieties. In an attempt to stop counterfeiting, various tamper-proof and authentication measures are now being put into place (Mennel et al. 2014; Boef et al. 2019; Ashour et al. 2019). For example, seed companies have developed a system called *'kakasa'*, which uses coin-scratch technologies to confirm authenticity (Access to Seeds Foundation 2023). The system works by a user scratching off a coin-scratch surface and freely texting a number with the code underneath. A return message then confirms if the bag is genuine. The aim of these tools is to prevent counterfeiters and provide farmers with more assurance that they are purchasing genuine products. Achieving both of these objectives is hoped to: ensure farmers obtain genuine formal seed system products; feel confident to buy more products in the future and; achieve greater productivity through this shift to certified seed. There are however some assumptions with counterfeiting arguments that deserve unpacking.

The first assumption is a more minor point about the scale of the threat. African smallholders acquire only around 2.4% of their seed from agro-dealers (McGuire and Sperling 2016). Even if they wanted to buy more, the formal sector offers a limited range of crops that support, at most,

[4] Described by Bold *et al.* (2017) as a low-quality low-adoption equilibrium, preventing farmers from buying improved seed and instead depending upon local varieties from informal seeds systems.

a portion of household needs. In this context, it seems unlikely that counterfeiting of certified seed is the main culprit restraining Ugandan productivity. Even if the formal seed was of the highest quality, it supplies around 10% of farmers' seed; with the rest coming from informal sources. Some argue that relying on informal seed is what limits farmers, and so the presence of poor-quality certified seed discourages farmers from changing to more productive options (Bold et al. 2017). It is however worth contextualising that certified seed is only available for a fraction of the wider crop diversity farmers grow. Therefore even if certified seed was of certain high quality, farmers would still rely on informal seed systems to cater for the greater diversity of their crops.

The second assumption is much more challenging for the formal seed sector: that seed found to be of poor quality is not also genuine. In a surprising oversight, nearly all studies on Ugandan counterfeit seed judge what is fake by germination rates, crop initiation and field performance (Joughin 2014; Mennel et al. 2014; Bold et al. 2017; Barriga and Fiala 2020). This assumes that genuine seeds cannot also perform poorly. The way to confirm the authenticity of the seed would be to check if the seed genetics match that of the labelled variety. Doing so would confirm the presence of mixing, and provide clarity on which seed is performing poorly. The one study that looked at genetic purity of certified seed found it to be high throughout the supply chain (Barriga and Fiala 2020). This suggests that certified seed bags are not being mixed with different varieties from those labelled. If these same bags are performing poorly in the field, the problem is not with counterfeit seed, but the quality of genuine seed. Such a suggestion is particularly damning for the formal sector, given that it frames its seed as of superior quality to the alternatives.

Counterfeit or not, it appears that there are seed quality problems in Ugandan formal seed systems. The question therefore is where this quality problem originates in the supply chain, from production to farmer. This is especially pertinent as certified seed must be officially regulated upon bagging, prior to delivery. The products are transferred to agro-dealers by company delivery men, and the agro-dealers are instructed to handle seed by regulations to ensure quality.[5]

One less conspiratorial but alternative reason for failing seed could be seed spoilage. Seeds are alive. While remarkably resilient, they have a lifetime and if exposed to unfavourable conditions, they will die. Such conditions might be physical stresses that fracture seed structures or adverse environmental conditions, such as temperature or humidity extremes, that cause seed to perish.

[5] For instance, agro-dealers are not permitted to open certified seed bags for sale.

Since Barriga & Fiala's (2020) findings refute widespread seed replacement with non-certified varieties, it could instead suggest poor seed handling in formal supply chains might be the cause of seed damage and subsequent germination failure. Such a conclusion presents a significant, but hidden, risk to smallholders who are expected to transfer to formal seed systems.

Seed longevity is best ensured by keeping the storage conditions cool and dry. Examples of this can be found in every major seed bank internationally, where seed is often kept between 4°C and -20°C, and at low humidity (Taba et al. 2004; Sadaka, Atungulu, and Olatunde 2016; Crop Genebank Knowledge Base 2023). Clearly, these same conditions are not possible at the field, but seed meant for farmers is also not intended to be stored for long periods of time. The question is however, how much these higher temperatures and humidities affect seed viability over time.

Corn Temperature (°F)	**Corn Moisture Content (% Wet Basis)**						
	15	**17**	**19**	**21**	**23**	**25**	**30**
75	115*	37	16	9	6	5	3
70	154	49	22	12	8	6	4
65	206	66	29	16	11	8	5
60	275	88	39	22	14	10	6
55	414	133	58	32	21	14	8
50	621	199	88	48	30	21	12
45	931	299	131	72	45	32	18
40	1413	448	197	107	68	48	27
35	2126	671	295	161	102	72	41

Figure 7: Maize grain safe storage estimates. The table above shows the number of days of days of safe storage at set conditions. Adapted from Sadaka *et al.* 2016.

Surprisingly little literature exists to predict the effects of unfavourable storage conditions on seed viability over time (Sadaka, Atungulu, and Olatunde 2016).[6] Certified seed has a printed expiry date, which farmers are advised to avoid if expired, but can still lose viability within this time if poorly handled or stored. What is needed is to understand the extent of this risk to smallholders, where it might exist and how formal seed systems might prevent it.

There are no reports of the environmental conditions seed faces in Ugandan supply chains. Even these certified seed supply chains themselves are rarely described in detail. As an overview, there

[6] A key informant in a major European seed company even stated that they had never checked the effect of environmental conditions on seed longevity. Such a test was not seen as important as seed is sown shortly after purchase and low germination rates were not generally a problem reported by farmers. The informant did however suggest that this was the case for European-based farmers, and that climates elsewhere might have more impact where storage conditions are not controlled.

are several stages where seed spoilage could take place:

1. In seed production, prior to bagging for sale.
2. During logistics of seed delivery to agro-dealers.
3. During ago-dealer storage.
4. During farmer storage.

In theory, seed spoilage at point one above should be captured by the batch testing of government regulatory agents. Where spoilage is observed, the seed batch is not permitted for sale. This monitoring point would therefore suggest that spoilage is likely occurring in the stages afterwards. Since no studies have investigated this pipeline, we start at the next logical stage of seed logistics from seed companies to agro-dealers. Understanding how these systems operated, and where risks might be, adds clarity to the counterfeiting story playing out in Uganda.

5.1 Methodology

We sought to measure; the network of actors and behaviours in formal seed supply; the conditions seeds experience in formal seed supply and; how the resulting seed performed in the field. We therefore required a mixed methods approach, summarised in the table below:

Method	Approach	Type
Seed expert interview	Semi-structured interview	Qualitative
Seed expert focus group	Focus group discussion	Qualitative
Seed journey sensors	Environmental sensor	Quantitative
Germination tests	Lab-based test	Quantitative
Agro-dealer surveys	Surveys	Qualitative
Local farming practice	Semi-structured interviews	Qualitative
Farm field trials	Field trials	Quantitative

Table 2: Overview of data collection methods

The overall design was to:

1. Understand how the formal seed sector operates in Uganda for the provision of improved maize.
2. Learn the main seed delivery mechanisms for Ugandan certified seed.

3. Understand the inner workings of this logistics system from the perspective of both sellers and buyers.
4. Monitor environmental conditions in bags during transport from seed processing centres to agro-dealers.
5. Test germination levels of monitored seed immediately after transport.
6. Plant, grow and harvest monitored seeds in comparable conditions to those used by local Ugandan farmers. Record these results and check for correlation between performance and monitored conditions.

Using the above approach provides insight into the environmental stress levels in seed supply and the degree of impact this has during initial transportation.

This research was undertaken in collaboration with two of the top five largest seed companies in Uganda. Research took place prior to and during the 2021 Ugandan maize growing season. Starting with seed production in December and finishing with the maize harvest in late August.

This fieldwork coincided with COVID-19 lockdown restrictions, which prevented travel to Uganda from the UK. Field data was therefore collected remotely by enumerators working for The Field Lab Uganda, a research company based in Mbale, Eastern Uganda.

All companies and individuals involved in the research have been made anonymous. All interviews and surveys were voluntary, and respondents informed that the decision not to take part would remain private. Ethical clearance for the work was granted from both the Ethics Committee at the School of International Development (University of East Anglia), and the Ugandan Ethics board.

5.1.1 Interviews, focus group and surveys

Our investigations into potential seed spoilage required three groups of qualitative discussions with respondents. These are:

1. Seed expert interviews.
2. Seed expert focus group discussion.
3. Agro-dealer surveys.
4. Local farming practice interviews.

All interviews, focus groups and surveys were either conducted in English or in the local language, at the respondents preference. Interview and focus group findings were collected as written notes, and analysed using a thematic analysis approach.

Box 10: Secrecy in sales

Originally there was going to be a fourth group of interviews with seed company salesmen as they travelled seed supply routes. Company management approved these plans but salespeople were less receptive. Enumerators faced a frosty reception upon arriving to join the salespeople for the journeys. Upon investigation, it was discovered that these salespeople are in competition with both other companies and each other. Our respondents were suspected to be taking notes on their clients or sales strategies, regardless of whatever evidence we gave. Consequently, this respondent group was dropped, out of concern that responses might have not been honest or deliberately changed to protect their livelihoods.

5.1.1.1 Seed expert interviews

Seed expert interviews were conducted with seed company officials. The major Ugandan seed companies were invited to join the research through email contact details. Two followed up the invitation, offering members of their operation leads as respondents.

Further individuals outside of seed companies were purposively chosen for interviews based on their role in seed production and regulation, or as representatives for agricultural associations and groups. A snowball approach was employed from interviews to identify further individuals for interviews. A focus group discussion was also held with 14 seed system experts on the topic of risks to seed viability in Ugandan seed supply chains

Seed expert interviews sought to understand how seed processing, logistics and sales currently take place in Uganda. Respondents were also asked for their thoughts on counterfeiting and the potential for spoilage in seed systems

The full question list can be found in the appendix.

5.1.1.2 Seed expert focus group

A workshop was held with 19 key informants from across Ugandan and international seed experts. These included staff from across FAO, Ugandan agricultural offices, MAAIF, NGOs, Ugandan trade associations, breeders and universities. The topic was on the potential for spoilage in seed systems and how to prevent it. The workshop aimed to understand the context of the Ugandan formal seed sector, where risks to seed quality exist and how risks might be reduced to protect farmers.

5.1.1.3 Agro-dealer surveys

Surveys, semi-structured interviews and observations were conducted with agro-dealers from two districts; Busoga and Kapchorwa. These two districts were purposively chosen due to their comparative proximity to our monitored seed production hubs. Busoga is relatively close to the production centres whereas Kapchorwa is more distant. This comparative component was included to test for potential differences in agro-dealer composition, practices and mindset, over geographic space.

Agro-dealer surveys sought to understand: how dealers operate, seed acquisition and farmer behaviours. Along with this background information, the survey asked: how much seed agro-dealers purchase; the frequency they purchase from seed companies; their main customers; how many stores similar to theirs are close to them and; where, how and for how long they store certified seed. A final part of the survey was designed for the enumerator to complete based on their observation of the business premises and activities.

Agro-dealers were contacted through the assistance of seed company field promoters who have lists of every registered agro-dealer in an area. Thus, every agro-dealer in our chosen areas was systematically invited to the study. This total respondent number came to 71 agro-dealers: 42 in Busoga and 29 in Kapchorwa. The difference in number of dealers is partly due to the size difference of the two areas.

Field enumerators visited agro-dealers in person. During visits, the owner or staff of the agro-dealer was asked a series of survey questions, followed by a semi-structured interview. Enumerators had an observation checklist which was completed immediately after leaving the premises so as not to impose further time demands on the business. All of these documents can be found in the appendix of this report. Surveys and observations were analysed using STATA 17. Interview responses were coded for qualitative analysis. Coded terms were further analysed in STATA 17 to identify counts of how regularly certain responses were reported.

5.1.1.4 Local farming practice interviews

Part of this study examines the germination and yield performance of monitored certified seed in local farming conditions. These farming conditions were designed to be scientifically sound, whilst also being representative of the way that farmers grow maize seed. To achieve this, farmers were interviewed at the field site, to understand how they conduct maize planting, care and harvesting.

We sought to simulate the conditions that local farmers would use to grow seed in the field. To emulate these conditions, key informant interviews were conducted by field enumerators with smallholder farmers surrounding our field site to understand the methods of maize farming they use.

Enumerators conducted interviews with eight farmers purposively selected from two sub counties in Sironko district. Farmers were equally represented from both commercial and semi-subsistence farming to give a broader understanding of local farming practice. The commercial farmers were defined as those growing maize on two acres or more, and the semi-subsistence one acre or less. In addition to the farmers, an extension officer for the same areas was interviewed to add local recommended practices for maize cultivation. All participants were anonymously recorded. Semi-structured interviews were designed to gain understanding of local farming practices for maize farming.

5.1.2 Seed tracking

Companies transport seed in trucks which constitute a metallic box storage area with an inner plywood lining. Seeds are packaged in a range of sizes, from 2 kg bags upwards, which are bundled together in packs of around 50 kg. These larger bundles are placed in the transport area of the van in mixed piles with other farming goods.

We systematically tracked every vehicle that left the production centre following this selling method. This amounted to 31 deliveries between February and May. This number was originally expected to be around double this number but one of the seed company partners encountered accounting challenges that delayed their planned deliveries for the first growing season of 2021. Our time period was chosen based on when farmers purchase seed and prepare for the March-May rainy season. Staff driving the vehicle were aware of the tracked items on board but were informed that our experiments were not aimed at tracking drivers and could not be linked back to them.

These explanations were made to reduce the chance of Hawthorne Effects, where participants act differently when aware of being observed.

Three 2kg bags of maize seed were monitored per delivery journey. This size was chosen on account of it being the most commonly purchased size by smallholders. It also happens to be generally the smallest bag size seed companies offer. iButton remote sensors[7] were used to track temperature and humidity, combined with a date and time reading every 10 minutes. iButtons were added at the processing facility and the bags were sealed by the company using the same method used across all seed bags. The time was recorded when bags were sealed, when travel commenced and when a journey ended. One iButton was added per tracked bag. Three tracked bags travelled with each journey. These bags were bound in the same bundle containers as non-tracked bags. Data were routinely downloaded off each sensor after returning to the processing centre. Data analysis was conducted in STATA 17. Python was used for data visualisation, using the Matplotlib and Seaborn libraries.

5.1.3 Seed germination

Germination tests were conducted after seed shipment. These tests recorded the proportion of viable maize seeds in a bag. From a regulatory standpoint, germination rates should match the >90% seed companies aim for. Our tests occur after the first stage of the supply chain, taking place at the point at which seed has left the seed processing centres and has been delivered to the first agro-dealers and wholesalers in the supply chain.

The following protocol for approximating germination rates is adapted from (Pinto et al. 2012) and the methods used by the Ugandan seed companies to test the performance of their own seed.

Equipment:

- Bags of seed
- Large trays
- Lake sand
- Water

Protocol:

Two seed bags were randomly selected from the three that travelled on each monitored journey. These two were chosen by numbering the bags and then blindly pulling a number from a hat.

[7]Examples can be found here: https://www.ibuttonlink.com/collections/ibuttons

Seed was randomly selected from chosen bags through the following process: bags were opened and batches of 50 seeds blindly drawn from across the top, bottom, centre and sides of the bag. Four of these batches took place for each bag, totalling 200 seeds per bag and 500 seeds per journey. This made for a total of 15,500 seeds analysed.

The following steps were taken for each batch of selected seeds to initiate germination:

1. Lake sand[8] was placed in each container and water poured over until the sand was evenly damp.
2. Seeds were spread evenly over the surface of the damp sand.
3. Containers with seeds in were covered.
4. Containers were left at room temperature, away from direct sunlight. Sand in the containers was periodically checked to ensure it stayed damp. Where sand started to dry out, more water was added.
5. Seeds were checked after four days and a total count made of the number that had germinated. Seeds were covered again after counting.
6. Another count was made after 7 days (including the seeds that were counted previously).

Figure 8: Photo of seed germination tests.

[8]This is a type of soil that is used specially by Ugandan seed companies for germination purposes. It can be acquired commercially but ours was kindly provided by one of the seed companies.

5.1.4 Farm field trials

Field trials measured the performance of maize seed following the environmental conditions recorded in logistics. Performance tests included seed germination, seedling vigour and harvest metrics for seed from monitored journeys in formal system supply routes.

The hybrid maize variety Longe-5 was grown in the field. Our field trial emulated the conditions and practices of smallholder farmers locally to the field site. These practices were discerned through semi-structured key informant interviews.

Field site test plots were directly traceable back to recorded journeys and thus, the experienced environment conditions could be compared with metrics of plant development and harvest. Plant development in the field is affected by many factors but we sought to observe if differences in establishment and yields can be explained as a result of logistics conditions experienced prior to planting.

The field site was based in Sironko, Eastern Uganda. The total area amounted to an acre of land. The area was flat and no visible differences could be discerned between the fertilised and unfertilised areas. The field was in an agricultural area and surrounded by other active smallholders.

5.1.4.1 Farming method

Farming methods identified through local farmer interviews were incorporated into our study design. Based on these findings, our farming approach included the following features.

The majority of farmers local to our area lack irrigation and depend on the rains to water crops. We planted at the same time as local farmers and relied on the rains to maintain a sufficient soil moisture content for growth. Plots were planted by hand. Inorganic fertiliser is sparingly used in our sample area. To reflect this, our study area was split into two fertiliser areas; one side using inorganic fertilisers and the other without. This allowed our field site to be representative for farmers that do use fertilisers, and those who do not.

In accordance with local practice, the first stage of land preparation involved slashing and clearing overgrown grass so that the land can be ploughed. Once cleared, the farm was ploughed twice by tractors, with two weeks between the first and the second ploughing. Germination rates were measured at seven days and establishment counted at 21 days. Weeding took place at two weeks and six weeks after planting. Pesticides were also sprayed at this second weeding time. Spraying products used matched those of surrounding farmers, depending on the pest pressures of the season. One seed was planted per hole, which differed from farmer practice of planting two to three per hole. Cobs were counted after approximately 125-130 days and recorded. Cobs were then harvested and a mean weight taken.

One notable exception in our study that differed from local farming practice was the planting of seed in a grid formation (described in the figure below). This formation was unavoidable due to our requirement to segregate blocks of seed from each journey. However, the spacing between maize plants within those plots was based upon local maize planting practice.[9]

Two i-button environment sensors were activated at the field site at the start of the growing period. One was planted 5cm into the soil between the non-fertilised and fertilised areas. This soil sensor was set to take a temperature and humidity recording every 90 minutes. Another sensor was placed on a platform above the soil level to capture the ambient conditions every 90 minutes.

5.1.4.2 Seed and plot selection

Seed selected for growing was randomised at both the bag and seed level.

Randomisation took place through the following process:

1. **Randomly selecting a bag:** Conditions in three seed bags were recorded for each journey. These bags were numbered from one to three and one bag selected through blindly drawing a number from a sack. Seed was selected from this bag as described below.
2. **Randomly selecting seed:** Seeds were drawn blindly from the bag and placed into lots of 35 seed. This process was conducted eight times in total, resulting in eight separate containers of 35 seed. The first packets were randomly allocated to plots on the unfertilised side of the field, the last four in plots on the fertilised side.
3. **Randomly selecting a plot:** Our field site had 56 plots on both the fertilised and unfertilised sides of the field. This took place through allocating a seed lot with a number that was blindly drawn from a hat containing numbers from 1-56. Once a number is taken, it is not replaced. This took place for both the unfertilised and fertilised sides respectively.

The above selection process was made just prior to planting. Seed packets were marked with

[9] This spacing has been informed through key informant interviews with farmers and farm extension workers surrounding our field site. During these interviews we found that smallholder and farm extension advice for planting spacing was very similar.

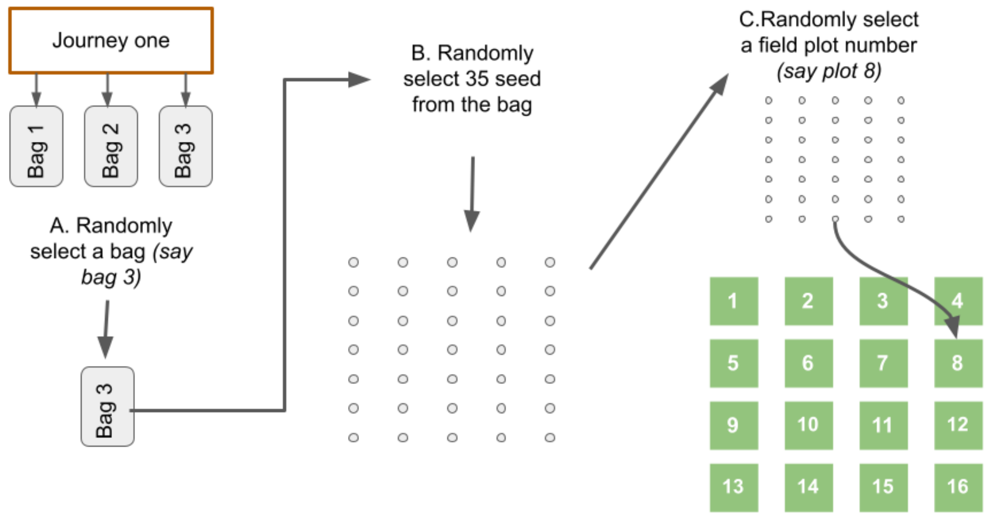

Figure 9: Selecting seed to grow.

a number and taken to their respective grid number for the field staff to plant. The field staff planting the seeds were blind to the journey the seed originally travelled on.

Grids of 12 feet with a five foot border between plots were marked on the soil. Each planted plot of 35 seeds required 144 square feet of space. Seeds were separated by two feet and rows were separated by three feet. Plots were separated from each other by a five foot border. Overall this required a grid of 112 plots. This gives a total number of seeds planted as 3,920 (one per hole) over a combined area of 29,358 square feet. An eight foot gap separated the non-fertilised and fertiliser areas.

5.1.4.3 Sowing, growing and harvest

Seeds from each journey were planted on the same day, through the hired help of local farmers. Seeds were planted in 5 cm holes in a 12 foot by 12 foot square plot. Planted seeds had 2 feet between each other and 3 feet between rows. For the fertilised field side, a bottle cap of DAP fertiliser was applied to each hole, as is practised by farmers locally. One seed was added per hole and covered with soil afterwards.

Measurements were taken throughout the growing season. Following local farmer and extension practice, seed germination was measured seven days after planting. This took place through

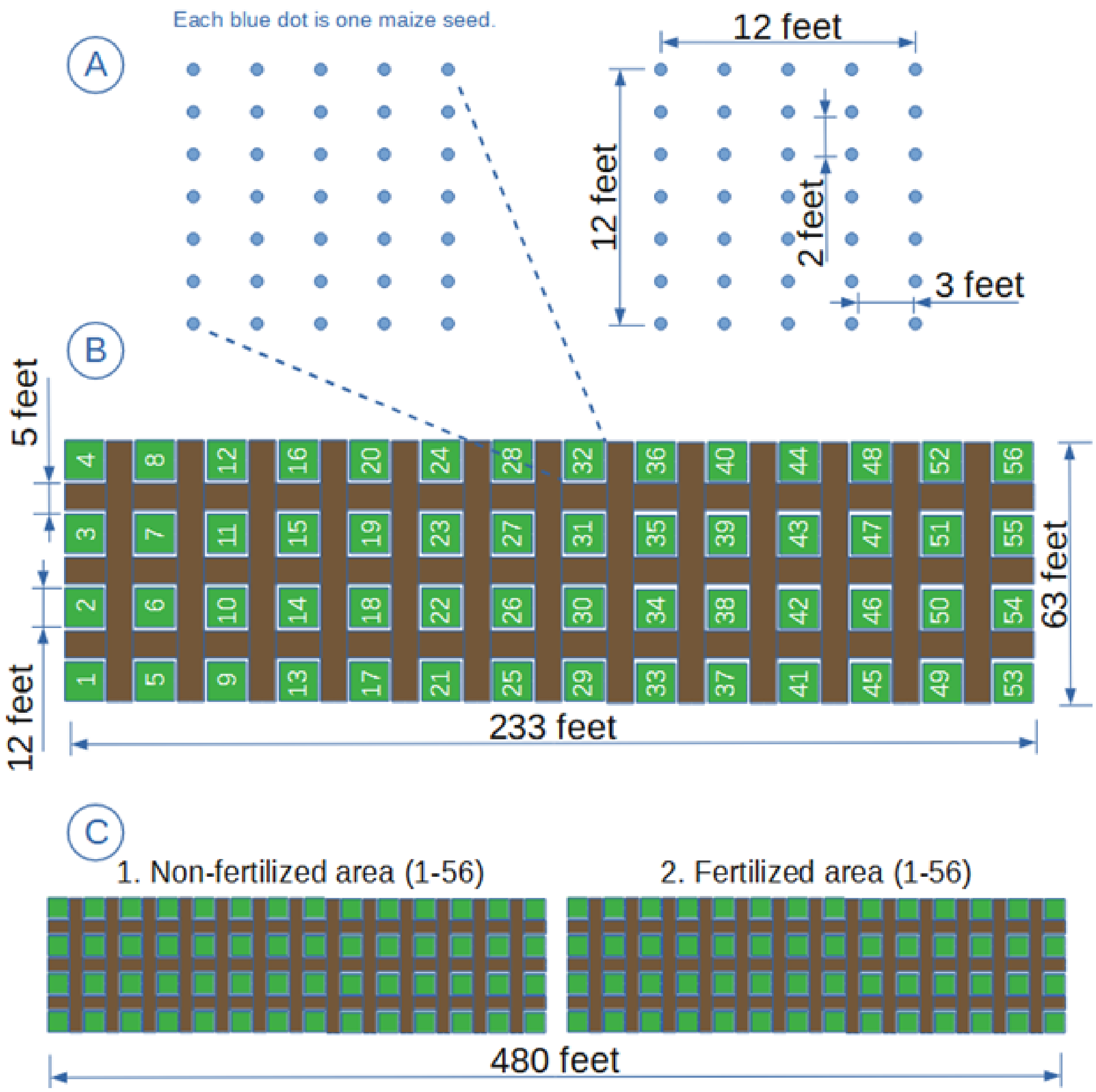

Figure 10: Farm plot arrangement.

enumerators recording how many seeds within the plots have broken through the soil. This will be recorded as a number out of the total of 35.

After 21 days, seed establishment was measured as the percentage of seed that has survived and produced three leaves. This three leaf check is used by farmers locally to confirm that the seedling has established itself sufficiently. After approximately 125 days, the number of cobs were counted per plant, per plot. Upon harvest, the cob masses were recorded. A mean cob weight was established from this for each journey. Instances of flooding, pest or disease damage were noted.

All crop measurements were recorded in Excel and analysed in STATA 17. Python was used for data visualisation, using the Matplotlib and Seaborn libraries.

5.2 Results

Results are organised into the following sections:

1. **Overview of the formal seed supply:** where I share findings from interviews with key informants across seed companies and the focus group.
2. **Agro-dealers:** reporting the findings of the agro-dealer interviews, surveys and observations.
3. **Logistics conditions and seed germination:** the temperature and humidity conditions experienced by seed in the first stage of the supply chain.
4. **Farming set up and field trials:** This is split into two sections. The first section that shares findings on local farming practices from interviews with farmers. The second section reports findings from the field trials.

5.2.1 Overview of Ugandan formal seed supply

The formal seed system has official standards which are enforced by regulators at different stages of the production process. These regulators are usually MAAIF agents. Formal inspections must be conducted before a company can bring a product to the market. These tests check purity, seed quality and germination rates. If the variety passes the test, an inspection certificate is issued, permitting the certification and sale of the variety. This process is called the 'seed quality assurance system'. In 2013, an agreement was made between MAAIF and the private seed sector to the mechanism of labelling seed. Consequently, a blue certification label is now used to accredit high quality seed. Proponents argue that this system ensures the quality of formal seed products over informal options. Seed companies are trying to improve on quality standards.

The following order of operations are conducted as part of formal seed systems:

1. Seed production
2. Seed processing
3. Marketing and distribution.

Each of the processes is described in the sections below.

5.2.1.1 Seed production

Seed production happens at three levels, across a range of actor types. First, breeder seed is produced by the research station in smaller quantities, after which inbreeding is conducted, or parent seed production for hybrid varieties. For hybrid varieties, the parents are crossed to create the lines for multiplication. After the hybrid has been produced, the seed is multiplied in the fields.

Ugandan seed is mainly produced by contract farmers working for seed companies. These contract workers tend to be larger commercial farmers who are able to produce seed in larger quantities. These contract farmers are located widely across the country.[10] They are provided with the seed companies need multiplying, and the resulting harvest collected for company use. Companies may send officials to check how the seed is growing through the year and prior to harvest. One risk to seed quality at this stage is that farmers may add foreign elements (e.g. grain, stones, etc.) to bulk up the order to meet their contracts.

Not all companies rely on contract farmers. While one of the companies relied on contract farmers, the other conducted this multiplication stage themselves through their own field staff. Whichever approach is taken, the resulting seed must be cleared in the field by a regulator from MAAIF before it can be harvested. These checks are mainly to confirm the absence of pests or diseases from the batch. A seed company official will check the seed prior to delivery. This second test is mainly to check the seed moisture levels, which for maize should be about 24% at the field gate. Once harvested, the seed is transported to the company processing centres.

During the transportation of the unprocessed seed from the production point to the processing

[10] In this case, Mubende, Kayunga, Nwoya, Soroti, Lira and Serere.

point, there is potential for mishandling, or environmental conditions that affect the viability of the seed. Seed viability can be affected during the transportation process from the production, to the processing point. Thus further checks are made after processing.

5.2.1.2 Seed processing

The moisture content of maize arriving from the fields will be around 24%, and has to be dried before it can be shelled. This drying is conducted over two steps by processing staff, using specialist machinery. First the cobs are placed in bins with hot air ventilation until dry enough for shelling. Next, continuous drying is used to reduce seed moisture levels to around 13%. The company will then store the resulting seed in this state until they believe there is suitable demand. Once there is demand, the next stages of seed processing occur through the following stages:

1. **Cleaning:** Cleaning involves the mechanical removal of any chaff, broken seed, and stones with the product from harvesting and drying.
2. **Grading:** After cleaning, seed is graded by weight, shape, and size to provide farmers with a more uniform product.
3. **Dressing, treatment and conditioning:** Next, the seed is dressed and treated. During this stage, insecticides and fungicides are applied to protect the seed. This treatment protects the seed against soil-borne diseases and insects. The product is then dyed a bright colour to make users aware of the applied chemicals.
4. **Packaging:** Finally, the seed is packaged and made ready for delivery. Package sizes can vary but 2kg bags are generally the smallest size produced. Previously, some seed companies sold in larger sizes, such as 5kg, but these have been made smaller to make seed more accessible to smallholders. These smaller sizes also indirectly aid authenticity, as larger bags were more likely to be opened and split up for sale, increasing the potential for adulterated products. Once sealed in the packaging, the guidance is that bags should not be opened until planting, to protect the seeds. The packaging itself contains information about the variety, the certification stamp and other planting information. This information is displayed in written and pictorial form, to cater for illiterate consumers. Packaging material varies between companies and products. Some are transparent while others are more opaque. An expiry date is printed on certified seed, after which time the seed is considered not fit for sale.

Figure 11: An example of a certified maize bag. Neither this bag nor this company was involved in the experiment.

Seed processing, particularly the drying stage, is critical for seed viability. Even when the post-drying processes are well handled, incorrectly dried seed raises the chance of poor seed germination and under-performance. The challenge is that treated seed can obscure quality checks, appearing flawless despite a defective product within. Such risks are reduced by the regulatory testing by MAAIF officials.

Clearly, capacity demands mean that it would be impossible to check all seed shipments. Instead, quality control tests are conducted on random batches of processed seed, checking criteria such as germination, physical condition and seed moisture content. Should the tested seed meet the minimum quality standards, it is cleared for sale with a certificate. This confirmation permits the seed to be sold as certified seed, marked by the blue stamp on seed packaging. Key informants felt that certification services are expertly done, but there is a major capacity shortfall in regulatory staff. Indeed, the certification label is therefore not a complete assurance of good quality seed.

This echoes other reports that approximately four inspection agents must cover 25 national level companies, and over 900 seed growers (Barriga and Fiala 2020).

Further inspection into the regulation situation brings another challenge to light: regulation stops after the seed leaves the factory. Beyond that point, seed viability is assumed constant until an expiry date of a year is met. Some key informants however suggested that regulators are looking into how to track seed quality in the post-certification stages. This later regulation has not been officially announced at the time of writing.

5.2.1.3 Seed marketing and distribution channels

Companies have several channels through which they sell, or market their seed. The main ones include agro-dealers, wholesalers, government agents and walk-in customers.

Agro-dealers and wholesalers generally buy seed through direct communication with the company or through travelling company sales agents. These groups tend to be the main customers for seed company products. We explore more of these purchase arrangements in the next section.

The government sometimes buys seed to distribute to lower local governments through programmes, like Operation Wealth Creation or NAADS. These government arrangements can be attractive to seed companies as they can be large and offer more guaranteed sale of seed than selling to other actors on supply chains. These guaranteed sales come however at a cost. Key informants shared how NAADS programmes buy hybrid seed at 4000 UGX per kilogram. This is a challenge as it barely meets the minimum production costs for hybrid seed production, without including marketing, logistics and profit. Despite this low offer, the government is estimated to buy around 30% of the formal sector seed, restricting the business that seed companies can achieve. The system operates through the government advertising contracts for seed, and seed companies submit tenders in response. Successful companies are awarded the contract to supply seed to the government programmes. A tangential point here is that these seed aid programmes can be detrimental to local seed sellers (see box 11 below).

Box 11: Seed aid knock-on effects

A knock-on effect of government seed aid programmes is that farmers abandon buying seed from the established distribution channels. This is particularly problematic for agro-dealers who may persist on annual sales. Missing a season of sales can therefore risk some businesses to fail. Restarting these businesses is also difficult, both on account of the start up costs but also the threat of aid programmes impacting sales again. Thus, while seed aid can be a vital part of disaster recovery, it can remove the same seed supply systems farmers rely upon once the aid finishes. This phenomenon was mentioned during seed discussions, and has been reported widely in the literature (Sperling, Cooper, and Remington 2008; Sperling and McGuire 2012).

A final, but smaller client group, are walk-customers who visit the companies directly. One company official mentioned that large-scale farmers sometimes prefer this option as there are no upper restrictions on the quantity of seed purchased directly from the factory. Companies felt some farmers also prefer this approach as they are more confident of the seed quality. These claims were made giving the freshness of the seed from processing, the direct interaction with the seed producer and the omission of stages and actors in supply chains that could influence seed quality.

Where seed is delivered along supply chains, there are three main types of Ugandan seed delivery:

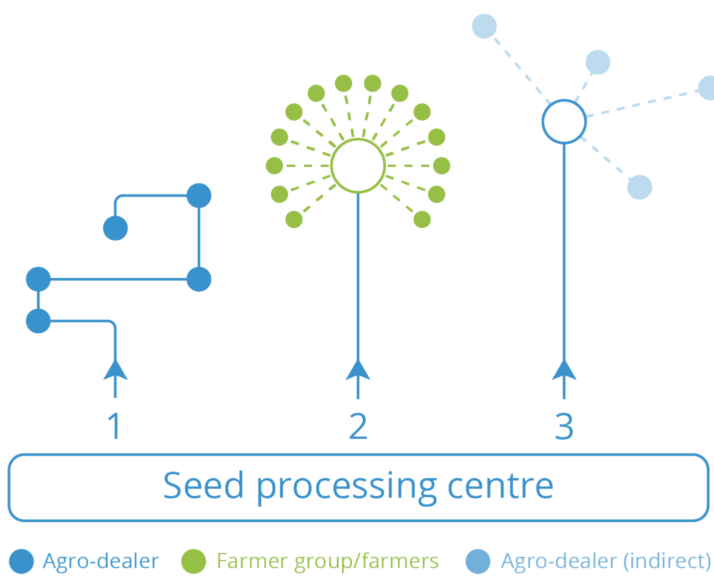

Figure 12: Formal seed delivery methods.

1. **Route sells:** These tend to be the most common methods by which companies sell seed. Route sells operate through company trucks driving along routes or 'redistribution channels', delivering seed to agro-dealers across districts, until their cargo of seed runs

out. These routes may be uncertain beforehand, differing between travelling salespeople and how far they travel along the route before the seed cargo is completely sold. Some companies plan the routes based on pre-made orders, while others sell on an *ad hoc* basis as they go. Company salespeople influence routes through their own marketing behaviour and relationships with shops. These same informal relationships and marketing strategies between different salespeople, causing some to be more lucrative. Secrecy around marketing strategies was suspected to partially explain why enumerators were not wanted on delivery shipments, as per the original plan.

2. **Bulk orders:** Seed companies receive larger orders (eg. 2000 metric tonnes) online from farmers groups. When this happens, the seed company sends a truck directly to a central local point. After this point, the seed is distributed from the central point to farmers and the company has no further involvement. A similar arrangement occurs with Operation Wealth Creation, where the army takes on the role of distributing seed. In either case, the central point might be somewhere like a sub-county office. Seed is either then shared with farmers from that point, or individuals travel to the county office.
3. **Regional/district product placement orders:** A similar model to the previous approach to deliver large aggregates of agro-dealer orders. Here the company sends a given amount of seed to a central office, who then sorts the orders to agro-dealers. One informant felt that this process is important as, while the delivery from the seed company is on time, the seed might not all leave this central point and remain in the destination storage conditions for longer periods of time. It is largely unknown what the quality of this storage is like, and the length of time the seed stays at this point. Both factors could impact on the risk of seed spoilage. One company expected this model to become more common in the future as a method by which to distribute seed across the country. Currently however, this form of delivery remains less common than route sells.

5.2.1.4 Seed spoilage

Company representatives felt there are two situations that can result poor quality certified seed:

1. **Poor demand and market forecasting:** Poor demand and market forecasting, or seasonal set-backs in production, mean that surplus seed is often left over at the end of the season. For example, a company might meet the entirety of a regional product placement order, but find that only half of that seed reaches farmers. As mentioned earlier, the storage conditions of this seed is unknown. It is also unknown what happens to the remaining seed.

2. **Unscrupulous players in the supply chain:** Companies felt that there are individuals who sell counterfeit products to farmers. These counterfeits are dyed grain, bound in company packaging. Companies rationalised that counterfeiters do this in the knowledge that farmers cannot differentiate grain from seed, and trust the products sold by agro-dealers. One company based these claims on their own investigation they had run, where a distributor was suspected to have sold ten times the amount of their seed than their records state had been supplied.

Seed officials felt that environmental conditions in seed channels could influence seed quality and viability. These concerns were however made without empirical evidence of conditions, nor their effect.

5.2.2 Findings from agro-dealers surveys

We surveyed 71 agro-dealers across the two districts, 42 in Busoga and 29 Kapchorwa. Nearly all agro-dealers in both locations were situated in towns and along main roads. This effect was particularly apparent in Kapchorwa, where agro-dealers were almost entirely concentrated along a single road.

5.2.2.1 Method of operations

Agro-dealers across our sample tend to be small shops, staffed by one or two people, with room for around five customers. Nearly all respondents identified risks to seed health and methods they practise to prolong seed life. These methods included, keeping temperatures cool, keeping seed away from water, not stacking bags too greatly and keeping seed away from direct sunlight. This uniformity of practice is unsurprising given that a number spoke of agro-dealer training events they attend. As a result of advice from training events, seed is often stored on palettes, to keep it off mud or concrete floors. With regard to where farmers store seed on the premises, 63% store seed on the shop floor, 55% in a back room and only 28% report having a special storage space. These various rooms tend to be protected from the sunlight or dampness but observations from enumerators added that many have open doors and windows.

Generally, seed care methods were consistent across all agro-dealers. One slight difference in practice between our districts is that in Kapchorwa, agro-dealers open seed bags and dry them in the sun. They do this to ensure the seed is dry enough for storing. This practice goes against the conventional regulatory guidance to keep seed bags sealed to protect the seed. Agro-dealers

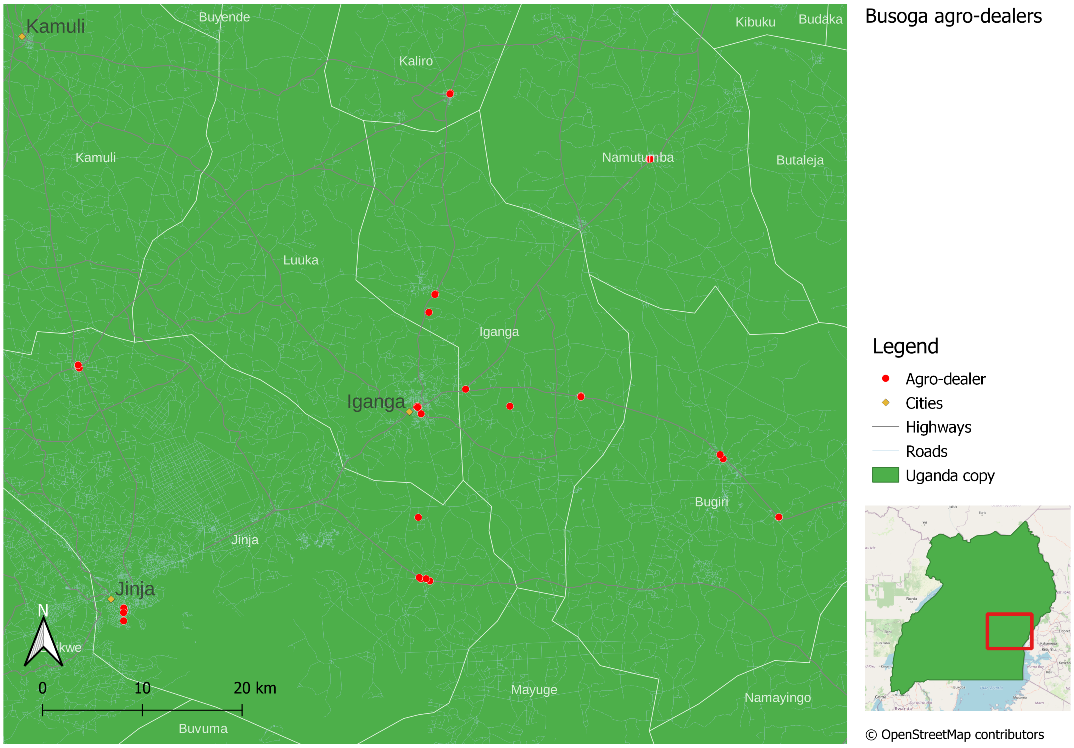

Figure 13: Agro-dealers in Busoga.

however felt that drying the seed in this way reduced the chance of moisture damage to seed viability. An additional consideration is that anti-counterfeiting measures suggest avoiding seed bags that have been opened on account of adulteration concerns. Despite this, enumerators observed that seed was sold in open bags at 31% of visits. Another possible explanation for this was that open bags allow for seed to be sold in smaller denominations, which could be more accessible to farmers who wish to experiment with a variety.

Agro-dealers across our two districts show homogeneity in their target customers and stocked products. They are well aware of this homogeneity, with 45% of our sample reporting that there are more than 11 similar shops to them in their local area. Notably with regard to products, our enumerators observed around half the sample selling local crop varieties and saved seed in addition to certified seed.

All of the agro-dealers sell to smallholder farmers and 86% also sell to large-scale farmers. Shop workers differentiated farmers into these groups by two approximations. The first is the amount

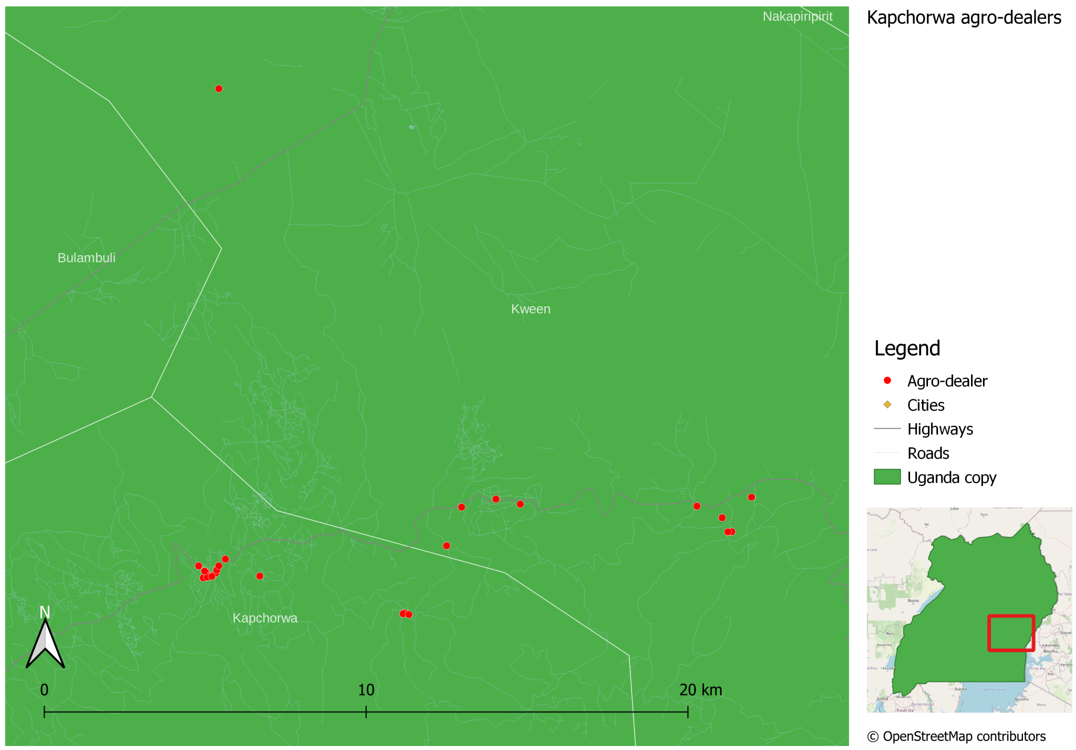

Figure 14: Agro-dealers in Kapchorwa.

of seed that they purchase, with smallholders preferring smaller quantities of seeds and inputs. Secondly, agro-dealers defined large-scale farmers as focusing on commercial incentives, while smallholders are assumed to be mainly farming for personal subsistence. This dichotomy is likely hazy at the borders but was one that agro-dealers immediately used to distinguish farmers.

Agro-dealers in our study see smallholders as their main clientele. This is worth comparing with farmers, who report that excessive distance from the farm, high price of goods and relatively large sizes of purchase options are all reasons why agro-dealers are a lesser source of seed and instead appear orientated to wealthier, large-scale farmers. In addition to farmers, agro-dealers sell to: other agro-dealers, wholesalers, mobile traders, and general stores (46.48%, 22.54%, 19.72% and 18.31%, respectively). The amount of agro-dealers reporting to sell to each other as this must offer narrow potential profit margins to the buyer who must sell the resulting seed on. This must be especially so given the level of local competitors and the repeated mention that farmers favour the cheapest option. The finding of agro-dealers selling to wholesalers is also surprising given that agro-dealers generally purchase only the amount of seed that they believe

Who do agro-dealers sell to?	Percentage
Smallholders	100
Large-scale farmers	85.92
Agro-dealers	46.48
Wholesalers	22.54
Mobile traders	19.72
General stores	18.31

Table 3: Who agro-dealers report to sell to

that they will sell. Thus, they are unlikely to have the amounts required to stock wholesalers, who generally deal in larger quantities.

Product	Percentage selling
Hybrid seed	100
Pesticides	100
Fertiliser	95.7
Farming tools	85.92
Local crop varieties	54.93
Food	2.82
Non-farm good	1.41

Table 4: What agro-dealers report to sell

An unsurprising finding is that all agro-dealers sell hybrid seed and pesticides, and nearly all sell fertiliser and farming tools. These are the goods that agro-dealers were designed to sell, and these numbers demonstrate that there is little variation across agro-dealers in this design. What is surprising however is that around half the sample sells local crop varieties. The role of agro-dealers is to sell improved varieties that, in theory, should outperform local varieties. The fact that half the sample are selling local varieties demonstrates that there is still demand for these products alongside the improved alternatives.

5.2.2.2 Seed supply and demand

Agro-dealers purchase seed from an array of companies, with 61.97% of our sample ordering from more than six different companies. 64.79% of businesses report to choose seed companies based on farmer suggestions. Only 18.31% of our sample mentioned quality as a driver for choosing a company. The same percentage reported purchasing mainly on which company was the cheapest, arguing that farmers are most likely to buy the cheapest products. These findings suggest that farmers have quite an influence on which seed companies agro dealers stock. While agro-dealers ultimately have the choice of what they stock, only the minority appear to be stocking products based on their own perception of seed company quality or accessibility.

Agro-dealers mainly acquire seed through telephone calls. They either call the seed companies to arrange a delivery (61.97%), or may be called themselves by the seed company (52.11%). These calls might be on the day of the delivery (43.66%) or agro-dealers might simply buy seed when a truck arrives (46.48%). Despite phones being central to purchasing seed, this appears to be limited to calls, with only 2.82% reporting to use WhatsApp for communication. Similarly, only 2.82% use emails to arrange seed deliveries and none of the agro-dealers in our survey arrange seed deliveries online.

Agro-dealers choose which varieties to buy based on previous demand and what farmers say they prefer (78.87% and 70.42%, respectively). This was corroborated in interviews where 91.55% of agro-dealers cite farmer suggestions and purchase behaviour as the main drivers for what crop varieties they stock. Combined, these factors suggest that agro-dealers appear to stock their shops based on demand-side pull effects rather than supply-side push effects. For example, we found no businesses who report stocking varieties based on company guidance. However agro-dealers do find out about new varieties through a number of company driven initiatives (see table below). This demonstrates a subtle difference in how agro-dealers obtain information about new varieties and what they make their stocking decisions based upon. This could suggest a reason why Ugandan agro-dealers are still predominantly selling varieties of maize that have been on the market since 2010 despite likely breeding developments in that time.[11] The exception to this is when farmers suddenly shift demand to new varieties in response to local demonstration activities. A challenge here is that remote agro-dealers generally stock lower amounts of these newer seeds, causing them to struggle to fulfil the unexpected demand shift.

The majority of agro-dealers believe that the market for certified seed is increasing (80%).

[11] Such older varieties include Longe 5 and Longe 10.

Method	Percentage reporting
Radio/talk shows	50.70
Advertisements	30.99
From the company directly	30.99
Though field promoters	25.35
Agro-dealer/farmer training	23.94
From posters	18.31
From farmers	18.31
Demonstration events	16.90
Other agro-dealers	11.27
Social media	2.82

Table 5: How agro-dealers discover new varieties.

This demand increase was justified due to greater yields and climate resilience improvements certified varieties offer over local varieties. 28% also reported that improved varieties have shorter maturation than local varieties, allowing farmers to yield harvests earlier. These three topics are likely closely related to one another. For example, better resilience raises the chance of higher yields in adverse conditions. Similarly, farmers relying on rain-fed agriculture might experience better yields from early maturation as they require fewer weeks of favourable weather. Of those who felt demand is not changing or is decreasing, 70% attributed this to the high prices of improved varieties. Only 10% felt counterfeiting was a reason for the sector to not be growing. One caveat to consider is that agro-dealers could be more inclined to report that business is growing. Constructing this image might make them appear successful and encourage more confidence in their products. Thus, these reports are insightful but should be compared carefully with the reports of other producers and seed customers.

The majority of our agro-dealer sample start selling seed in February and March and consider the season as closing around April and May. These estimates coincide with the deliveries we tracked which range from late February to mid May. It is however worth noting that these were not the first, nor final, deliveries the seed company conducted. It seems likely that deliveries after this time window are less likely to be purchased, as they have missed the season.

One local narrative is that seed companies are often late to get seed to the agro-dealers in time for the farmers to purchase and plant. Similarly our field trials were unable to include seed from

Month	Seed buying starts	Seed buying closes
February	24.29%	1.43%
March	60.00%	18.57%
April	15.72%	31.43%
May	0%	41.43%
June	0%	4.29%
July	0%	2.86%

Table 6: When agro-dealers report the seed buying season starts and finishes

all of the journeys we followed as the farm manager refused to delay planting any longer out of concern that we might miss the season. Many farmers around us planted earlier than we did. It therefore seems likely that seed does reach agro-dealers at a time when most farmers have already planted. It is not clear what happens to seed left over from the first season.

Agro-dealers in our survey estimate that around 9% of their seed is left over between seasons. Most claim that they only buy what they know they can sell. This is especially so as seed has an expiry date which disincentivises agro-dealers from buying more than can be sold. Our agro-dealers stated almost unanimously that seed left over from the first season is stored for no longer than two months. This specific time however could be for a number of reasons and not necessarily a set shelf life that is adhered to. Firstly, the "two months" could refer to the time between end and start of growing periods around the two Ugandan rainy seasons.[12] Here, perhaps it is assumed that the seed will be stored in the interim period and sold during the next month. Alternatively, some agro-dealers mentioned that seed companies will collect unused seed and return it to the company. We heard no mention of this practice from seed companies.

Overall, 57% of our sample believe that there are risks to seed health in delivery. However, this belief varied with the two districts. In Busoga 67% of respondents believed there to be risks in transport chains. In Kapchorwa, 41% of respondents shared this view. Of those who believe that there are seed quality risks in supply, 50% think these stem from temperature fluctuations in transport. Mixing of seed at the processing centres (either accidental or deliberately) and storage conditions were also suggested to bring risks to seed quality (20% each). Despite the view of agro-dealers here, experts at the focus group discussion mentioned push-back from private actors to regulate seed in supply chains for quality, despite pressure from the government and

[12]Approximately March-May and September to December in Eastern Uganda.

policy. Instead, there is a feeling from the private sector that they are limited in their capacity to measure seed spoilage in the system. This aligned with a general feeling from key informants of a lack of regulatory capacity and equipment to monitor throughout the supply chain.

Risk	Percentage reporting
Temperature in delivery vans	50%
Mixing of seed	20%
Prolonged storage	20%
Processing problems	17%
Torn packaging from over packing	10%
Seed not dried before transport	5%
Weight on seed in delivery	2.5%

Table 7: Where agro-dealers believe risks exist to seed viability

Ultimately, the concern with these risks in supply is damaged seed which fails to grow. There was geographic split in responses in how often agro-dealers hear reports from farmers of seed not growing. Agro-dealers in Busoga appear to hear more frequent reports of seed not growing while those in Kapchorwa seem to rarely or never have such reports. A point to recall here is that agro-dealers in Kapchorwa regularly open seed bags to dry to contents, while those in Busoga keep bags sealed, in accordance with industry advice. It could therefore be that the practice of drying seed could result in fewer cases of seed failing to germinate. This might however be a coincidence and so requires further study.

Of those businesses that report farmers complaining, 70% believe that it is due to farmer practice errors. Poor quality seed is the next highest suggested reason but quality depreciation here might be attributed to factors after seed production (such as degradation in supply systems or farmers' stores). Despite other reports of widespread counterfeiting in Ugandan seed systems, this was rarely suggested as a reason for seed failing to grow.

5.2.2.3 Counterfeiting

Reports of counterfeiting were opposed across our two sites. 98% of agro-dealers in Busoga believe that counterfeiting is a problem while 86% in Kapchorwa believe it isn't. These patterns between locations correlate with agro-dealers reporting failing seed. There does therefore seem to be a link between local failing seed and suspicion of counterfeiting. Of those agro-dealers

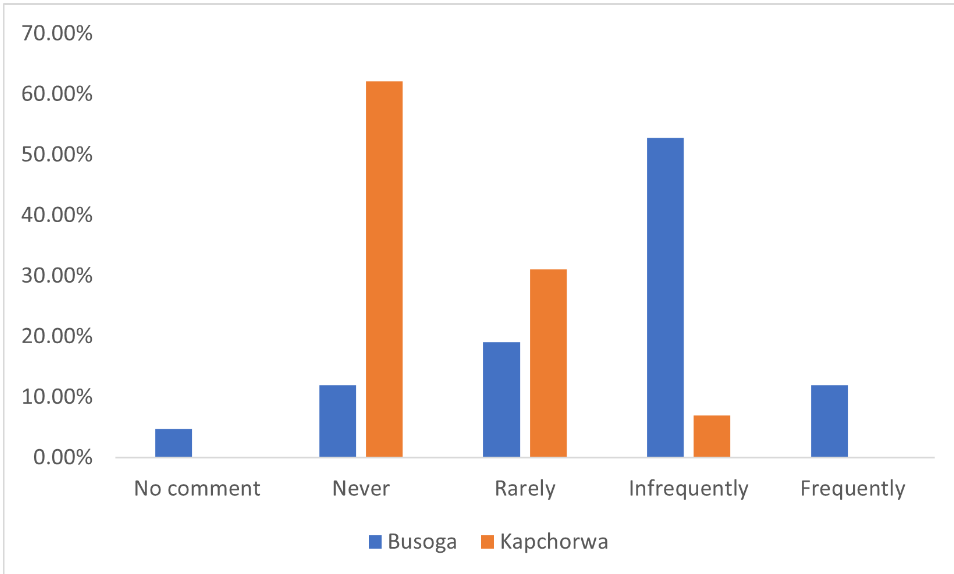

Figure 15: Farmers reporting seed not growing.

who state that counterfeit seed is an issue: 42% believe it stems from seed companies; 38% that the source is businessmen; only 2% believe agro-dealers are involved and; 18% state that they are unsure where the problem comes from. Interview respondents repeatedly mentioned that fake seed manifests through collusion between seed companies and businessmen; although they added different weighting to whom they felt were the source of the challenge. This uncertainty continued with regard to the form counterfeiting takes. Only around half of those reporting counterfeiting offered an idea of how it might come to be and there was little general consensus (see table below). Many simply did not know.

This lack of consensus touches on a deeper issue of what counterfeiting actually is. The word "counterfeit" seems to be defined broadly by our sample. In the regulatory sense, counterfeit seed is when a specific variety is sold to a farmer but the contents of the sale are deliberately mixed or replaced with other varieties or inorganic matter.[13] Critically, counterfeiting in this sense is about a replacement of genetic purity over the overall product. For agro-dealers and farmers however, the term "counterfeit" was used more broadly to include sale of damaged or expired seed. Thus, it's worth noting that counterfeit seed appears to be understood locally as fake *and* poor quality seed. Seed quality here refers to the physical and phytosanitary status of the seed. In a regulatory sense, the indicator of counterfeit seed would be genetic variation but

[13]For example, stones being added to bags.

Reason	Percent reporting
Shortfalls in farmers' knowledge or practice	69.57
Poor quality seed	34.78
Bad weather	15.22
Poor storage	13.04
Counterfeit seeds	10.87
Seed planted too deep	10.87
Company didn't dry seeds	8.70
Pest and/or disease pressures	2.17

Table 8: Reasons given by agro-dealers of why farmer seed might not grow.

Reason	Percent reporting
Created during factory processing	15.56%
During seed treatment	11.11%
Struggle to meet demand	11.11%
Selling expired seed	6.67%
Through seed mixing	4.44%
Poor quality seed	2.22%

Table 9: Reasons given by agro-dealers of how/why counterfeit seed occurs.

in these local terms, the indicators are more general signs such as wrong variety growing, seed failing to germinate, or poor yields. Therefore an individual knowingly selling expired seed, but genetically accurate to the description, is still attempting to sell a counterfeit product. These understandings of 'counterfeit' seed are important as they show a more general use of the word that does not always align with interventions to prevent counterfeiting. The challenge here is that ignoring this potential communication oversight risks the design of interventions that fail to address the problem. For instance, the Ugandan government has invested in 'coin scratch' labels on bags to confirm a genuine product for farmers, but these labels will make difference to seed viability loss due to poor storage conditions (Mennel et al 2014). These results therefore demonstrate the importance of ensuring clarity in what stakeholders understand as counterfeit for seed quality challenges and solutions.

Agro-dealers in our interview seemed to be suspicious of activities that the seed companies have insider knowledge of. For example, agro-dealers felt that the specialist knowledge companies have of processing or treating seed provide them with an opportunity to take advantage of other actors. The reasons why they rationalised this on behalf of the companies was surprisingly empathetic. While businessmen were broadly accepted to be profit driven, seed companies were suggested to practise counterfeiting in a desperate attempt to keep up with demand. There was one practice in particular that was mentioned by respondents as a potential opportunity for companies to sell expired seed. Agro-dealers are well aware of seed expiry dates. Many of them claim to keep little seed at the season's end and reported that they can give seed back to the companies if they haven't sold it. Some wondered what happens to this seed and if it might be mixed back in with the next stock, or sold by corrupt company members as high-quality seed. During our travels with seed companies, we did not hear about this practice of collecting unsold seed. Although not captured as part of this research, further study could confirm if this seed is returned, and what happens to it.

Many agro-dealers reported that counterfeiting is not a problem in Uganda; especially in Kapchorwa. Instead 50% stated that they never hear reports of counterfeiting. The next most commonly reported reason why counterfeiting isn't an issue (12%) is that buying directly from the company ensures purchase of genuine seed. This point seemed to overlap with another, that seed companies would not run the reputational risk of being caught selling counterfeit products. This response suggests that some agro-dealers expect counterfeiting to stem from the points between them and the company. It also suggests that some agro-dealers feel the trusting relationship they share with the company prevents opportunistic behaviour, as they would be readily able to identify fraudulent sources. This reputational risk component seems likely considering the rise of competition. The Uganda private seed sector has dramatically grown from three companies in 2000 to approximately 23 as of 2023. As mentioned earlier, agro-dealers purchase from many seed companies. Should they be able to identify one company as selling fake seed, they can change to another. The only caveat to this is that companies bid to obtain a specific variety (e.g. Longe-5) and agro-dealers might be reluctant to drop companies that stock the specific varieties farmers request. This is particularly likely given the earlier mention that it is farmers' varietal requests that are most likely to influence agro-dealer stocking.

Agro-dealers across Busoga and Kapchorwa show a marked difference in reports of counterfeiting. Those in Busoga report more regular seed problems and known issues with counterfeiting. Those

Reason	Percent reporting
Never hear of counterfeiting	50%
Buying directly ensures genuine seed	11.54%
Companies wouldn't risk their reputation	7.69%
Counterfeiting doesn't happen locally	3.85%
Regulation prevents counterfeiting	3.85%

Table 10: Agro-dealer explanations of why seed counterfeiting occurs.

in Kapchorwa however state that farmers rarely report seed problems, and that counterfeiting doesn't happen in their locality. It's unclear from our surveys and interviews as to why this difference might be. On nearly all other accounts, these two groups of agro-dealers appear almost identical. The only observed difference between these groups are the aforementioned seed drying practices and that agro-dealers in Kapchorwa stock Kenyan varieties by nature of their proximity to the border. However, it seems unlikely that the addition of Kenyan seed would affect more general counterfeiting incidence. Further interviews with farmers and actors in these seed networks might further explore and triangulate these findings. If this same pattern is observed, these two districts might serve as useful comparisons to identify where there are quality challenges to seed systems.

5.2.3 Logistics conditions and seed performance

Seed companies transport seed in a number of ways. Our experiment follows the most common type of these, which are termed 'route sells'. In this model, company staff in the vehicle attempt to sell to agro-dealers, as they travel along a general direction away from the production centre.

5.2.3.1 Environmental conditions in transport

Two kilogram bags of seed are transported in bundles of 50 kg, and piled into a truck with other agricultural inputs. The storage spaces of the trucks we followed are enclosed. We did however hear that some seed companies and delivery vehicles use flat bed, open trucks for delivery.

Overall, 98,386 environmental data points were captured over 31 journeys. 29 Of these journeys were conducted with Company b, while only two were conducted with company A. Originally, many more journeys were planned with company A, but accountancy challenges within the business prevented many seed deliveries for the 2021 maize growing season.[14]

Conditions in seed bags are warm and humid. Average seed bag temperatures are 25.65°C, with a standard deviation of 1.99°C. Average seed bag relative humidity is 68.12, with a standard deviation of 3.74. These conditions fluctuate with the time of day, despite seed package materials and containment on enclosed trucks.

As shown in figure 10, temperature and humidity fluctuations have a daily pattern. Temperatures tend to be lowest between 7am-9am, and highest between 6pm-7pm. In contrast, the highest humidities tend to be between 5am-7am, and the lowest humidities between 12pm-3pm. Figure 10 shows this in the inverse relationship recorded between these two environmental conditions in seed bags. This figure also demonstrates a difference between conditions measured between the two companies.

Temperatures were similar between both companies, with one company A being slightly warmer on average than company B (27.27°C versus 25.57°C, respectively). Company A also recorded slightly greater standard deviation in temperature, with 2.37°C for company A versus 1.93°C for company B. Humidity showed the greatest difference between the two companies in both mean value and standard deviation. The mean humidity in company A's seed bags is 61.48 while company B 68.45. The most striking difference was in the standard deviation of humidity (visible in both figure 11 above and figure 12 below). Seeds with company A experience a smaller range of humidities in transport compared to seed with company B, with a standard deviation of 1.36 versus 3.50. As mentioned earlier however, many more journeys were monitored with company B, which might explain some of this difference.

Journeys from processors to the final agro-dealer destination take on average 4.6 days (or 119.7 hours). Drivers and sales staff sleep in central towns along the route, while the seed remains in the parked vehicle outside. These are the total journey times, which our bags remained on until the end. Other bags of seed were delivered en route, making this figure a maximum journey length estimate, not the average of all seed.

[14] The exact cause if this was never explained to us but it seemed to be regarding inconsistencies in budget flows. During this time, seed remained in the processing centres, bagged and ready to go while our enumerators waited but never to be sent. Missing a season of sales seemed disastrous to the company, but the matter was not resolved over the three months we remained in communication with the company.

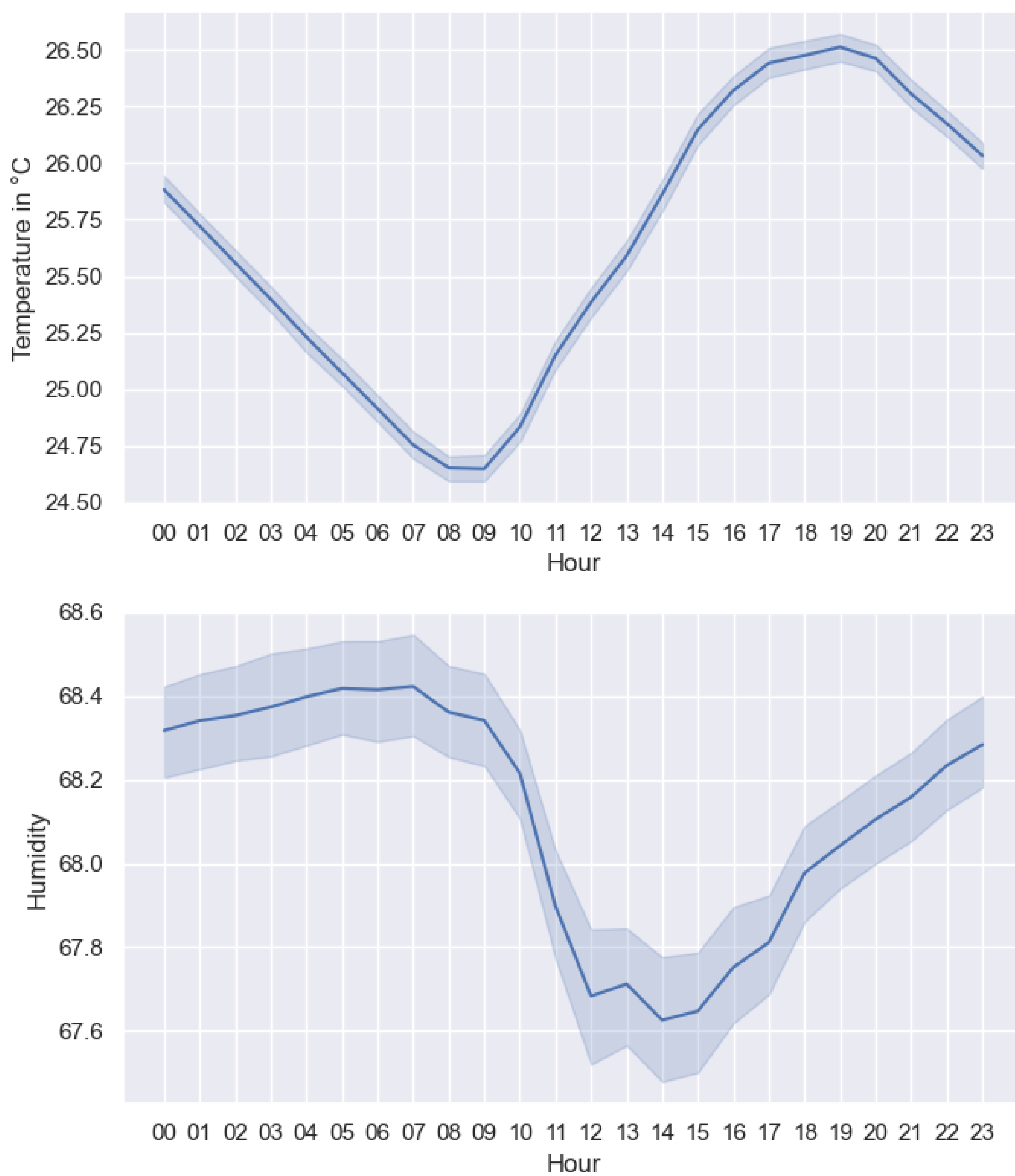

Figure 16: Daily fluctuations in temperature and humidity.

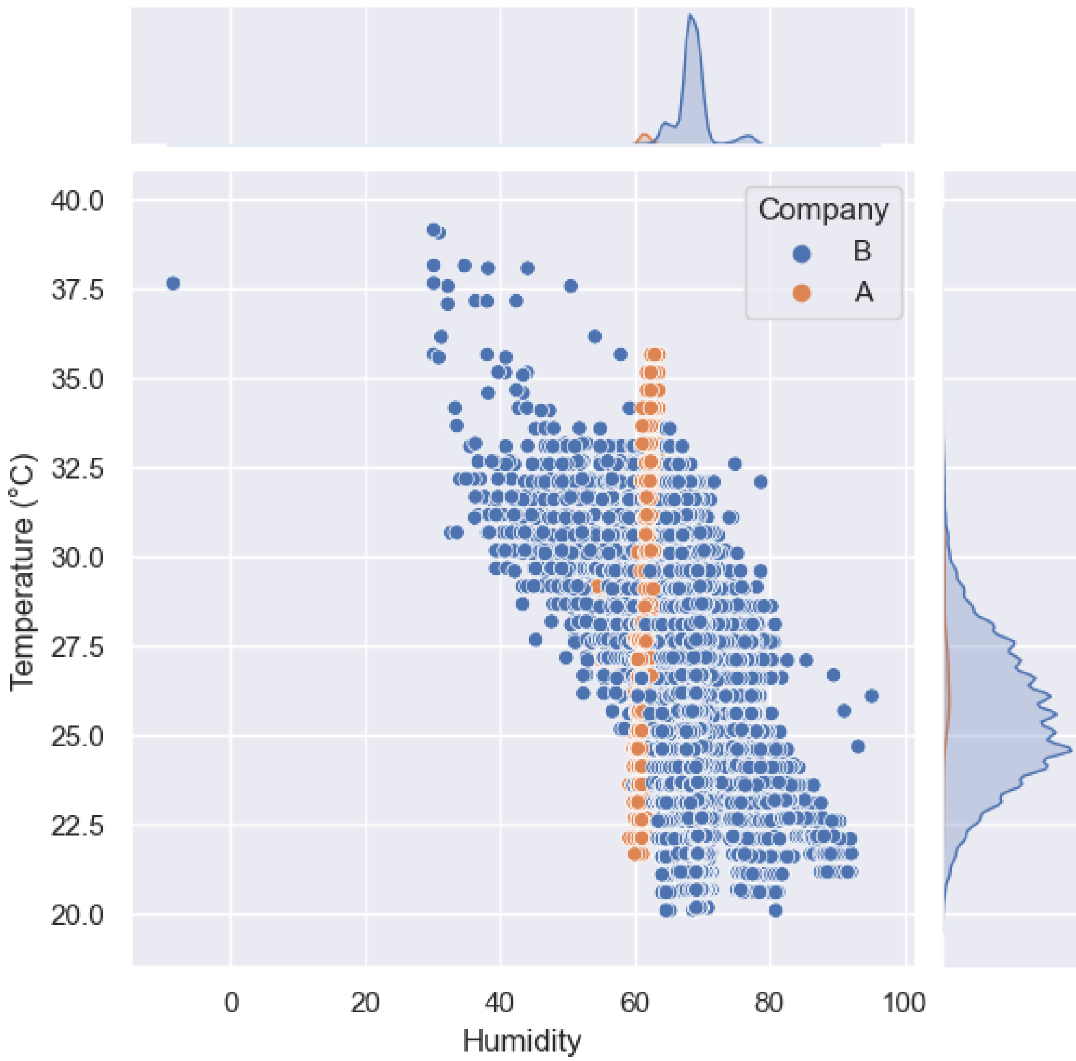

Figure 17: Environmental condition distributions between companies.

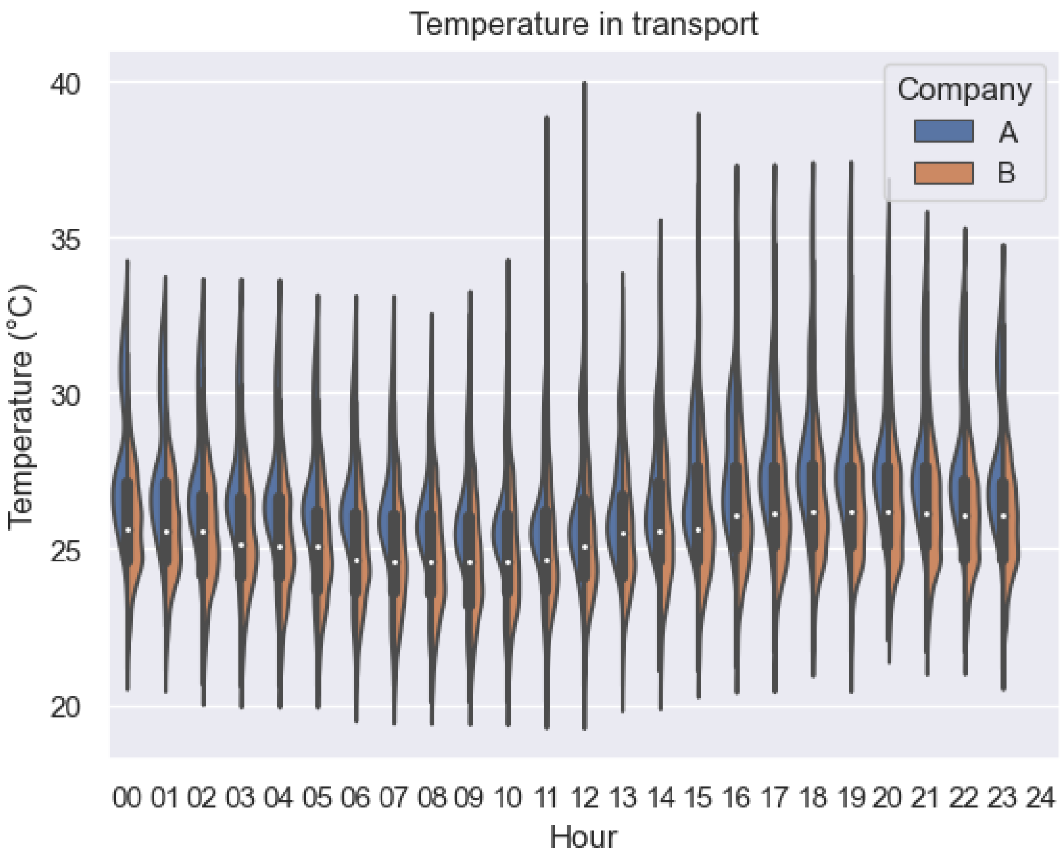

Figure 18: Temperature differences between companies.

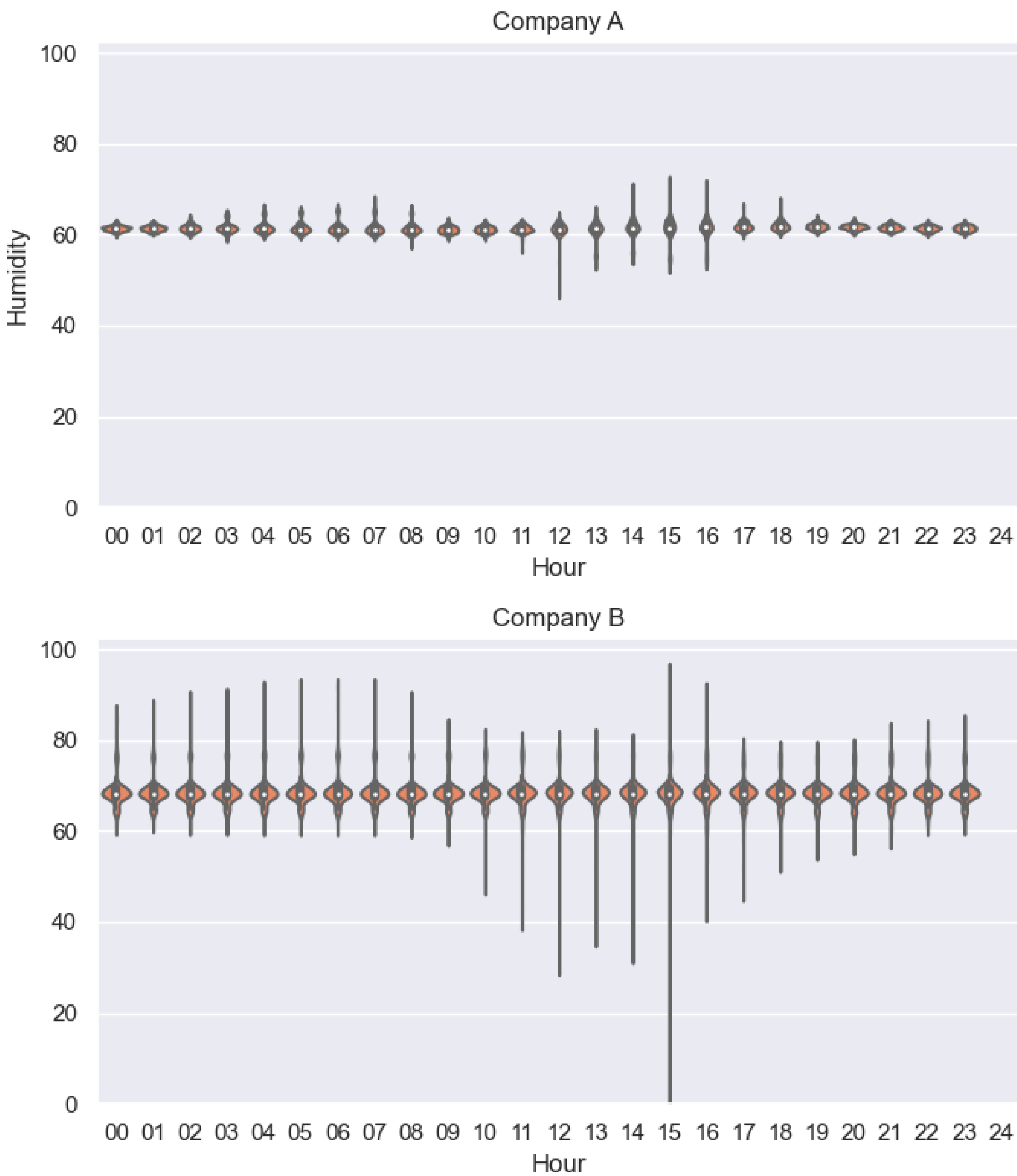

Figure 19: Humidity differences between companies.

Figure 20: Time in delivery.

5.2.3.2 Lab germination

Germination rates under lab conditions were recorded from monitored bags. These lab tests were measured at four and seven days. Under lab conditions, 78.9% of seed germinated after four days, and this number rose to 87.7% after seven days. Such figures are close to the 90% germination rates that Ugandan seed companies aim to achieve. These lab conditions are however ideal for germination and differ from field conditions. These findings do however confirm that germination rates of seed immediately out of seed companies are generally high.

Mean temperature and humidity conditions experienced in transport affected lab germination rates. For a degree rise in mean temperature in transit, there will be a predicted 4.55 rise in number of germinating seeds after seven days ($P<0.000$). Similarly but smaller, for every increase in mean relative humidity, number of germinating seeds after seven days is expected to decrease by 0.58 ($P<0.000$). Similarly for every unit increase in temperature standard deviation, predicts a 17.07 increase in number of germinating seeds after seven days ($P<0.000$). Conversely, a unit increase in humidity standard deviation is predicted to decrease seven day seed germination by -1.88 ($P<0.000$). Germination rates therefore appeared to perform better under warmer and

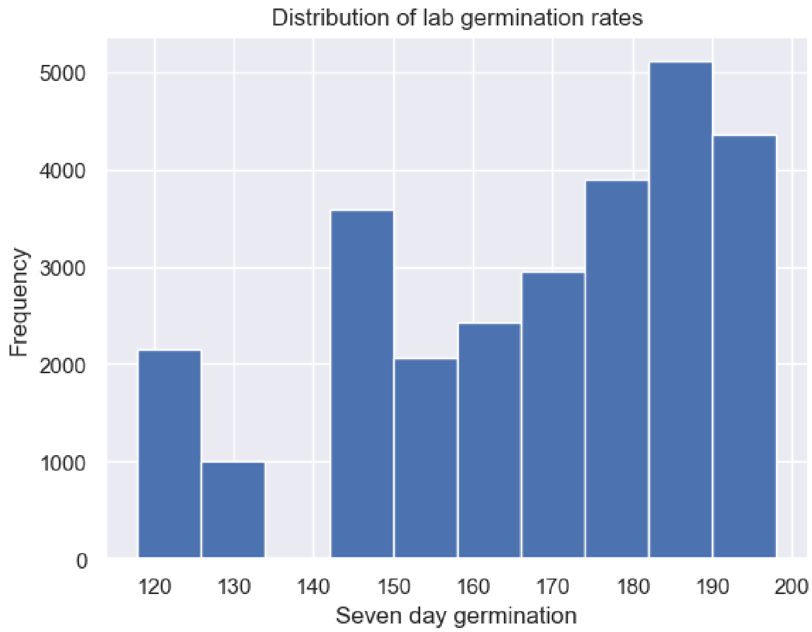

Figure 21: Lab germination rates after travel.

dryer conditions. Greater standard deviation in temperature particularly raised germination rates, although the opposite was so for standard deviation in humidity.

Journey time has no significant effect on seed germination, but graphical representation suggests there could be some pattern between journey length and seed germination. Further study with more journeys could be taken to confirm this (see figure 16).

5.2.4 Farming set up and field trials

Here we share both the findings of the qualitative interviews with local farmers that informed our farming set up, and the resulting harvest data from the field trials.

5.2.4.1 Local farming practice

In Sironko, men tend to own the land and are often the primary decision-makers for farming practice. Farmers tend to harvest between one and five acres. Most of the farmers grow hybrid maize, either purchased from agro-dealers or sourced from saved-seed. They commonly grow the varieties of Longe-5, Longe-7, Longe-10 and occasionally the Kenyan sourced DK hybrid variety. Traditional varieties were rare in Sironko. Where they were grown, they tended to be kept in

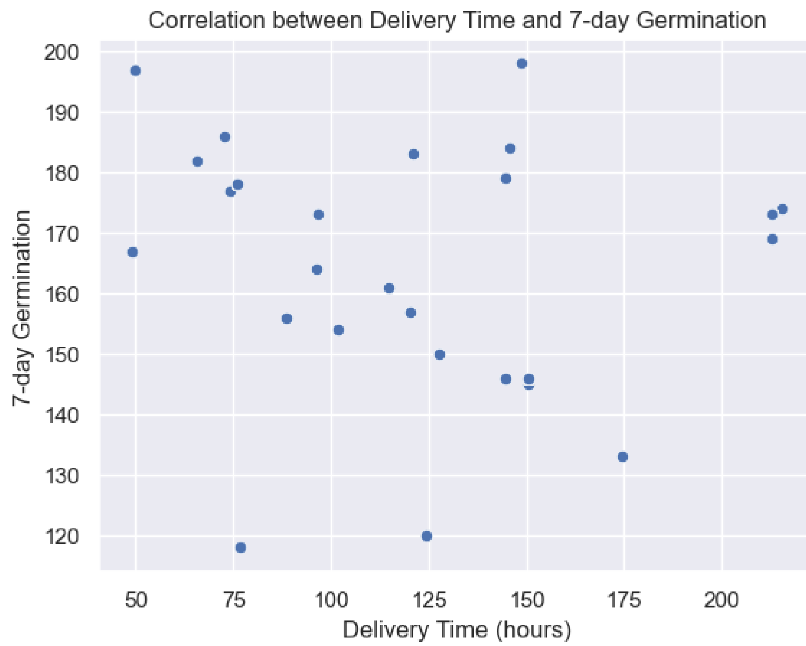

Figure 22: Germination rates with journey time.

smaller amounts, for household roasting snacks rather than as a commercial crop.

Farmers have different preferences for when they purchase seed for the harvest. Some buy weeks in advance while others wait until a few days before. Farmers who buy two to three weeks in advance do so because the price of both seed and fertiliser increases when the rains begin. Purchasing seed in advance also ensures that farmers have the seed, despite whatever financial emergencies might arise. Others buy seed days before harvest in the rationale that it is fresher. Agro-dealers begin stocking seed just before and during the rains. Therefore seed that is present prior to that time is more likely to be older seed, which farmers feared may have expired.

Farmers are well aware of the need to carefully store seed to maximise its potential in the field. Farmers preserve seed by keeping the bag off the floor to prevent dampness; this might be achieved by hanging the bag up, or placing it on top of a palette or cupboard. Farmers were taught these storage practices by company extension agents, who also gave the farmers polythene bags for seed storage. Some farmers reported to open bags after purchase and dry the seed. Farmers do this due to experiences of purchasing damp seed, which later failed to germinate. Some farmers also soak the seed before planting, to increase the speed of germination in the soil. This practice was said to be a strategy for farmers who plant late.

Farmers have set calendar dates in mind for when to plant. The rains in Sironko are expected to start on the 10th of March. Farmers then tend to plant between the 15th and the 20th of March. Some farmers will also plant if there has been three consecutive days of rain since the 10th. The concern farmers have is that they plant seed and then the rains stops. Leaving the seed in the ground risks it drying out, going mouldy or, succumbing to diseases or being eaten by birds or insects. As one farmer put it:

> *"When you're involved in farming, it is like you're gambling. When you predict it might rain soon, just go ahead and plant. If by the 15th of March the rains have not started, you can go ahead and plant in the hope that between 17th -20th, it would have started raining. If you planted the treated maize seed, you don't need to worry about it being eaten by insects or hens."*
>
> Sironko farmer, local farming practice interviews.

Farmers choose the amount of seed to plant based upon the seed type. Most farmers reported to plant around 6kg an acre of improved seed. Those planting saved seed reportedly plant up to 10kg per acre. Local agricultural extension workers stated they recommend 8 kg of seed per acre. The amount of seed used over the acre depends upon the spacing between plants, the amount of seeds per hole and concerns of competition for nutrients between plants. Farmers will plant two to three seeds per hole if it is improved seed, and three to five if it is saved seed. If more than two germinate in a hole, they uproot the least established after two weeks, leaving only two growing. Farmers plant multiple seeds to reduce the risk of seeds failing to germinate, or being damaged by pests. Companies in the area advise farmers to plant only one or two seeds, but key informants confirmed that few farmers follow this guidance.

Farmers choose the spacing between maize plants by the type of seed being planted. When farmers plant improved varieties, they leave two feet between holes and around a metre between rows. The spacing is similar for saved seed but the space between holes is reduced to around one foot. These measurements in practice are made approximately, where farmers use their own feet or hands to determine the sizes.

Agricultural extension workers advise that fertiliser is applied twice during the crop growing cycle. The first stage is at planting, where approximately a bottle cap of diammonium phosphate (DAP) is applied to the hole where the seed is planted. This stage will require around 40 kg of DAP per acre. The second application is a 'top dressing' with urea or NPK (nitrogen, phosphorus, and potassium) after 45 days, when the maize is at knee height. This practice does however vary, with some farmers making this application two weeks after planting. This top dressing stage requires around 50kg of fertiliser an acre. Despite knowing this input advice, most farmers do not apply fertilisers. Those who do, only apply a top dressing. Farmers argue that the first stage is not necessary, as the soil has enough residual nutrients to support the maize until establishment. Extension workers did not agree with this, stating that financial constraints are more likely to be what limits fertiliser application. DAP costs around 2500 UGX per kg and NPK/urea around 2000 UGX per kg, therefore costing around 200,000UGX (approximately £40 per acre) in total (2500 x 45 + 50 x 2000). These costs should be considered in combination with further costs outlined below.

Out of the eight farmers surrounding our field site, only three confirmed to consistently use fertiliser. These same three defined themselves as commercial farmers. Two other farmers had never used any fertiliser and the remainder only applied fertilisers when resources permitted. Farmers themselves had no clear consensus on the proportion of others using fertiliser. Some argued that fertilisers are the only way to achieve a return on investment, because of the degraded soils.[15]

All interviewed local farmers used pesticides. Pest pressures have been increasing in recent years, making pesticides essential. Farmers usually apply pesticides during the first weeding and when the cob has started forming. This frequency might increase depending on the severity of pests.

There are multiple management stages to maize farming that require time and investment, outlined below. All the following cost estimates are per acre:

- **Clearing:** The first stage involves the clearing of the land. This stage commonly uses slashing, but can also include clearing through burning and weed killers. Paying to slash an area of land costs between 30,000 - 50,000UGX per acre. The next stage is to plough the land.
- **Ploughing:** Ploughing is usually achieved with a tractor, with only the poorer households still relying on oxen. The land is often ploughed twice before planting, with a two week gap. Each round of planting costs between 80,000 - 100,000UGX, depending on the time of year. Prices are low from the start of February and increase with the approaching growing season in March.

[15] As one farmer put it, *"you will end up working for the road"* meaning that if you don't apply fertiliser, the returns will only be enough to cover your transport to the field.

- **Sowing:** The sowing stage comprises of two steps; sowing the seeds and covering the seeds. The combined cost of these two stages is around 50,000 UGX.
- **Weeding:** Weeding normally takes place at two stages. The first is after two weeks, the second after 45 days. The costs of weeding are based on the number of rows. An acre accommodates between 120-160 rows, depending on the spacing used. It costs 500 UGX to weed a row, therefore requiring a total of around 140,000 UGX for the season (500 x 140 x 2).
- **Spraying:** Spraying coincides with the weeding and also generally occurs twice. Spraying products range from 10,000 UGX to 50,000 UGX and hiring someone to spray costs 10,000 per acre. Total costs are therefore around 80,000 UGX per season.
- **Harvesting:** Harvesting takes place after around 125-130 days from planting. It requires firstly cutting the maize stems and then removing the cobs. The cobs are then collected and returned to the farmer's store by tractor. The process normally takes between six to eight people. Harvesting costs around 35,000 UGX to cut the stalks down and 50,000 UGX to remove the cobs, costing around 85,000 UGX in total.

Activity	No. per season	Price (UGX) per acre	Total
Clearing	1	40,000	40,000
Ploughing	2	90,000	180,000
Initial fertiliser	1	100,000	100,000
Sowing	1	50,000	50,000
Weeding	2	70,000	140,000
Top dressing	1	100,000	100,000
Spraying	2	40,000	80,000
Harvesting	1	85,000	85,000
		Total:	**775,000**

Table 11: Costs involved in seasonal activities.

After this process, local extension workers suggested that farmers could harvest around 17-20 bags of maize from an acre, if they follow agronomic best practice. Maize harvests in Uganda are generally measured in bags, with a bag weighing approximately 100 kg. Farmer estimates however were less consistent, but generally lower than this amount.

5.2.4.2 Field trials

112 plots of 35 planted seeds were recorded. This amounted to 2,420 recorded cobs at harvest. Germination rates in the field were 32.7% at seven days, 55% lower than the lab germination rates. A mean average of 52.9% of plants were established at 21 days. Maize plants that reached harvest produced an average of 1.3 cobs. Combined with survival rates, this made for approximately 26 cobs per 35 plant plot. Cobs had an average mass of 219.6g at time of harvest.

Surprisingly, maize plants on the fertilised side generally performed worse than plants on the unfertilised side. Only 26.62% of fertilised plots had germinated after seven days, compared to 35% of unfertilised plots. This comparative difference reduced by establishment at 21 days, but fertilised plants were still lower with 50.7% survival compared to 54.9% in unfertilised plots. This initial difference and recovery can be observed in figure 17. Figure 17 also shows the difference in seedling survival between fertilised or unfertilised sides. In both instances, the fertilised side had lower overall variation. The unfertilised side had greater variation, but generally higher seedling survival.

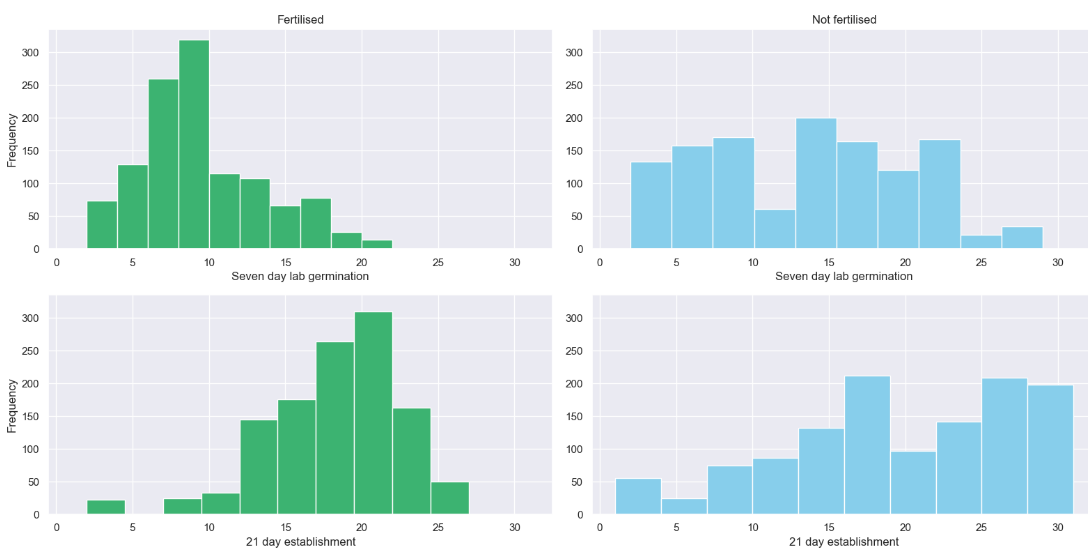

Figure 23: Germination and establishment.

Both fertilised and unfertilised crops showed fairly similar distribution with regard to the number of cobs per plot. Overall, the unfertilised side did however achieve the lowest and highest number of cobs per plot. Fertilised plots also produced slightly smaller cobs on average, at 217.4g versus 221.7g in the unfertilised side.

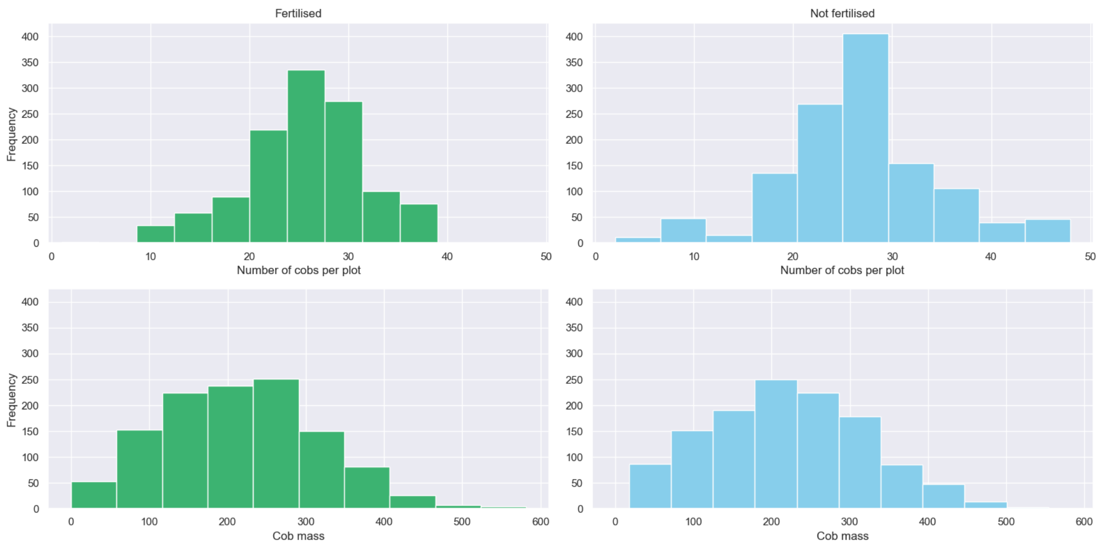

Figure 24: Cob number and cob mass.

Linear regression models tested the effect of environmental conditions in logistics on plant performance. Mean, maximum, minimum and standard deviation recordings in logistics were included for temperature and humidity as predictors for seed germination, as well as the fertilisation status of the field. No two variables for temperature and humidity were included in the same model to prevent issues of collinearity. Collinearity occurs when predictor variables in a regression model are highly correlated with each other. This can lead to issues in interpreting the individual effects of each variable. Mean, maximum, minimum and standard deviation values for temperature within journeys are likely to be correlated and cause challenges with interpreting the contribution of each variable. High collinearity might also inflate the standard error of the coefficient estimates. For example, a high mean temperature is likely to also have higher maximum and minimum values. Secondly, these aspects of temperature or humidity might have similar distinct effects on seed performance, including them all therefore could bring issues of collinearity in the effect on seed performance. As such, we explore each aspect across seed germination, establishment, number of cobs and cob mass.

Combining mean temperature and fertiliser in a regression model reveals that fertiliser has a significant effect on seven day germination rates, reducing the number of germinating seeds by -4.4. Mean temperature in storage has no effect on seed germination after accounting for the effect of fertiliser on the field. We then applied separate regression models for both the fertilised and unfertilised sides of the field. We find that mean temperature in logistics does have an effect ($P = 0.034$ and $P < 0.001$ for fertilised and unfertilised sides respectively) suggesting that mean temperature does have an effect on field germination when fertiliser is not accounted for. This effect is however small, with an increase in mean temperature causing a 0.54 or 0.47 rise in seed germination number in fertilised and unfertilised sides respectively. These patterns are closely similar to the outputs for maximum and minimum temperatures. Standard deviation of temperature in transport has a more paradoxical effect across fertilised and unfertilised sides of the field. On the fertilised side, a degree increase in temperature standard deviation is predicted to reduce germination number by 1.2 ($P = 0.001$). On the unfertilised side of the field, an increase in temperature standard deviation by one degree is predicted to increase germination number by 5.5 ($P < 0.001$). Mean humidity decreases seed germination by 0.21 ($P < 0.001$) and this effect is increased slightly on the unfertilised plots to reduce germination by 0.4 ($P < 0.001$). Results are similar, but with a smaller effect for maximum and minimum humidity. Standard deviations in humidity both increase germination rates by 0.41 and 0.35 respectively ($P < 0.001$ in both cases).

At 21 days establishment, fertiliser continues to have a significant effect on plant survival number but the effect reduces to -1.4. At this plant development point, mean temperature in transport does not have an effect. Maximum temperature is significant across both fertiliser treatments for 21 day establishment, but the effect is small at around 0.1. Minimum temperatures predicted a decrease in plant establishment number by -1.4 across all plots. Transport temperature standard deviation remains paradoxical, predicting an increase of 4.8 plants in plots in unfertilised areas and reducing plant number by 1.7 unfertilised areas. Mean humidity has a significant, but small, effect on the number of seeds surviving in unfertilised plots after 21 days, reducing numbers by -0.41 for each point rise ($P < 0.001$). Mean humidity however had no effect on fertilised plots. Maximum and minimum humidity negatively affected plant 21 day survival, but the effect was small. Standard deviations in humidity had no effect on 21 day survival.

With regard to cob numbers, fertiliser reduced the number of cobs from a plot by 0.61. Mean temperature positively affected plot cob number on unfertilised fields by 0.67 ($P = 0.011$), but paradoxically reduced plot cob numbers by -1.04 on fertilised fields ($P < 0.001$). The same pattern of effect could be found for maximum temperatures, but with a smaller effect. Minimum temperatures had a slightly stronger effect on unfertilised sides, predicting to reduce cob numbers by 0.89 per unit increase. Mean humidity increased the number of cobs by 0.66 per unit increase on unfertilised plots ($P<0.001$). This effect was the same but smaller for fertilised plots (A coefficient of 0.25, $P=0.002$). Similar effects were observed for minimum and maximum humidities but with smaller effect sizes. Standard deviation in humidity is predicted to reduce cob numbers by -0.61 per unit increase ($P<0.001$) on fertilised plots, but had no effect on unfertilised plots.

Fertiliser applications had no effect on the mass of harvested cobs. Temperature and humidity experienced in transport had no effect on harvested cob masses.

5.3 Discussion

5.3.1 How the formal sector operates

These findings give further insight into how the formal seed sector operates in Uganda. The system relies upon a range of institutions, each with their own needs but highly dependent upon one another. These routines and interactions influence how improved seed technology manifests in Uganda.

Seed companies are complex arrangements of specialised actors, working to multiply, process, package, market and deliver seed. These arrangements rely upon the multiplication of seed, supported by contract farmers, and the repeated sale of products to government programmes or numerous small independent agro-dealers. Regulatory bodies set the operating rules, licensing who can sell seed and what those products are. Government seed programmes purchase and distribute seed as aid. Agro-dealers operate as small independent businesses in a highly competitive space to respond to farmer demand. Farmers have their own routines and dispositions by which they source, use and reuse seed. While the overall performance of these actors reifies modern seed technology, the needs of each group are not always in alignment. Instead they create arenas of interaction, where actors compete for the most efficient use of their resources, and the potential profit it offers. The effects of these self-preserving behaviours ripple out across the wider seed technology space, influencing what, and how, seed technology persists.

Examples of tensions can be found in: regulatory standards constraining which crops are commercially sustainable; contract farmers adulterating seed bags to bulk up orders; government programmes setting unsustainable prices for companies to produce seed at; agro-dealers threatened by government seed aid programmes; and suspicion throughout the system of counterfeiters who threaten the 'high-quality' products on which the formal system legitimises itself as the premium seed source. Another assumption is that the formal sector is a conduit connecting farmers to the latest improved technologies. Instead we find agro-dealers are more likely to respond to purchasing behaviour, regardless of technology novelty. As such, many of the best selling varieties have been on the market for 15 years. While policy might position agro-dealers driving modern variety proliferation, ultimately they are bound by commercial pressures to meet demand. Here, it appears that demand revolves around sticking with what has worked in the past. These kinds of competing interests are not surprising, but remaining mindful of them is important when much discourse reduces the overall objective of the formal seed sector as united towards a goal of raising productivity. The reality is that the system is formed of composite arrangements, and not all of these result in the rapid deployment of new technologies to farmers.

5.3.2 Regulation and quality control

A common narrative for the formal seed sector is its assurances of high-quality goods that result in the subsequent return of higher, dependable yields. Instead, we find how difficult it is to ensure high quality in practice, despite significant resource investment by seed companies. These findings support other literature that question the regulation standards in Ugandan seed supply (Mennel et al. 2014; Bold et al. 2017; Boef et al. 2019; Barriga and Fiala 2020). Achieving these high-quality goods is difficult on a number of grounds. The first challenge here is that government regulation capacity cannot keep up with overall production. There are simply not enough regulatory agents in the country to monitor the quantity of certified seed entering supply chains. This echoes other reports of under-staffing in regulatory bodies (Joughin 2014; Barriga and Fiala 2020). Consequently, while products might be listed as certified, it remains uncertain if this regulation has taken place. Even where regulation has validated the product's quality, this is only at the entry to the supply chain. Consequently, seed quality regulation is blind to most of a seed bag's lifetime on the market or in storage. This is however not to say that companies are producing poor products. To the contrary, we find that lab germination rates are high (approximately 79%-88%), demonstrating the high quality of the products we purchased. Instead, we are interested in the validity of this 'certified' status as products move through supply chains towards end users. While others have looked at the potential for counterfeiting in the system, here we consider quality implications of environmental stresses on seed in supply chains. As our findings show, seeds experience adverse conditions from the first step of the supply chain.

We find that conditions in seed bags during transport are hot and humid. Despite seed packaging and transport within company vehicles, seed bags experience daily fluctuations in environmental conditions. The packaging of one company appears to prevent humidity changes more effectively than the other company, but temperature remains high throughout. Additionally, these results are taken from specialist company trucks designed for seed delivery. Other transport vehicles, such as open trucks, are also used to transport seed and offer less environmental protection. Our data shows that seed bags offer little protection from environmental conditions. This finding emphasises the importance of seed storage conditions in transport and storage for seed viability. The next question is how these conditions affect seed.

We find that conditions experienced in the first days of the supply chain affect seed viability. Bags that experienced higher temperatures were more likely to have a slightly higher germination rate (2.3%). This effect is particularly so for bags that experienced greater standard deviation in temperature (8.5%). These temperature findings go against conventional guidance that seeds store better with cooler temperatures. One possible explanation might be that the seeds we followed had higher moisture content than recommended for storing. In this case, warmer temperatures may have helped seeds to dry. This suggestion is perhaps supported by the lower reported incidence of seed failure where agro-dealers open and dry seed. More in-line with standard seed storage practice is that seed germination was slightly improved by lower relative humidity in bags. Something to bear in mind is the detected inverse relationship between temperature and humidity in seed bags, meaning that bags with lower humidity likely also experienced higher temperatures. Seed packaging might also influence the effect of humidity with regard to how permeable the material is to water vapour. Our findings suggest that the majority of bags experience humidity fluctuations, suggesting permeability. More breathable bags might offer less protection against humidity changes. Less breathable bags might offer the opposite, but this might also prove problematic when combined with heat and higher moisture content seed. If higher temperatures are causing seeds to dry, evaporating water will remain as vapour in the bag, before condensing on surfaces at cooler temperatures. In less breathable bags, this might result in condensation on the inside of the bag, which risks the premature germination of seed in contact with it, or the potential for mould to initiate. Thus, the problem is a tricky one. There are risks to having both moisture permeable and impermeable bags. Impermeable bags might provide the most moisture protection, provided the seed is sufficiently dried beforehand.

It is important to consider the implications of our environmental and germination findings. While the effects of our findings are generally small, they suggest two important features. The first is that modern seed directly from seed companies offers a potentially high germination rate. Therefore, while regulatory capacity might struggle to achieve the certification standards it promises, the products themselves appear to offer high viability. Thus we find evidence of high quality seed goods on the market, *at the point of leaving seed companies*. These findings are in contrast with studies that report modern variety goods are generally of a low standard in Ugandan markets (Mennel et al. 2014; Bold et al. 2017; Boef et al. 2019). Conversely, they are in support of findings that report good seed quality in Ugandan formal seed supply Barriga and Fiala (2020).

The second feature is that although effect sizes are small, we find significant influence of environmental conditions in logistics on seed viability. While this provides evidence that seed logistics from companies are unlikely to be a major cause of seed failure, it raises concerns of these same risks throughout the rest of the supply and storage change. Our findings show significance after only the small number of days following logistics from the company. After this first delivery stage, seed might be stored in agro-dealers, sold, transported and stored with farmers over much longer lengths of time. Thus while our findings appear to show minor differences after a few days, this raises the possibility of greater seed viability changes from longer timelines. This might be especially so given that agro-dealer seed stores may be less protective than company vehicles and generally more exposed to outside elements. Thus further study could look into the effect of environmental conditions on seed during longer lengths of storage, and through later actors in formal seed supply. Doing so could confirm any cumulative influence of conditions on seed viability, and where risks might exist to seed viability.

An even deeper challenge for the formal sector is whether regulated goods actually result in reliable goods for smallholders. Our findings suggest that even certified seed might offer limited returns under the conditions by which the intended end-users operate. The certified seed we purchased directly from companies still achieved only 32.7% field germination after seven days. Germination rates were even lower in the fertilised side of the field, with around a quarter of seed germinating by seven days. Germination rates increased to around 50% after 21 days, but farmers stated that they re-sow if a hole hasn't germinated in the first week. These low germination rates are particularly challenging for smallholders given that modern varieties were around five times the price of locally saved seed at our location. These field germination rates also explain why farmers tend to plant two to three seeds per hole. It's worth comparing these germination rates with our lab results.

Lab results suggest certified seed has the potential to give high returns, so low field germination rates cannot be explained with poor quality seed. The lab set-up however offers near ideal conditions for germination. One explanation for comparatively lower field germination is that the conditions and farming practices are not as suitable for initiation. Agro-dealers surveys demonstrated a similar view; that failing seed can be explained by farmers not following best practice.(This suggestion is somewhat ironic given that enumerators found agro-dealers not following advised seed storage practice) There are a number of themes here to discuss based upon the farming set up, local context and claims of the blame lying with farmer practice. I will start with the field conditions.

A noticeably surprising result from our field trials is that fertilised plots performed worse than unfertilised counterparts. Fundamentally, fertilisers supply nutrients that are important for plant development. It is therefore surprising that our unfertilised side of the field performed comparatively better. There are a number of biological and methodological reasons why this might have been the case. It could have been that nutrient imbalances or excessive application negatively affected germination. For example, over-application might alter soil pH, increasing toxicity and affecting nutrient availability and uptake. This however seems unlikely, given that suggested and measured fertiliser was applied, coupled with general reports of nutrient scarcity in smallholder fields. Another alternative could be that fertiliser applications affected the local microbial community, influencing germination. This could be the case but this risk seems low given that all studied seed was treated to protect against microbial threats. Another, more ironic, possibility is that the fertiliser our field staff purchased was adulterated, as other counterfeiting reports have suggested (Bold et al. 2017; Sanabria et al. 2018; Ashour et al. 2019). Alternatively, it could be that there were unobserved ways in which the two sides of the field differed. For example, the fertilised side of the field might have been slightly raised, causing nutrients to flow down to the unfertilised side during the rains. Conversely, the fertilised side of the field might have been downhill, raising the chance of flooding stress during the rains. While neither of these features, or other perceivable differences, were observed across the site, including multiple and separate field sites in future tests could methodologically reduce this confounding factor.

What these fertiliser findings do however emphasise is the uncertainty smallholder farmers navigate. Our field trials sought to closely emulate local practice, mirroring the routines of the smallholders who actively farmed around our plot. Even the planting process itself relied upon local farm labourers to facilitate the process. Farmers in these contexts are advised to purchase modern seeds and inorganic fertiliser at significant additional cost. In following this same practice, only half of our plants grew and fertilisers actually reduced performance. As possible our aforementioned explanations above also demonstrate, it is difficult to ascertain *why* exactly the recommended practice performed poorly. Lab germination tests show it cannot be due to poor quality seed, confirming seed quality does not necessarily deliver optimal field performance. Outside of this, there is little empirical reason why germination remained low. If one was a smallholder farmer in this situation, the simple answer might be to not invest in these approaches, since they appear to be unreliable. Here, neither poor quality seed nor counterfeiting can offer an explanation. While the private sector and extension agents might blame this kind of situation on how farmers use their products, it is worth turning this accusation around. If farmers are following formal sector best practice and still seeing poor performance, are products being made that are ill-suited to end-users contexts and needs? Are the actors tasked with helping smallholders, designing approaches for a different context? For example, the formal seed system has focused efforts on government certification, but this regulation raises prices and subsequently reduces accessibility. Clearly farmers need good quality products, and especially so when paying high prices, but as our experiment shows, prioritising certification goals might still bring limited returns in the wider environment of smallholder farming. Certification is a part of the overall product need, but should be considered alongside technology access and availability dimensions. These concerns are amplified when considering Ugandan agricultural policy pushing to make certified seed the norm. Such transitions demand greater investment by resource-poor farmers yet, as we show, may not result in a dependable product.

5.3.3 Counterfeiting

Our study does not investigate counterfeiting directly, but finds suspicions of it throughout the system. There appears to be no clear consensus where counterfeiting might originate. Seed companies believe it might be agro-dealers, while agro-dealers believe it might be seed companies. Where these accusations of counterfeiting come up, most could also be explained by poor quality seed. The exception to this is one seed company reporting that more of their products were sold by a dealer than they record supplying.

5.3.4 Concluding thoughts

This chapter has looked at the formal sector. It gives a snapshot to the model that Ugandan policy sets to become the main system for crop technology deployment. As we show, supplying formal sector maize to agro-dealers is a complex and resource demanding process. We find that the seed products leaving agro-dealers are of high quality, but that logistics stages place additional stresses on seed transported through the system. We find that the conditions in supply do have an effect on seed viability, but that the effect size is small. These findings are therefore insufficient in their own right to offer a plausible explanation to reports of failing seed in Ugandan formal seed supply. Our experiment does however occur at the very start of the supply chain and cumulative exposure to adverse conditions might however result in a greater effect on seed viability. Further studies throughout both agro-dealer and farmer storage would confirm this.

Agro-dealers are aware of storage condition risks, but few have the infrastructure to offer adequate long-term storage. Another point to note is that warmer conditions in transit appeared to correlate with higher germination rates. These findings are counter to general practice of keeping seed cool for greater longevity. They do however make an interesting comparison with lower reports of seed failing in areas where agro-dealers dry seeds. This could suggest that seeds leaving formal supply centres may have higher moisture content than advised.

Our study also gives insight into the make-up and operations of Ugandan seed companies and agro-dealers. Rather than a carefully organised system that delivers crop innovations to farmers, we find that selling behaviour is more opportunistic, and bound to farmer preferences for older varieties. Many sales were conducted in passing, and served more to resupply popular choices, rather than a strategy to offer newer innovations. This calls into question the position of influence agro-dealers and seed companies have in shifting farmers to new technologies. Thus, one possible mechanism to encourage new variety uptake might be to focus awareness amongst farmers directly and rely on agro-dealers to respond to changes in demand.

Our study also gives insight into the farming methods smallholders rely upon. We demonstrate the level of uncertainty in these systems. Germination was markedly lower than lab results with the same seed. Despite the additional investment, fertiliser had no effect on yield, and marginally reduced germination. In these situations, it is easy to see why farmers might be reluctant to pay for more expensive inputs, when the results maybe negligible.

Chapter 6

A rose by any other name: is seed terminology obscuring smallholder uptake of modern varieties on informal channels?

> "The dichotomy between formal and informal seed systems disappears in farmers' fields."
>
> (Dey et al. 2022, 370)

6.1 Introduction

Agricultural literature and development agendas are filled with explanatory adjectives to differentiate farming objects, practices and institutions. For instance we have: 'smallholder' farmers compared to 'large-scale' farmers; 'organic' or 'synthetic' methods of farming; the differences between 'precision' and 'regenerative' farming and so on. The diverse world of agriculture would be difficult to navigate without these adjectives and the categories they represent. But as much as these adjectives help analysis, they can also oversimplify and homogenise groups which in reality are quite different (Giller et al. 2021). Further, the labels given to a context are predominantly critiqued on technical specifications; for example a farm product is organic or otherwise based on the use of synthetic or natural inputs. Less attention is given to the inherited organisation of actors and power components these groupings bring.

As much as navigating agriculture through these simplifying labels can assist in analysis and communication, their uncritical use risks obscuring the situation. This confusion can cause knock-on effects to how initiatives are designed and implemented.

In this chapter, we critically reflect on how the labels of "modern" and "local" seed are used in Uganda, how they differ in conception across actors and how they rationalise or legitimise behaviours in pursuit of agricultural development targets.

As explored in the previous chapter, a common narrative is that Ugandan farmers are trapped in a cycle of low yields due to low adoption of certified seed from formal seed channels (Mennel et al. 2014; Agra 2017; Bold et al. 2017; Rege and Sones 2022; Barriga and Fiala 2020). Here, the crop varieties that smallholders grow are often reduced into the binary groups of "modern" or "local" (*Uganda Vision 2040* 2013; Bagamba et al. 2023). This language of crop varieties has been used across sub-Saharan African development plans in a technocratic strategies to food security and poverty eradication (Ellis and Biggs 2001; Toenniessen, Adesina, and DeVries 2008; Agra 2017). The underlying inference is that smallholders are constrained, from a food security and economic perspective, by reliance on local varieties. These local varieties are considered to be low-performing and poorly regulated in comparison to modern varieties. In this narrative, the greatest threat to smallholder farmers is prolonged reliance on local varieties, which circulate through uncertified informal seed systems (Juma 2011; Pretty, Toulmin, and Williams 2011). Here, varieties are not only an identifier for technology structuring, but also inference of alternative utility; modern *needed* varieties vs local *constraining* varieties.

These "modern vs local" groupings provide the basis to dictate farming strategies, driving policy narratives on improving food security and raising agricultural productivity. Along with these technical arguments comes donor investment, varietal ownership and the specific expansion of formal seed channels; despite their limited role in smallholder food security (Toenniessen, Adesina, and DeVries 2008; Tansey 2011; Ulmer et al. 2014; McGuire and Sperling 2016; Sperling et al. 2020).

But what do these terms of modern or local really mean? Technically, "modern" varieties generally refer to the progeny of foundation seed, produced by private, commercial enterprises who own the intellectual property to the germplasm (Joughin 2014; Arora, Bansal, and Ward 2019). This germplasm is produced and marketed as the certified seed products explored in the previous chapter. The product should be near genetically identical, providing predictable and uniform growth across the field to aid farm planning and processing.

"Local" varieties on the other hand often refers to landraces, older varieties and orphan crops, circulating as locally saved seed from previous harvests (Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019; Sperling et al. 2020). These varieties are bred and maintained by farmer selection and exchanged or sold on unregulated informal markets (Mastenbroek, Sirutyte, and Sparrow 2021).

Seed channels mark another way in which certified (modern) and local seed are separated by space and institutions: local seed is not permitted in the formal seed systems of agro-dealers who stock industry-produced, government-regulated products.[1] Agro-dealers are positioned by policymakers as the primary agent to deliver the latest biotechnologies to the field, despite approximately 90% of the seed used by African farmers being sourced from informal channels (Odame and Muange 2011; McGuire and Sperling 2016; Adong and Manager 2021).

The main challenge to the Ugandan agricultural transformation agenda is that modern varieties are not being taken up by farmers - or at least, not if one uses the formal sector dichotomy of modern and local seed. In this chapter I ask, how do farmers differentiate between seed dichotomies, and why are farmers choosing the channels that circulate local seed if certified seed should offer better returns?

Counter to arguments of low adoption, I show how Eastern Ugandan smallholders are choosing "modern varieties", but not in the way the term is being used by the formal seed sector; and through different channels targeted by the formal sector. Here I share why farmers make this choice and how these insights could inform crop technology proliferation.

Drawing on the phenomenon of *mwaka moja* in Uganda, I argue that African smallholders are already accessing modern varieties on a wider scale than estimated, but that this movement is overlooked as it falls into the category of local seed. *Mwaka moja* is a local term that directly translates to "one year". In its most literal form, it refers to seed that is one generation descended from a certified variety that was purchased from the formal sector. Instead of using the formal outlets favoured by government investment, farmers appear to be gaining modern varieties

[1] Although, as we saw in the last chapter, a number of agro-dealers stock saved seed.

through local seeds and informal channels.

As I will show, farmers choose seed systems on account of the greater affordances they offer and how they align with local networks and practices. By applying a technographic lens to seed technology, we consider beyond the material qualities of what makes seed useful to farmers, to also include communication flows, inherited routine structures and influential institutions. This approach provides insight into the institutional environment surrounding farmers but we also seek to understand what drives farmer decision-making as they navigate these spaces. To do this, I draw on the theory of affordances to consider the influence environments and crop products have on the perceived utility that crop technologies offer farmers (Scarantino 2003; Glover 2022). Applying these approaches shows how farmers are not the passive recipients of exotic seed technology that policy assumes, but active agents of change who shape the technology ecosystem around them towards different needs. This combined approach leads to wider critical reflection upon whether the current modern variety transformation-style policy ambitions ultimately provide farmers with better varieties in the field, or instead primarily legitimise the expansion of formal private sector actors and the private control of genetic material. I share recommendations from these findings to inform seed delivery strategies that help farmers achieve useful technologies in their fields.

6.2 Methodology

The first objective was to understand farmer behaviours within the context, what influences these behaviours and the potential for change. A technographic approach was taken to investigate the integrated social behaviours and institutions involved in the practice of seed technology (Jansen and Vellema 2011; Arora and Glover 2017; Glover 2022). This analytical approach was supported by applying a theory of affordances lens to farmer, producer and trader responses (Scarantino 2003; Glover 2022). The technographic component guided the approach to understand what crop technologies farmers use and how they navigate seed channels. The affordances lens sought to understand which channels farmers choose to access useful crop varieties, reason for these choices, and how seed channels compare. Both of these approaches are expanded upon in the next section.

6.2.1 Technographic and affordances approach

The practice of technology is not solely material, but inherently social, relying on organising, communicating and structuring of actors (Leeuwis and Aarts 2020; Glover 2022). Crop technologies are an example of this. They rely on ongoing complex processes and organisations of actors to configure and reconfigure material products over successive generations. The resulting seed is both a process and a product of the technology performance.

The continued existence of crop variety technology, and seed producers, relies on the repeated practice of protocols, flows of communication and institutions. For example, these might include: the introgression of useful genetics by specialist agents; the bulking and processing of seed by seed producers and; movement of material through supply actors. Each of these tasks relies on the complementary completion of tasks by other groups. There are hierarchies of decision-making power across these task groups that define the rules and routines of others. For example, Those with business management roles might have decision-making power over what crops or forms of cultivars[2] the rest of the institution focuses efforts around.

In particular, we are interested in how farmers navigated the range of seed source channels available to them in order to best meet their needs. Seed systems are complex interactions of actors and social structures, organised around the task of making, sharing and using crop technology. Using a technographic lens allows the comparison of crop technology differences between modern, local and *mwaka moja* seed, across technical and social dimensions. This lens, inspired by others, includes (Jansen and Vellema 2011):

1. **The making:** Considering how techniques, actors and roles are involved in seed technology use and development. For example, this sought to understand how actors use seed, who sells seed, where they trust seed technologies, which actors they work with to conduct seed technology and what seeds they avoid.
2. **Distributed cognition:** Investigating how tasks and communication flows are ordered by institutions and actors. Here we sought to understand; how actors are organised to produce seed technologies; the roles of actors in these systems; power hierarchies between formal and informal system actors; how behaviours play out across these groups and; how they believe crop technologies are changing.
3. **Rule construction:** Understanding how rules, protocols and hierarchies are organised across seed technology. This might be how rules enable actor groups to work over space.

[2] e.g. hybrid vs open-pollinated varieties.

Routines also include how risk management and resolution shape behaviours. For instance: how are actors across the system bound to act?; who decides this?

From this approach, we considered the affordances that seed technologies offer to farmers. Affordances here are the range of perceivable action possibilities offered to the actor within the environment. This includes:

1. The range action possibilities the technology provides. For example, the range of uses and ways that actors perceive to interact with the object. These might differ between seed technologies.
2. The relation components of perceived utility between the actor and the object. These might be how the perceived action possibilities of objects alter with characteristics of the actor, or between different actor types.
3. The characteristic background circumstances that alter the usability of the technology. For example, what features and changes in the environment trigger the utility of the object for the actor?

Overall these consideration can be used to investigate how and why actor behaviours change between the individual and the setting. This approach guided both the choice of research tools, and the design of those instruments. Smallholder crop and seed system preferences were investigated through a mixed methods approach of focus group discussions, surveys and key informant interviews. These methods also sought to clarify the strategies farmers are using, and a crop-level perspective of the seed interfaces available to smallholders. The instruments are expanded upon below.

6.2.2 Seed channels

This work sought to understand how farmers view and choose between different seed channels, for their priority crops. This data was captured through focus groups discussions and key informant interviews.

Participants were randomly selected from two, also randomly selected, villages from the Sironko District. Villages were randomly selected by drawing names from a bag containing only rural locations, where farming was commonplace. The process to randomly select participants was more involved and relied upon the following approach. A list of households and members was drafted with the help of the village administrative agent. In total this amassed to 150 households.[3] Four households refused to be registered and were omitted from any further interaction. Household names were selected at random by numbering all participants and drawing numbers blindly out of a bag. Only one participant was invited from each household. This process was conducted independently for three different groups. The first group was an equal split of men and women between the ages of 18-65. The second was comprised of youth, split by gender and defined as those of 18-25 years of age. The final was a group of elders, defined as those over 60 years of age. Bringing these three groups together sought to capture the views from a diverse range of participants.

Participants were told that joining would be entirely voluntary, that the discussions would take place on general topics related to farming, that no specialist knowledge would be required and conversations would be in the local language.[4] Farmers were equally represented from both commercial and semi-subsistence farming groups. Farmers self-categorised themselves into these groups. Commercial farmers were generally those who farm over two acres of maize, while subsistence farmers cultivate an acre or less.

Ten focus groups of six people and thirty key informant interviews were held at Sironko District on the topic of priority crops, seed channels and purchasing behaviour. Focus groups selected their three priority crops. Groups were then asked to rank their preferred seed sources for these crops and assess the advantages and disadvantages of different seed channels. This included the quality, availability and accessibility of seed from different seed channels. Focus groups ranked seed channels by price, credit choices, diversity of options, likelihood of providing high yielding seed and trust in sources. Groups were then asked to debate on a number of statements on local seed use. Finally, participants were asked general questions and about their experiences with seed quality, purchasing and use.

Key informant respondents were asked semi-structured interviews on local farming practice, seed channels and changes to local farming over the past five years. These questions were similar to those asked in focus group discussions but sought to capture deeper information on why and how farmers navigate seed systems, assign value and select the best option.

[3] 64 in one village and 86 in the other.

[4] Generally Lugisu or Lusoga.

6.2.3 Informal seed sellers

There is a small but growing literature on the social interactions that dictate how informal seed systems operate, how seed moves through them and how farmers navigate informal channels (Sperling et al. 2020; Mastenbroek, Otim, and Ntare 2021a). We conducted key informant interviews with farmers and seed sellers on: informal/integrated seed networks; farmer seed/varietal selection; seed storage; history of, and changes to these systems; farmer views of how their ability to influence surrounding crop technology; what farmers feel is needed from seed systems and; varietal improvement.

Fourteen key informant interviews were held with farmers and traders involved in informal seed selling. Key informants were purposively selected, based on local recommendations of people who were known to have expertise in informal seed trading. These recommendations came from farmers, local leaders and agricultural extension workers. All participants were informed that involvement was voluntary and that answers would remain anonymous. Eleven informants were based in Iganga District of Busoga County. Three were based in Sironko. Questions were included on: how informal seed systems operate; the range of actors and networks involved in these systems; who has power and control in these systems; how quality and the potential for counterfeiting manifests across seed systems; what they feel is needed for seed systems and varietal improvements.

6.2.4 General interview features

All discussions took place outside, in semi-enclosed spaces, away from crowds. Any passing bystanders who joined were requested to leave to maintain privacy within the group. Upon arrival, each participant was asked to confirm their name and age to confirm their identity. If there was suspicion of impostors, the participant was asked to provide their phone number, which had been collected during the drafting of the sampling frame.[5]

All interviews were recorded as notes in conversation with the enumerator who conducted the data capture method. These notes were written up and analysed using a thematic analysis approach.

[5]Not all households had a phone, but most did. There was one case of an impostor, where a man in his 60s attempted to join a focus group for youths.

6.3 Results

6.3.1 Overview

Farmers cultivate between half an acre and four acres, with most farming between approximately 1-2 acres for all their crops. This total is a mix of owned and rented land. Growing conditions are heterogeneous across relatively small local areas, causing a diversity of crop portfolios across respondents. For example some farmers within the same sub-county might grow rice in swampy paddies, while others struggle with dry soils.

Respondent interest in certified seed varied depending on the crop. Generally, farmers believe agro-dealers sell good products but that these products come at a high cost. High prices were more likely to be accepted with market-focused crops, like maize, but avoided with less valuable crops, like beans. Although many farmers reported to have bought seed from agro-dealers, informal sources provide the majority of planting materials. For the more specific crops where farmers purchase from agro-dealers, they tend to choose locally well-regarded dealers, or those they have a personal connection to. Personal connections came in the form of highly regarded locals, or traders through which they had a history of repeated custom. These connections were important as they offered trust that brought with it a perceived lower risk of poor quality or counterfeit goods.

Many farmers could tell disaster stories of seed failing to germinate locally, but these were said to be uncommon events. Where it did happen, it was often explained as: purchased from an untrustworthy source; an accident or human error in supply; seed damage during storage or; poor practice during planting. Where seed failed, it brought significant knock-on costs in land preparation, time and potentially missing the rains. These costs were potentially disastrous for subsistence farmers who might lack the finances to buy replacement seed. Because of these risks to seed performance, a number of farmers mentioned steps they take to ensure crop coverage across the field. These included: performing seed germination tests to confirm viability prior to planting; soaking seed overnight before planting to prime it for germination; planting multiple seeds per hole to account for failing seeds.

Most of the farmers we spoke to do not use fertilisers, but many spray insecticides. Farmers see fertiliser and insecticides as best agricultural practice but cannot afford the products. Those who did apply fertilisers or pesticides argued that the return on investment was worth it. A related argument was that certified seed should only be grown if fertilisers and sprays are used; or the harvest returns might not justify the initial investment. For this reason, some farmers avoided certified varieties, as they lacked the means to acquire these associated inputs. Curiously, some farmers also had the belief that once one applied inputs, the field would always require fertilisers and so avoided applications on this lock-in concern.

Nearly all of the sample wanted more farming advice from extension workers. Many also mentioned that the access to growing guidance is a reason to purchase from agro-dealers. Farmers particularly valued advice on what varieties to buy, when to plant and how to store. Farmers were also clear in that they want this advice by in-person training and demonstration events. It was generally felt that agricultural extension workers do not visit the field enough and that farmers would welcome greater engagement.

Generally farmers hear about new varieties at agro-dealers from the radio. They did however share concerns that companies should not rely too heavily upon radios for outreach, as it might not reach all farmers. Otherwise respondents generally hear about varieties through farmers. A common way for farmers to be convinced of good varieties would be to approach neighbours with good harvests and ask what they are growing. A regular way to access useful varieties would be to request that successful farmers reserve some seed/planting material from their harvest for the seed buyer to collect later.

Choosing modern varieties did however not necessarily mean that the variety itself was a recent creation. Even the modern varieties farmers mentioned choosing, such as Longe-5 for maize, have been in production for decades, despite newer varieties being released and available. Some farmers even seemed to have a loyalty to a specific variety due to previous success, and were reluctant to change. Sticking with one variety also ensured a level of certainty, within a situation of seasonal uncertainty. Seed companies might also be driving these older varieties as they are said to have preferred Longe-5 on account of its low production costsbopen marketing rights to it (Mabaya et al. 2021). Some newer variety exceptions to this were found in farmers growing the Kenyan 'Bazooka' hybrid maize and some newer cassava varieties. Overall however, this preference challenges the assumption that the formal sector naturally results in farmers accessing the latest varietal innovations. If anything, the commercial pressure to supply demand for older varieties meant that many agro-dealers had limited agency to supply the newest varieties, for which there might be comparatively little farmer interest.

Farmers report that long-term storage of seed is generally a problem. A key consideration here is whether farmers differentiate between storing of *seed* (for growing) and *grain* (for consumption).

The important difference is that seed needs to remain alive, while grain does not. As such, seed preservation requires greater care than grain storage. We find that seed is sometimes selected and stored differently from grain, but not by all farmers. Rats, weevils and mould are all major causes of seed spoilage. Farmers had a range of methods to prevent these threats, but generally it was felt that farmers struggle from lack of adequate storage facilities. Conversely, agro-dealers and informal seed traders were thought to have more reliable seed on account of their storage facilities.

Where farmers relied upon their own storage methods, many mentioned hanging or sealing seed in containers and keeping them in warm, dry places. A number of farmers also spoke of routinely drying their seed in the sun to prevent seed spoiling. Drying seed publicly also served to advertise a stockpile of seed that could be sold to passers-by. An unexpected factor that influenced seed preservation was in what farmers believed is best for seed health on account of the anthropomorphism they associated with seed. In Sironko, farmers describe the embryo of the seed as the 'heart' of the seed, whereas farmers in Busoga refer to the 'eyes' of the seed. This led to behaviours where farmers would project care methods onto the seed as if they benefited these human traits. For example, farmers in Busoga would keep seeds in the sunshine, to open their eyes and prevent them from sleeping.[6]

A general observation is that farmers and traders feel that farming life is becoming harder. This was combined with a sense that the cost of living is rising. Consequently, there was a feeling that poverty is becoming worse and that food shortages are becoming more regular. At the same time, those who sell all of their goods are still struggling with the cost of educating their children. As farming has become harder, more people are borrowing to purchase the inputs required to raise yields. As such, farmers increasingly have pre-season debts to repay, in addition to other pre-existing household financial pressures. A concerning pattern is that farm sizes appear to be decreasing, and harvests with them.

6.3.2 Crop priorities

In Sironko, the order of crop importance is generally in the order of: maize, rice, cassava, beans, tomatoes, groundnuts and sweet potato. These crop priorities appeared to be consistent across genders and ages. Focus groups concentrated on the top five of these priority crops: maize, beans, tomatoes, cassava and rice. Each of these crops had slightly different strategies of use,

[6] Informal seller groups, interview 5.

which are briefly outlined below.

Maize was by far the main priority crop, offering both financial income and a food source for the house. After maize, farmers focused on either rice or cassava, depending on the agro-ecology of their land. Generally, farmers tended to focus on one or two main cereal crops, beans and a cash crop, such as tomatoes.

There are a few differences for crop preference based on the gender of the respondents. Often husbands and wives shared farm management equally. Larger sales of maize or rice were often sold by men but this was not always the case. Men tended to sell at more distant trade centres on account of their greater mobility, as women were occupied with household tasks. Some participants also suggested a belief that men are better at negotiating. Women were however not excluded from markets and regularly bought and sold a variety of products over a range of distances. Some couples would travel to sell the products together. Others would delegate this task in relation to other farm, house or business demands. This similarity across gender also appeared to be the case when purchasing planting materials.

Below, I expand on observations related to the four priority crop groups.

6.3.2.1 Maize

Maize is ranked as the priority crop for both food and cash reasons. It is seen as the first crop to mature that "saves" households from hunger. Women voiced an additional preference for maize over cassava, stating that children prefer to eat it. Maize harvests were measured in number of 100kg bags, with actual harvest sizes varying between 3-15 bags from an acre. Some of this is intended to go to market, with men being slightly more inclined to sell the bulk upon harvest. Generally however, most farmers keep the majority of the maize harvest to eat, or to sell on an *ad hoc* basis. women often mentioned that they were in charge of *ad hoc* maize selling, to cover household bills as they arise. Sellers try to store the seed for at least two months, as the selling prices increase with time since the harvest as supplies become scarcer. When partners sold maize, some went together or they took steps to ensure that both knew how much the harvest sold for. Generally the couple would use the majority of the earnings to pay school fees and buy household assets. In some cases, the husband would give the wife an amount for her own spending.

6.3.2.2 Beans

Beans are an important crop to all except those with waterlogged farm areas. They are valued as a key nutritional compliment in local meals, served as a sauce with maize-based *posho*.[7] Beans have the potential to be lucrative as prices rise dramatically near the end of the season as local reserves have run low. Few however rely on beans for income as they are generally grown on small areas and yield only just enough for household consumption. A further challenge for farmers who do harvest large yields is that beans are hard to store due to pest and mould pressures.

People grow the local bean varieties of *Kaynyewa*, *Saitoti* and *Wairimu*. *Kaynyewa* is by far the most popular, favoured for its flavour, colour, cultural value and, subsequently as a result of these preferences, higher market price. Some also grow yellow beans. These fetch a good market price but have the risk of losing their sought-after yellow colour in wet or cold seasons, reducing their value and sales.

6.3.2.3 Cassava

Respondents saw cassava as a crop that feeds families through the hunger season. Some ranked it highly because of this dependability and referred to it as an 'emergency crop'. Others saw this necessity as unavoidable but would not consider cassava as their priority crop. This is partly because few rely on cassava for income. Farmers plant cassava eight months to a year before they need it. This time demand means that other crops are more lucrative for those hiring land. Because of the lengthy growing period, cassava is the last food source when the other staples have run out.

Respondents generally prefer to eat maize over cassava and this influenced a further disdain for cassava when maize supplies ran out. A final dimension is that cassava competes with maize for growing area, forcing farmers to choose between the two. As such, participants with smaller farms had to strategically plan when to harvest their cassava to ensure they had sufficient space for their maize crop.

This space component brought a gender dimension to cassava farming. One female respondent stated that men and women might see cassava differently. Women tend to farm smaller areas, causing more competition between cassava and maize. Men however tend to have larger plots, allowing them to keep cassava as a useful reserve. Youths also made a similar argument regarding

[7] A starchy cornmeal cooked in boiling water until it reaches a firm dough-like consistency.

older generations having more land and so being under less pressure to choose between cassava and maize crops.

Sironko farmers grow the cassava varieties of 'Kampala', 'Nigeria', 'Aporu' and 'South Africa'. Farmers tended to generally like the taste of Kampala in a range of cooking methods. Nigeria on the other hand was reportedly bitter to eat roasted but produces particularly good flour when milled. A smaller number reported to grow Aporu on account of its long tubers. Many used to grow South Africa but its yields are reportedly becoming worse in the local area.

6.3.2.4 Rice

Rice is a lucrative cash crop in Sironko for farmers with swampy land. Thus, the crop is considered a priority for farmers with wet growing areas, but disregarded by those with dryer lands. Even those who plant rice, plant it later in the year and consequently rank it as lower in household importance than maize. This was because maize provides both needed food and income at the end of the hunger season, while rice was purely a market-focused addition. With that said, it was the income from rice that farmers used to purchase more expensive household assets, like livestock.

Rice farming tended to be more popular with younger people. This is because the swampy conditions required for rice cultivation are labour intensive and bring health risks. For example, rice farmers can encounter snakes, or get leeches which carry the risk of typhoid. For these reasons, older farmers prefer to avoid rice farming on account of greater health concerns than younger farmers. Some of the women saw rice as more of a man's crop on account of being a cash crop. It is generally the men who take rice harvests to larger, more distant trading areas to sell. This meant that some wives were unsure of the amount the harvest sold for, but claimed not to mind as long as there was sufficient food for the household.[8]

6.3.3 Seed channels

Farmers listed a possible seven different seed sources for the selected focus crops. These sources can be categorised into four informal seed channels and three formal channels.

Informal channels are: home-saved, farmer exchange, local shops and local markets. Here, farmer-exchange refers to informal arrangements between farmers. Local shops and markets differ

[8]As one lady described, *"for mothers in the home, as long as there is food, they don't worry about what happens to the rice"*.

in a number of ways. Local shops might be informal seed stores and general goods shops. They tend to be situated in permanent building structures in towns, and run by traders. They may specialise in seed selling, or sell seeds alongside other goods. Local markets on the other hand tend to be a mix of day-traders and farmers, trading goods in temporary and semi-permanent market stalls. Local shops tend to remain in one place and be staffed by a few individuals. Markets might be more variable, forming where farmers can generally provide and purchase goods between one another. As such, one is more likely to purchase from the same person at a local store, but through more one-off encounters at markets.

Formal channels are: agro-dealers, the National Agriculture Advisory Services (NAADS) and government agricultural research stations. Agro-dealers are the specialised agricultural supply shops for seeds, inputs and farming equipment, as outlined in the previous chapter. NAADS are more spontaneous visits from government programmes that provide farmers with free certified seed, inputs or agricultural tools. These goods are allocated by either government agricultural extension workers, or the army.[9] Research stations were rarely mentioned by participants but were known to them. These stations might be the National Agricultural Research Organisation (NARO) research offices, or they could be smaller government sub-county field offices. These research headquarters tend to be staffed by agricultural extension workers who lead on local agricultural projects.

For each crop, farmers consistently ranked informal seed sources as their primary sources, although the priority of channels differed by crop (see table below). Focus group findings corroborated with those from interviews.

Formal seed sources are lower priority seed channels for most local priority crops, and do not feature as sources at all for others. Instead, many farmers rely predominantly on informal seed channels to obtain useful varieties. There are two slight caveats to this. The first is that farmers may not obtain all of their seed from a single source. This meant that some might buy from agro-dealers, but in smaller amounts and as a fraction of their overall cultivation. The above table should therefore provide an indication of the most visited seed sources for each crop, while bearing in mind that farmers may select from multiple sources in preparation for the growing season. A second caveat is that agro-dealer sales may be more dependent on how favourable the previous season was for farming. This is on account of the comparatively higher costs involved in buying certified seed and fertiliser. In successful years, farmers may have more finances to

[9] As mentioned in the introduction to this thesis.

Priority	Maize	Beans	Tomato	Cassava	Rice
1st	Local shop	Home-saved	Home-saved	Home-saved	Farmer exchange
2nd	Local market	Local market	Local market	Farmer exchange	Local markets
3rd	Farmer exchange	Local shop	Agro-dealer	Local market	
4th	Agro-dealer	Farmer-exchange	Farmer exchange	Research Centre	
5th	Home-saved	Agro-dealer	Local shop		
6th	NAADS	NAADS	NAADS		

Table 12: Farmer seed channel priority rankings by crop.

purchase from agro-dealers. In less productive years, farmers may rely more heavily on informal sources.

There was a temporal aspect to farmer seed source preferences. Farmers reported that five years ago, home-saved stock would have been the first choice for maize seed but that this has changed in recent years. Participants seemed particularly aware of this transition and gave a number of reasons why it was happening.

Firstly, the introduction of high-yielding modern maize hybrids to the local area provided farmers with new options to experiment with. In Sironko, many farmers are growing modern varieties, which they obtain from local markets, other farmers and agro-dealers. Those varieties that are specifically mentioned are the varieties ‘Longe-5’, ‘Longe-7’, ‘Longe-10’ and ‘DK’ hybrids. Longe-10 was particularly liked for its high yields and shorter height, which reduced the chance of lodging damage from winds. Some of the men mentioned a new hybrid, ‘Bazooka’, gaining popularity but it is generally more expensive than the Longe varieties. While the DK hybrids are considered less palatable when freshly eaten, the flour is pure white which is well-liked locally. DK was also favoured as a comparatively small amount of the yield is lost as bran during the milling stage. This amount lost as bran can be much higher for traditional varieties. A positive side of extra bran however is that it can be used as animal feed. One traditional variety, *Katumani*, was grown by a handful of farmers and only on small plots if so. *Katumani’s* comparatively low yields make it a secondary choice for many but some use it as a strategy for quick finances due to its short maturation time. *Katumani* was however the only traditional variety of maize that we encountered being grown in Sironko. Generally, we found few cases of farmers using traditional maize varieties.

The second reason home-saved seed is no longer the top channel is due to rising prices and increasing prevalence of financial poverty. Farmers felt that was common practice in the past to save maize seed for the next season. Now however, participants felt there is greater pressing financial pressure to sell the entire harvest to pay debts and meet their needs. Further, the rising prices of maize flour have incentivised farmers to mill and sell their entire seed stock in one go. Doing so provides the greater financial agency in the house, and the income to buy seed when the season starts. This behaviour does however replace the previous practice of saving some maize for food, and to sell for ad hoc costs. As such, it appears that farmers are now choosing greater financial agency, over the seed security that home-storage offers. Another consequence of this change is that maize seed security is shifting to relying on repurchase from other seed sellers, rather than one's own saved stocks.

Informally-sourced maize seed is either purchased from local seed stores, local markets or other farmers. In the past, farmers might be given seed as payment for labour but this practice has become less common. Instead, sharing and exchange of seed has largely been replaced by monetary exchange for goods or services. This change of payment type makes sense given the aforementioned shift to farmers selling most of their harvests as flour. Clearly however, some farmers must sell seed to informal seed merchants to resell. This arrangement makes sense from a seed quality assurance point of view, given that stores tend to have better infrastructure than farmers for seed storage.

Farmers obtain all of their cassava from informal sources. Planting materials came predominantly in the form as stems, which could often be obtained freely from other farmers. Acquiring stems also made it easier for farmers to avoid diseased plants, as they could inspect the source. A smaller number bought cassava planting materials from research stations, arguing that fresh stems give a better yield. Farmers stated that very occasionally, the government shares new cassava varieties, but often these go to village leaders.[10]

Beans are sold by agro-dealers but farmers find these too expensive. Instead, nearly all respondents buy bean seed from informal sources. Farmers argued that despite the price difference, yields

[10]This was actually encountered during fieldwork, where one respondent reported to have access to new cassava varieties due to her relation to the village leader.

are reportedly the same from either formal or informal sources. Informal sources tended to be other farmers or informal seed stores. A repeatedly mentioned challenge however is that beans are often in short supply on informal systems due to high local demand and short supply. Two compounding factors for this are low bean yields and that bean harvest reportedly spoils easily in storage, further decreasing available seed reserves. Both mould and insects are major drivers for bean spoilage, for which there were limited local prevention methods. The most common preservation method mentioned by farmers was the stressed importance of leaving bean husks in with the seed during storage to prevent weevils.

All rice was purchased from informal sources. Most respondents purchased rice from other local farmers but some travelled to more remote markets to find better varieties. Those who travelled, sought areas which are renowned for rice growing. This behaviour is perhaps more typical for Sironko, where rice growing is less common generally, encouraging farmers to travel to obtain seed. It does however demonstrate, firstly, that smallholders are willing to travel further distances for good varieties and, secondly, an indication of the factors that inform the decision of where to buy seed. While travel incurred costs, these were thought to be partially offset by the lower rice prices at these locations, and the financial returns such varieties might offer. Farmers reported to grow 'Winter-9', 'Super' or '*Kaiso*' rice varieties . Winter-9 is sought after for its large grain, white colour and its resilience to breaking during milling. Winter-9 also bends as it reaches maturity, making it harder for birds to eat. Super is liked but it produces lower yields than Winter-9 and takes longer to mature. Super does however get a good market price and is well-liked by consumers for its aromatic qualities. Siroko rice farmers used to grow a local variety called *Kaiso* but this is becoming less common on account of its comparatively lower yields.

6.3.4 Informal seed sellers

One component of this research sought specifically to document how informal seed sellers exist and operate. While agro-dealers are relatively homogeneous in design, informal seed sellers tend to be more diverse (Sperling et al. 2020). Respondents in this category could roughly be considered as belonging to one of three groupings. These are as follows.

6.3.4.1 Farmers trading seed

At a fundamental level, informal seed trading exists as farmers using seed selling as part of their livelihoods. The majority of seed traders we spoke to focused mainly on maize, but were also willing to sell a range of beans, groundnuts and any other locally grown crops. Respondents in this category were generally farmers who sell seed when the opportunity presented itself. These opportunities tended to occur in one of two ways. The first was if a farmer had highly-performing seed in the field, other passing farmers would notice and ask for some of the seed at the end of the season. This local observation could also take place later in the year, as farmers dried their seed in public. Buyers might be repeat customers, those who had heard recommendations or just passes-by. Some farmers also reported traders purchasing seed in this way, identifying them by the scales they carry to confirm the sales. Others however were wary of traders as they tended to drive a harder bargain to allow for their own profit margins. These same behaviours deterred some farmers from selling to informal seed stores.

Another common method informal seed trade around planting times was to actively search across neighbours. When farmers needed seed for planting, they might call on neighbours to ask for seed to purchase or take on loan. These kinds of exchange might happen with any farmer, but some farmers were particularly sought after, as they were regarded to be particularly knowledgeable or reliable producers of seed. Some of these farmers might grow certified seed, but buyers did not seem to distinguish on this factor. The main focus was how the crop appeared to be performing in the field or how the seed looked. What farmers particularly liked about this approach was the safe knowledge that the seed had performed well in the local agro-ecology before. One observation with these opportunistic sellers however is that few processed seed differently to grain. In general, farmers focused on producing grain. Where respondents mentioned selling seed, this generally came out of the same storage as grain.

Occasionally, some farmers were renowned for selling reliable seed and devoted more of time to seed production, but this was uncommon. Those who did, sometimes relied on storing and selling seed with a family member or friend who runs a store. Interestingly farmers selling seed did not see agro-dealers as competition. While they might be selling the same varieties, seed sellers felt there was significant difference between certified and saved-seed sales that both traders could comfortably co-exist. Some justified this by saying that there will always be farmers who avoid agro-dealers. In fact, some even saw the growing prevalence of agro-dealers as beneficial for their trade, as it raised the likelihood of there being sufficient quantities of high quality *mwaka moja*. A number of these traders also looked favourably on the role of agro-dealers as a valuable source of advice for farmer practice. There was also no sense of competition between farmers trading seed. Part of this might be explained by few individuals relying on seed selling as a priority livelihood. Another suggestion was that the demand for seed was much higher than local seed supply, meaning that traders had little difficulty in selling their seed stocks.

Where dedicated informal seed sellers were encountered, they appeared to operate independently, with no organised links to each other. While individual traders might know of each other, they did not see other traders as competition. Some even mentioned recommending buyers to other traders for particular varieties. While farmers in the area might be members of locally arranged groups,[11] this did not appear to be the case for many local traders. Instead, entrepreneurial informal seed sellers tended to operate separately.

6.3.4.2 Local seed stores

Local seed stores tended to come in two main kinds; general shops which included seed, and specialist shops that focused on saved seed. Most of these shops were small premises, operated by one individual, selling out of an enclosed storage space. A notable difference between agro-dealers and informal seeds sellers was open seed bags. While certified seed remains sealed until the purchaser opens it for planting, locally-saved seed was always open where it was displayed for sale. Seed bags at informal seed sellers would be opened and pulled back so that the contents are accessible to prospective buyers. During visits to informal sellers, passers-by would continually walk up to open bags, reach in, study the seed in their hand before tossing it gently back into the bag. Sellers appeared to pay little attention to these inspections and many passers-by would browse bags wordlessly in this way before moving on to another shop. This process was taking place constantly throughout interviews and marked a clear difference between informal and formal seed interfaces. It was clear to see how buyers of informal seed might feel more barriers with agro-dealers and certified seed.

While general goods shops tend to focus on household goods, they occasionally sold certified or locally-saved seed. Sometimes this was done to provide an additional product to more general customers. Other times, farmers requested merchants to stock seed as they trusted them to sell genuine products. Traders sourced local seed from farmers who visited, or sold surplus *mwaka moja* from their own harvests. Some traders inspected the fields of farmers who supply their seed, checking their practice and providing them with seed storage advice to protect the product. Doing so raised the chances of informal sellers gaining high-quality seed to pass on to their customers.

[11] Such as farming cooperatives, church groups, burial groups, etc.

Figure 25: Seed and grain being sold at a general goods store.

Where traders stocked both grain and seed, the two were always kept separately and treated differently. General stores were generally open to the elements and had little in the way of specialised storage facilities. Merchants did however speak of particular bags or storage chemicals that they used to protect seed differently from grain. Bags of seed and grain were visibly different, with seed being more uniform in size and sometimes dusty with insecticides. General goods merchants argued that saved or certified seed offer similar harvests, despite the higher prices for certified seed. Farmers with three acres or more were said to be increasingly likely to buy certified seed, as the farm size increased.

Counter to the range of goods at general stores, informal seed stores focused almost entirely on selling seed. Some also sold grain and others milled their products after sufficient time had passed that they could not guarantee viability; but seed was the primary business focus. Seeds were sourced from trusted local farmers. All maize varieties were *mwaka moja*, with some clarified as sourced from farmers who only grow certified seed. Informal stores appeared to be particularly careful about how they sourced seed and how it was stored. Similarly to general shops, some informal seed store owners mentioned visiting the farmers' fields to check the status of the crop in the field. Sometimes these checks were made to confirm the variety's performance in local conditions. Seed that was brought to the store was subject to careful scrutiny. Some informal sellers were remarkably perceptive of seed health, demonstrating techniques they used to ascertain seed quality. One seed seller showed how he could recognise different varieties of Longe seed by sight, ensuring customers purchased the correct variety. Dealers would also check if the kernel embryo was white, as discolouration signified damage to the seed. Other checks were made for insect damage, with one saying that he would also decline seed it had been treated too heavily with pesticides out of concern for seed viability. If seed failed any of these checks, they would be turned down by the sellers. Sellers were also seen to be sorting seed for uniformity, moving smaller or deformed seeds to bags intended for grain.

Rice, beans, pigeon peas and potato appeared to be the next priority products for informal traders. Beans in particular showed particular diversity of local varieties. These included *Kanyewa*, Tanzania, *Sitoti*, Obama (or red beans), *Watawa* and yellow beans. Stocked bean varieties were those that were well-suited to the area and offered locally-valued traits. These traits included early maturing, shorter cooking time, colour in cooked dishes.[12] Previously they stocked *Nabumfubo* and *Mufumbachai* beans but a poor season previously meant that these varieties had become locally scarce. Similarly one seller mentioned that he usually sells groundnuts but there was no stock this year, due to a poor harvest in the previous year. The absence of these varieties demonstrates the uncertain continuity of crops between seasons, where a poor season can quickly cause a local variety to disappear.

Informal seed traders reported few cases of locally-saved seed failing to grow. They explained this as a result of the quality products they sell. Traders felt that seed producers are honest with them about how seed is stored, the number of times recycled and other factors that might affect viability. They argued that the system operates on a self-policing process of trust and the repeated custom for reliable products. Those who sold poor quality goods would quickly lose customers. Rather than encountering instances of seed failing to grow, traders reported farmers confirming comparable returns from *mwaka moja* to their neighbours who grow certified seed. Agro-dealers on the other hand were viewed with suspicion, with some believing they sell expired seed. While this claim might have some basis, technically farmers are able to check the expiry date on certified seed bags and so can confirm if a bag is past its expiry.

Stores confirmed that *mwaka moja* sells for around half the prices of certified seed alternatives. One trader confirmed that he makes around a 17% profit on seed he buys from farmers. This same trader estimated that he sells around 1,500kg of seed in a season. He also believed this figure to be about 50% more than local agro-dealers achieve, and used this claim to demonstrate

[12]Red beans were associated with blood and so believed to be healthy to consume.

the demand for *mwaka moja*.

6.3.4.3 Integrated seed system

One of the interviewed informal seed groups we spoke to was a Local Seed Business (LSB) focused on sweet potato production, but also sold beans, cassava, plantain and aubergine; all crops with lower market value than cereal alternatives. The integrated seed system is becoming more prevalent across Uganda and these groups can now be identified online and contacted (Mastenbroek and Menya 2015; Mastenbroek, Otim, and Ntare 2021a).[13] The LSB members encountered in this research had been trained by a government programme in how to maintain and multiply varieties to provide to local farmers. The resulting planting materials the LSB produces is inspected and sold as a more recent category of seed known as 'Quality Declared Seed' (QDS) (Mastenbroek, Otim, and Ntare 2021a). This certification status marks the seed as locally produced by farmers, but checked by local officials for quality throughout the production stages (described in more detail below).

The LSB had acquired its sweet potato varieties from the National Agricultural Research Organisation (NARO), International Potato Centre (CIP) and HarvestPlus. These varieties include:

- Orange-fleshed sweet potato: NASPOT 9, 8, 10, 12, *Kakamega*, *Ejumula*.
- White-fleshed sweet potato: Tanzania, NASPOT 1, Umbrella, *Muwulu*, *Aduduma*, *Bunduguza*.
- Beans: NARO 1, 2 and 3.
- Cassava: NAROCASS 1, 9 and 14.

LSB sweet potato varieties are grown in designated gardens that are inspected three times in a season by a local government regulatory inspector. The inspection includes checking the progression of the crop and confirming the absence of pests or diseases. More recently, these tests have been conducted with the support of an app called "*viazi vitamu*".[14] The LSB members take photos to log the progress of the crop, which are confirmed by official inspectors on field visits prior to harvest. A similar process is followed for beans and other crops, but without the support of the app. Upon successful completion of the inspection, the QDS batch is certified to confirm the seed viability and moisture content. The subsequent seed harvests are either stored

[13] Which can be viewed here: https://tinyurl.com/jmcm5arf

[14] Which means 'sweet potato' in Kiswahili.

locally, or transported to specialist storage facilities.

LSB members were extremely knowledgeable about varietal differences, able to give precise guidance on how to grow and process each of their varieties. The LSB differed from formal seed systems in that it provided a two-way flow of information between farmers and breeders. LSB members worked with both the breeders and the farmers, able to learn from both sides and provide a conduit between the two groups. There are two examples of how this interface benefited variety improvement and uptake.

1. **The improvement of crops originally designed on the formal system:** The arrival of orange-fleshed sweet potato to the area was expected to be a great success in reducing vitamin A deficiency. However, despite the offer of improved nutrition and promotion by NGOs, local uptake remained low. While formal bodies tried to raise demand through advertising the nutritional benefits of the crop, the LSB worked with farmers to understand why they preferred other varieties. For example, they found that many farmers prefer the dense starchy quality of white-fleshed sweet potato and this quality also made it a popular breakfast choice from the remaining cooked sweet potato from the previous evening. Orange-fleshed sweet potato on the other hand is comparatively much softer and sweeter after cooking; both qualities that farmers disliked, especially as a breakfast sweet potato dish. LSB members heard this feedback first-hand and were able to share this back to breeders, along with the local variety preferences. This allowed breeders to develop new varieties of orange-fleshed sweet potato that were more suited to farmers tastes and uses, which in turn increased uptake.
2. **Preservation of locally valued traits:** Farmers visiting the LSB shared well-liked local sweet potato varieties, but those which are comparatively low-yielding. Here, the farmers wanted to maintain these useful traits but as part of a more high-yielding variety. The LSB worked as a convening agent for the farmers to gather and document the varieties that they wanted to improve. The LSB then shared these locally-valued varieties with breeders who crossed the local varieties with modern versions to find favourable mixes of traditional and high-yielding traits. The LSB then gave these varieties names that sounded like the local language, to demonstrate this heritage and encourage local adoption.

As well as providing varieties, the LSB provided a source of education for planting and preparing their varieties. More generally, the LSB provided locally specific methods of which varieties to choose, how to grow and store them. This training included teaching the difference between storing food and seed, and how to get the best out of planting materials. The LSB also taught farmers how to make a local pesticide[15] to provide a cheaper pest protection for less market-focused crops.

The LSB developed demand for their varieties through demonstrating their best uses to farmers. Demonstrations were held as events where farmers were welcome to visit and sample a range of prepared goods from each of the offered varieties. For example, attendees of a sweet potato event day were offered traditionally cooked sweet potato dishes, but also more innovative dishes such as sweet potato pancakes, biscuits and sweet potato juice. LSB staff would explain the different qualities of the varieties as they shared these dishes with farmers, providing comparisons with local varieties and sharing tips of how to achieve the best end product. The process helped farmers navigate the varietal choices offered by the LSB, and built demand for new and exciting choices. What's more, all of the varieties were on display, allowing farmers to inspect the diversity of sweet potatoes and vines. This also added a visual component as it was clear when farmers were purchasing collections of potatoes or vines.[16] In addition to events, the LSB advertised their wares through agricultural shows, radio programmes and local WhatsApp groups.

The comparatively low running costs of the LSB versus formal seed production meant that they could sell lower market crops as a sustainable business model. Even at lower prices however, LSB members mentioned that farmers are reluctant to pay for planting materials for crops intended for food rather than income. For example, few farmers wanted to pay for improved cassava when they can continue to re-stock their own cassava for free. LSB members felt that farmer demand will eventually increase for modern food-crop varieties, but it will take a longer time than for more business-focused crops.

The LSB was organised through a cooperative of farmers with independent plots, selling from a central location. The group appeared to be comprised entirely of women, many of whom wore matching orange t-shirts as a uniform; presumably because of the sweet potato colour. An agreement of joining the cooperative was that only the leader of the LSB is able to sell the seed products. While this seemed autocratic, LSB members were supportive of the arrangement and claimed it ensured the growth of the LSB. The reason for this was that each LSB farmer would be approached by neighbours requesting a free share of their harvests. Turning down these requests was morally difficult, despite the drain it had on the LSB's operations. LSB farmers

[15] Made from tobacco, garlic, cow dung and urine.

[16] Additionally, the event was fun. Farmers were clearly enjoying themselves and the atmosphere was one of excitement and cheer. It was clear to see why the event was well attended.

therefore appreciated being able to use the argument of potentially losing their LSB membership as a way to legitimise declining such requests. This arrangement was also thought to ensure that all customers pay the same price, as it was expected that many would use personal relationships to request lower prices. Clearly this arrangement placed significant power and control in the hands of the leader of the LSB, but it appeared to be both successful and welcomed by the members. Perhaps to prevent distrust, the prices offered to each customer type were well-known and advertised. Farmers would pay 15,000 UGX for a bag of vines, while NGOs pay 20,000 UGX. Customers of the LSB include: village locals, schools, NGOs and the district offices.[17]

6.4 Discussion

A common argument is that Ugandan smallholder productivity is restricted by relying on informal seed systems, which circulate poor quality and older varieties (Thomson 2008; Agra 2017; Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019; Conny J. M. Almekinders et al. 2021) . We however repeatedly find that farmers are already growing modern varieties, and they prefer to get these from informal sources. This begs the question, if farmers are not accessing modern varieties through certified seed, what type of seed are they using? Further, how do these sources compare and why do informal sources appear to be preferable to formal sources?

6.4.1 Modern varieties and *mwaka moja* seed

When farmers spoke about modern maize varieties, this did not necessarily relate to seed derived from the formal sector. Modern varieties were sometimes purchased as certified seed from agro-dealers, but they were also a regular option on informal channels. Participants generally agreed that certified seed *can* give a better yield than locally sourced seed, but that this is not certain. While many formal channels and initiatives associate informal channels with low-performing varieties, to the farmers they offered modern varieties of comparable quality to certified seed. Some also argued that saved seed performs equally well, or that their own-saved seed is more reliable than certified options. Comparative performance claims makes sense given that this saved seed was often the same modern variety as the certified alternative.

Most respondents had purchased certified seed within the last five years from agro-dealers. Many, however, more generally buy '*mwaka moja*'; which translates as 'one year'. *Mwaka moja* seed might also be referred to as "home seed", or "white maize seed" on account of it not having been

[17]The district often purchased seed or grain to give to schools.

treated and dyed.[18] In theory *mwaka moja* is the subsequent progeny from certified seed, but this 'first descendent' status was based on the word of the seller.[19] As such, the validity of the single generation element depends on the knowledge and trustworthiness of the seller. Overall, it seemed that some farmers and traders might take a less literal reading of *mwaka moja* as 'one year', and instead understood it more as a marker of its inheritance. Put another way, the emphasis of the *mwaka moja* term is a caveat that the cultivar originates from the formal sector, and subsequently a potential source of useful traits. This might make sense, given that farmers associated research centres with useful varietal innovations, even if they were dubious of certified seed.

Farmers spoke about growing modern varieties, without qualifying if the seed was *mwaka moja* or certified. For instance, a farmer would report to grow the certified variety Longe-5, regardless of purchase channel and seed type. This distinction, or lack of it, is important because it marks a difference in the narrative around Ugandan smallholder use of modern varieties. Formal actors say that modern variety adoption is low, but every respondent we spoke to grew modern varieties. As our seed channel ranking shows, the "local seed" *mwaka moja* version of a certified variety was the preferred acquisition strategy to access needed varieties. In theory, agro-dealers will not sell these locally saved seed, arguing that they are of lower quality.[20] While some, particularly wealthier, farmers are more likely to regularly buy from agro-dealers, many farmers gave reasons why they prefer to buy seed from local channels and avoid agro-dealers. While agro-dealers have been tasked with bringing modern varieties to farmers, farmers instead seem to draw on informal seed systems to gain these useful new varieties (Chinsinga 2011). *Mwaka moja* was the conduit by which farmers could access formally improved seed, while still harnessing the benefits provided by local seed supply. Even for wealthier respondents, *mwaka moja* was seen as something that enabled low-risk experimentation of new varieties, and acted as a stepping stone to move from subsistence to commercial farming.

Saved formal sector seed is likely to lose valuable traits. The potential for variation in generational performance and 'true-ness' to type with *mwaka moja* can be explained from a biological perspective. Most of the maize respondents were growing hybrids. Since this seed is offspring of an F1 hybrid cross, the resulting heterogeneity in genetics of the field population will quickly lead to plants in subsequent generations that further differ from parent lines; resulting in less

[18] As is the case with certified seed.

[19] Although some potential buyers reportedly check this with the farm who was said to have grown in.

[20] Although in practice, we find that around half of agro-dealers do sell saved local seed - see previous chapter.

predictable traits in successive generations. The same result is expected for open-pollinated varieties, but to a lesser extent due to less heterogeneity in the parent line. An additional detail to consider here is that maize is wind pollinated, meaning that genetic out-crossing is influenced by the varietal mix surrounding the plant (Aylor, Schultes, and Shields 2003). Thus, one potential benefit of growing a mix of certified and home-saved seed is the mixing of formal sector improved traits with traits for local adaptation. This effect would be difficult to control, and uncertain in result, but could explain why farmers had mixed views on how *mwaka moja* performed compared to certified seed.

Farmers expected trait variability over subsequent generations but many seemed ambivalent of its impact, stating that the yields of *mwaka moja* were comparable to those of the seed purchased from formal channels. This finding was surprising as yields from hybrid offspring should be noticeably lower than parent lines. One explanation could be that hybrid seed from the formal market is of low quality, which limits performance.[21] Another reason could be that farm conditions are limiting hybrid productivity. This might make sense given that few of the respondents use fertilisers and many saw agricultural inputs as unaffordable. Additionally, all respondents relied on rain-fed agriculture, and had little capacity to deal with either too little or too much rain. All of these factors raise the likelihood of sub-optimal growing conditions for the crop. Such conditions would limit the productivity of maize hybrids, bred to give the best yields under the optimal nutrient availability. As such it might be that limiting growing conditions are constraining productivity differences between parent and offspring lines; justifying saving seed.

An alternative explanation for similar yields between hybrid generations could be that the genetic heterogeneity in offspring lines caused some individuals to be better adapted to local conditions (Westengen et al. 2014). If farmers are continually selecting more adapted individuals, this might make these subsequent generations more competitive in local conditions. Such selection would require careful and prolonged practice by the seed collectors. We did encounter selection by farmers, but this was limited to keeping the biggest cobs or kernels for seed and leaving the others for grain. Still, perhaps even these more rudimentary methods to repeatedly resow the highest performing individuals are sufficient to select for local adaptation (Westengen et al. 2014). We did however find more varied and strategic selection with Local Seed Businesses. This group worked between farmers and breeders to develop beneficial growing traits (such as pest resistance) and consumer traits (such as cooking qualities). They also served to incorporate

[21] As explored in the previous chapter.

locally valued traits in improved varieties. LSBs in Uganda are however solely targeted towards less market-focused crops (Mastenbroek, Otim, and Ntare 2021a). Given our findings, there appears to be potential in how LSBs could improve *mwaka moja* of cash crops in collaboration with farmers. At present however, such practices bring legal implications.

Officially, the resowing and selling of *mwaka moja* is illegal under the 1991 International Union for the Protection of Varieties of Plants (UPOV) act (Jonge 2014; Wattnem 2016) . The act came into effect in Uganda upon joining the World Trade Agreement in 1995 which binds members to adhere to intellectual property laws (Tansey 2011; Ulmer et al. 2014; World Trade Organisation 2023). Respondents however made no mention of policing the resowing and selling of privately owned germplasm. While it seems unlikely that local government would be able to police this activity in the short-term, the law currently stands opposed to the majority of smallholder practice. As the formal sector moves to replace informal seed sources, it is unclear how these laws could outlaw and restrict the ways farmers are accessing modern varieties.

6.4.2 Seed access, availability and quality challenges across channels

Farmers had a range of reasons why they avoid agro-dealers which can be organised across seed access, availability and quality dimensions (McGuire and Sperling (2011); McGuire and Sperling, 2016).

6.4.2.1 Seed access

A fundamental principle of seed access is the cost a farmer must pay to obtain the cultivar. Farmers felt that agro-dealers sell high-quality seed but that this comes with a financial cost that some cannot afford. Seed prices vary across channels but farmers confirmed that agro-dealers charge the highest price for seed, as compared to local shops or markets (Chinsinga 2011; McGuire and Sperling 2016). Respondents reported that seed from agro-dealers is double to three times the price of *mwaka moja* from informal channels. At the time of writing, a kilogram of *mwaka moja* Longe-5 costs between 2,000-3,000 UGX, but costs around 6,000 UGX on agro-dealers. Agro-dealers also only sell in 2kg bags and upwards. Locally-saved seed however can be purchased in any amount. These prices fluctuate with the seasons, with agro-dealers raising prices closer to the rains. One informant saw this price hiking as a suggestion that farmers *can* afford more expensive seed, if sufficiently persuaded.

> *The reasons these agro-dealers have the leeway to raise the price is because people*

will buy anyway. So if it was really about poverty, it wouldn't be able to fluctuate so much. Because ultimately, agro-dealers know people will buy.

(Seed sellers group, Interview 5)

A number of respondents made a remark that certified seed is expensive to buy but the end product (the grain) still sells at the same price as locally bought seed. The feeling here was that some are reluctant to pay more to get the same end product. Clearly the aim of certified seed is to obtain higher yields for more product to sell, not an increase in the per unit selling price. Some however seemed to feel that certified seed should only command such prices if it provided a more valuable product, as well as a greater yield. An additional concern was that certified seed requires fertiliser to achieve the yields required to offset the price difference. This additional input cost further increased the price requirements that farmers expected with certified seed.

There were mixed views about whether more farmers would purchase from agro-dealers in the future. Some felt that the proportion would increase if more farmers found benefits in certified seed. Others felt that poverty was deepening, making the prices of agro-dealers even more inaccessible to farmers generally. This outlook was enforced by the commonly held view that soil fertility was declining, which further reduced harvests, and the resulting returns from farming. Under this scenario, the prices of certified goods and related inputs were expected to become increasingly inaccessible with time. These pressures are not felt uniformly across farmers. In the presence of diminishing harvests, the price of maize often increases, raising the returns on investment for those who can access certified goods and inputs. As such, the wealthier farmers were expected to make a gain while poorer farmers struggled.

Another accessibility component involves not just overall price of seed, but *when* that amount is paid. Certified seed is a higher price due in part to production costs in producing the seed (Chinsinga 2011; A. Mastenbroek and Ntare 2016).[22] Farmers purchasing from agro-dealers must pay upfront, whereas purchase of *mwaka moja* could be on credit, giving farmers more flexibility to spread investment costs. An alternative way for farmers to obtain modern varieties would be as donations. NAADS channels offered the potential for farmers to receive certified seed as donations but these programmes were too infrequent for farmers to rely upon them.

[22] Including lab-based breeding programs, processing costs and the need for company profits.

6.4.2.2 Seed availability

Respondents complained about agro-dealers on a number of seed availability grounds. The first is that agro-dealers are often situated away from the farm, making their products less locally available. The further distance brings additional access barriers. Travelling to agro-dealers brings additional costs in both transport payment and the time that could be spent on other activities. Agro-dealers are located in towns that respondents felt to be distant from their farms. This distance echoes other findings of agro-dealers being concentrated in towns or established high productivity areas, away from remote rural areas (Chinsinga 2011; Farrow et al. 2011; Odame and Muange 2011). Some respondents did however feel that the number of agro-dealers is increasing, and that this was bringing them closer to rural areas. Where there are travel costs, respondents confirmed that these are likely to be particularly imposing along age and gender dimensions, where the ability to leave the home for long periods of time is unequal across farming actors (Chebet, Adong, and Ninsiima 2015; McGuire and Sperling 2016).[23] Local markets and shops however were closer to farmers, making their products more available and reducing the costs of travel. These benefits are further enhanced by the greater range of utility markets offer. While agro-dealers are specific in what they sell, local markets sell a wider variety of goods. This meant that visitors could obtain seed at the same time as acquiring other farm and household goods, sometimes immediately after gaining finances from selling their own products. As such, visiting the market provided a more efficient and convenient way of selling and purchasing household resources.

Another availability dimension was timeliness. Due to the reliance on rain-fed farming locally, farmers need to have seed ready to sow for when the rains start. However, those who did venture the distance to agro-dealers confirmed other reports of being met with closed shops while the owner had left to pursue another activity (Chinsinga 2011; Staudacher et al. 2021). Those dealers that were open sometimes lacked the variety the farmer sought due to company deliveries not reaching the stores in time for the season. In contrast, neighbouring farmers, local shops and markets provided dependable availability of *mwaka moja*. Respondents could even book this in advance, asking if neighbouring farmers would save seed for them upon harvest.

Local seed availability on informal channels allowed farmers greater flexibility in choosing when to prepare their seed stocks for the rains. These informal channels provided a lower-risk approach

[23]This also applied to selling seed. As one respondent put it: *'it is mostly men who are selling seed because men are free to move.* Informal seed sellers, Interview 5.

than gambling on whether agro-dealers would have the seed in time (McGuire and Sperling 2013). This flexibility component is important as respondents mentioned that climate changes have made the rainfall patterns unpredictable in recent years. Having seed more generally available therefore made local farming more resilient to seasonal shifts. Despite government focus on formal seed sale, it was largely informal seed sources that provided farmers with this greater seed availability. Compared to agro-dealers, local seed sources offered a more reliable seed source for resource-poor farmers to draw on. Even informal seed traders felt local seed trading kept useful varieties in the community, to be easily accessed as required. There was however a caveat for this. Large seasonal shock events could dramatically impact local farmer production, which had a significant impact on the amount of locally available seed. In these events, farmers would have to find other sources to obtain seed from. In these instances, agro-dealers provided a way for farmers to access seed from beyond the local community.

6.4.2.3 Seed quality

Contrary to other reports, participants saw agro-dealers as comparable to local seed channels on seed quality grounds (Bold et al. 2017; Boef et al. 2019; Barriga and Fiala 2020). Participants felt that the agro-dealers have good infrastructure to store seed, but some dealers are trusted more than others. When people do buy from agro-dealers, the main quality check is to check the expiry date. There were however many farmers who could tell stories of agro-dealer seed failing to germinate. Farmers found these experiences to be particularly concerning given the comparative higher prices for certified seed. A challenge with such stories is that they are sensational to the audience, with the teller stressing the injustice of failed harvests. Farmers were visibly shocked at the telling of these tales and this sometimes made it difficult to determine if tales were exaggerated to boost the excitement of the story. There were however distinct similarities in these reports across locations, suggesting commonality in certified seed failing to perform.

Despite the regulation and strict packaging rules involved in the formal seed sector, farmers reported purchasing seed that was a different variety than labelled, or failed to germinate at all. Similar complaints were made for local sources but the majority of cases were reported to have come from agro-dealers in distant trading centres; something that was particularly disliked by farmers on account of the aforementioned travel costs involved. Respondents stated that this "fake seed" is the reason they would not purchase from agro-dealers again. *Mwaka moja*, on the other hand, offered more dependable results, which encouraged repeated use.

Respondents reported that *mwaka moja* is reliable on a number of quality and trust grounds. Conversely to counterfeit studies that frame informal seed systems as vulnerable to untrustworthy sellers, farmers spoke of trust and quality tests that they could conduct with informal sellers which give them the confidence to purchase (Joughin 2014; Longley et al. 2021; Mabaya et al. 2021). The most basic of these tests is that farmers ask local seed traders which farmers they obtained their seed stock from. Some farmers are locally known to plant good seed and naming them alone is an indicator of quality. Naming the individual also gave farmers the chance to check with that person to confirm if the seller was genuinely selling their seed. Farmers mentioned the presence of untrustworthy sellers, but these were generally unknown, opportunistic individuals; and generally avoided. These same farmer checks of seed origin are not possible when purchasing improved seed from agro-dealers. This means that farmers had to believe the word of the seller and overall, respondents did not trust agro-dealers. They felt the sellers deliberately sold them varieties which might not be adapted locally and knowingly sold fake or damaged seed. Farmers believed agro-dealers thought they could get away with this behaviour because they knew it would be expensive for the farmer to return. Conversely, instances of failed germination from local sellers was seen as more of a case of bad luck. Farmers rationalised this view on account of local sellers being known to the community, and would not risk their reputation by selling poor-quality goods. It is hard to see why this argument would not also apply to the sellers in agro-dealers, and indeed some agro-dealers were trusted. Generally however, there was a feeling that farmers were reluctant to shop with traders they did not know, and this appeared to be the default category for agro-dealer staff.

Ironically, formal sector quality assurance methods of seed dying and sealed bags were viewed by farmers as barriers preventing them from checking seed quality. Farmers have their own quality checks for seed which they conduct on *mwaka moja*. Formal sector methods of seed protection added barriers to these local quality checks. Firstly, certified seed is sealed in a bag to protect it from adverse environmental conditions and maintain batch identity. Farmers are expected to rely on the printed expiry date for seed viability, which they find to be misleading. Counterfeiting reports have resulted in the formal sector advising agro-dealers to not to open bags, and for farmers to avoid open seed bags. This however also means that farmers cannot check the seed within the bag before purchase; a given test with *mwaka moja*. Even if farmers could get into the bag, certified varieties are coated and dyed to protect against insect damage. While these treatments will support the development of healthy seed, they prevent farmer tests for other forms of seed deterioration from dampness or physical damage (see table below). Some

Table 13: Farmer quality tests

Maize	• Select bigger seeds for planting. • Check for holes that suggest weevil damage. • Check if the seed is broken or damaged. • Check maize colour, as white is better for planting. • Test dampness by biting the grain. If the grain splits, it is acceptable moisture content. If it does not split, it is too damp.
Beans	• Check for holes that suggest weevil damage. • Check to see if seed has already germinated. • If the seed is too light and 'shakes', it will not germinate.
Tomatoes	• Hold the seed in hands and if it sticks together, it is too damp and will not germinate.

farmers even mentioned removing the certified seed coating to reveal dead seed beneath. Farmers might be willing to forgo these tests if formal sector seed was reliable, but participants felt the opposite. Rather than an inviting purchase of high quality goods with a good return on investment, farmers felt that acquiring modern varieties from their formal channel of design is a risky gamble. Purchasing these same varieties as *mwaka moja* however allowed farmers to make a more informed decision and therefore one of reduced risk.

The formal sector differentiates locally saved seed as unregulated, and consequently lower quality. What we find instead is that farmers and traders are using their own checks to regulate the quality of their purchased local seed and this allows them to avoid low-quality seed. In naming one type of seed certified, one must avoid the implied assumption that non-certified seed is entirely unregulated. These assumptions are misleading at best. It is regulated *differently*, around the point of sale, using physical tests and drawing on social networks. Importantly also, the most risk sensitive farmers find this form of regulation to be reliable. Conversely, the certified seed around our respondents appears to be suffering from the very forms of quality issues that regulation should identify and prevent. This might be understandable on capacity grounds given that there are very few inspection agents in Uganda tasked with covering the country (Joughin 2014; Barriga and Fiala 2020). While it remains unclear as to where these potential quality issues lie in the seed supply chain, these findings caution against assuming that certified seed is more reliable than informal seed. Present methods of selling certified seed prevent farmers from confirming the quality prior to purchase. *Mwaka moja* on the other hand allowed farmers to access modern varieties, while still being able to check against quality threats prior to purchase. While other accounts report unscrupulous sellers operating in informal systems, our respondents instead held the most distrust for agro-dealers.

6.4.2.4 Local suitability

Farmers felt that new certified varieties performed badly due to not being suited to the local environment. Farmers meant this with regard to their local agro-ecology but this could also be because certified varieties are often developed to respond to the input levels of commercial farmers, that likely differ from smallholder plots (McGuire 2005; Joughin 2014). Respondents were concerned that they would invest in a variety that would fail to grow at their farm and this discouraged investment in new varieties. Conversely, the existence of *mwaka moja* seed was seen as a form of evidence that the variety had already performed in local conditions; as another local farmer had successfully grown it. Knowing this gave farmers confidence that the variety could perform in local conditions. Still, this concern over local suitability raises questions over how these new certified seed technologies are designed for the context, and who they are designed for.

6.4.3 The social side of seed technology

From an affordances perspective, the organisation of the Ugandan formal seed sector appears to block many of the relational dimensions between seed technology and smallholders that influence product utility. Respondents report that certified seeds are difficult to acquire due to access and availability barriers. These barriers are both material, where farmers physically cannot acquire seed, and socio-economic, where farmers lack the economic capacity to achieve certified seed benefits. These influences go on to dictate the affordances of modern seed across rural areas for different farmer types. For example, they determine where modern varieties offer use to poorer or less mobile groups. Adding to the financial risk of purchasing certified seed is that bags are impossible to quality test before purchase. Farmer seed tests are subverted by formal seed actors that enforce rules for regulation. Farmers might be more likely to abide by these rules, were certified seed not widely known to suffer from poor performance.

Farmers in our study feel blocked by, distant from and distrustful of certified seed and the agro-dealers who are positioned by the formal sector to disseminate new crop technologies. Agro-dealers were felt to have a position of power in this system and could use this to take advantage of farmers. There are power dynamics in how formal actors have created regulatory routines that overrule farmer know-how of testing seed quality. Rather than feeling enabled and included, smallholders felt inconvenienced and othered by the interface of formal sector crop technology. But likely for these very same reasons, farmers are using their agency to choose seed technology they can obtain without these social constraints.

Informal seed channels provided smallholders with context-friendly ways to perceive, test, and confirm the affordances that a new crop technology presents. *Mwaka moja* provided the mechanism to use these same informal channels for formal sector derived modern varieties. To the farmers, these cultivars they purchase from informal channels are the same as those on offer at agro-dealers; a view not shared by the formal sector. In this sense *mwaka moja* is not a different type of seed but a deliberate reconfiguring of the structures around the product into an alternate technology system that empowers farmer agency. Through *mwaka moja*, farmers could acquire useful products and incorporate them into the informal sector practices, communication flows and institutions of crop technology. This changed the capability farmers had to choose varieties around their needs. It empowered farmers to use their social capital and experiential know-how for quality assurance. The result is a more reliable option that risk-averse farmers found value.

If the aim is to get useful seed into the hands of farmers, perhaps the current situation is working better than many claim, with more farmers gaining modern varieties via the same informal seed systems that are framed as perpetuating low-quality germplasm (Toenniessen, Adesina, and DeVries 2008; *Uganda Vision 2040* 2013). In this sense, the formal seed system might be indirectly reaching a wider range of Ugandan farmers than projected. However, the private nature and expensive running costs of the formal sector make this model unsustainable for companies that rely on repeat custom. Further, the practice of *mwaka moja* directly threatens plant breeders rights for institutions who own the intellectual property to the genetic material (Ulmer et al. 2014). Under the Union for the Protection of New Varieties of Plants (UPOV) act, farmers engaging in *mwaka moja* are operating illegally but it seems unlikely that this will be policed at the scale needed to prevent the practice. Regardless, both seed companies and plant breeders hold influence in seed sector policy and pose lobbying power to push for agricultural policies that favour their interests. It is in the business interests of both these groups to push for their replacement of the informal seed sector, on grounds of the competition it poses, despite its priority role in proliferating new crop technologies to smallholders. This replacement of informal channels is justified on grounds of delivering quality-regulated seed that is better on account of the high-yielding germplasm. However, our respondents' experiences make them reluctant to trust the quality of seed from formal sources. Instead they see *mwaka moja* seed as a safer way to experiment with new varieties and yield a return on investment. Improving the regulation of formal seed quality might reduce experiences of poor-quality seed and encourage more farmers to purchase from agro-dealers, but this would not address the seed access, availability and suitability barriers that also discourage purchase. Instead it seems that farmers need a solution that offers useful variety innovations, with the interface of the informal sector.

A middle ground to connecting the benefits of both the formal and informal seed systems would be to encourage the expansion of integrated seed systems (Louwaars and de Boef 2012; Louwaars, de Boef, and Edeme 2013; Adong and Manager 2021). The LSB in our study demonstrated the twin track approach between formal and informal seed systems that integrated seed systems can bring for varietal innovation (Adong and Manager 2021; Mastenbroek, Otim, and Ntare 2021a). Through farmer trained task groups, the LSB moulded the material aspects of crop improvement, with the social elements of smallholder seed technology. It used demonstrations that helped farmers perceive greater affordances in new modern varieties. Through these exchanges, the LSB incorporated traits of cultural and symbolic value in modern varieties to better meet the needs of people who wanted to be part of the technology. The LSB did this while on lower running costs than the formal seed sector, which allowed the sale of seed at lower prices and on less market-focused crops. Since the LSB was locally based, their improvements were contextually suited and the interfaces closer to customers in more remote areas. This proximity made them more responsive to local needs. From a technographic perspective, it was not just the material products that benefited farmers, but also the arrangement of actors and institutions that empowered farmers and offered them utility. Farmers were welcomed to be a part of the breeding and exchange process that involved them differently to the purchase-focused agro-dealer interface of the formal seed sector. Instead, the LSB offered a model that more closely resembled the reciprocal engagement of informal seed networks, where actors blur the roles of buyer, producer and breeder, mutually contributing towards understanding of varietal needs and improvement. Rather than passive recipients of breeding outputs, farmers assumed roles as guides in the performance of varietal improvement. Farmers drew on these roles, using the agency they provided to shape and exploit the affordances of varieties towards their own needs. The LSB created the forums for farmers to assume these roles, and also profited by these arrangements through repeated farmer engagement and purchase.

6.5 Summary

Ultimately, farmers need access to the best crops for their nutritional and livelihood needs. Crop innovations offer opportunities to face growing climate change risk, and small-scale farmers are likely to be most vulnerable to these risks (Gizachew and Shimelis 2014; Harvey et al. 2014; Dhankher and Foyer 2018). The Ugandan formal seed sector has been tasked with bringing these innovations to farmers, which it does through selling certified seed through agro-dealer networks. Instead however, farmers seem to be choosing informal channels

Our findings show how subsistence farmers are accessing new varietal innovations through their own informal networks, and the importance of these informal seed sources for seed security. Avoiding agro-dealers does not however mean low adoption of *modern* varieties. Farmers want modern varieties, which is demonstrated through their active sourcing and cultivation of *mwaka moja*. *Mwaka moja* and informal channels offered farmers with comparable material qualities to certified seed, but with greater affordances to the range of smallholder actors. Integrated seed systems offers further potential to improve and proliferate modern varieties with smallholder needs in ways that the formal sector might struggle to achieve. Engaging with these systems, rather than attempting to replace them with a modern commercial model, offers farmers with greater opportunities to obtain useful crop varieties.

Overall, there is a need for plurality in seed systems to support farmer seed security (Mastenbroek and Menya 2015). Public investment should continue to invest in the formal seed sector, alongside investments in alternative approaches, such as integrated seed systems. These other seed systems might better improve farmer access to a nutritionally diverse range of crops, rather than being restricted to commercial crops. Where the formal sector targets smallholder purchase, the standard of regulation must be improved to help encourage risk-averse farmers to invest in certified seed. Quality Declared Seed offers a way to include farmer needs in varietal improvement in a way that empowers local crop technology institutions, and seed security.

Chapter 7

Shifting preferences for Ugandan seed systems

Despite Ugandan government strategy, farmers appear to be avoiding certified seed and the channels it is sold through (Joughin 2014; Bold et al. 2017; Barriga and Fiala 2020; Bagamba et al. 2023; Mordor Intelligence 2023). On the surface, formal seed channels offer farmers with a conduit to the latest crop technologies, sold as regulated products in the form of certified seed (Toenniessen, Adesina, and DeVries 2008; Thomson 2008; Agra 2017; Rege and Sones 2022). This model was championed as a way to improve productivity through the Green Revolution, and has subsequently been repeated across many countries internationally. From this point of view, it is unsurprising that the Ugandan government, like many other African governments, sees the transformation to formal seed systems as the answer to raising yield and reducing poverty (*Uganda Vision 2040* 2013; Naluwairo and Barungi 2014; Longley et al. 2021). To date however, seed uptake from agro-dealers remains low.

Low uptake from formal seed channels cannot be solely explained as a lack of farmer interest in modern varieties. To the contrary, as our previous chapter demonstrates, there appears to be ubiquitous demand and use of modern varieties in Sironko, just not necessarily in the form of certified seed from agro-dealers. This seems unsurprising given the potential returns modern varieties offer. It is however problematic given the intended role of the formal sector in bringing modern breeding discoveries to farmers. For example, if a new maize disease appeared that threatened farmers' fields, solutions from modern breeding innovations would be deployed solely through formal systems. Integrated seed systems are starting to offer another mechanism for varietal innovations to reach farmers, but these systems are more decentralised, target less market-focused crops, and have varying local presence across the country (Adong and Manager 2021; Longley et al. 2021). Instead it seems that farmers want modern crop technologies, but are less welcoming of the surrounding social structures designed for their deployment. Findings such as these show the importance of seed channels in the decision-making around varietal adoption.

A great deal of study focuses on how to change crop technology products to meet farmers' needs, but greater attention is required on these deployment channels, and how they could be optimised to best suit farmers (Rattunde et al. 2016; Mendes-Moreira et al. 2017; Weltzien and Christinck 2017; Meressa and Navrud 2020; Krishna and Veettil 2022). Seed channels fundamentally offer a range of products, but they also influence how farmers can identify, review and acquire seed technology (McGuire and Sperling 2013). Better understanding of farmer preferences between seed channels could be used to inform extension systems tasked with putting useful crop technologies in the hands of farmers.

As shown in previous chapters, farmers choose from a range of seed channels for a range of reasons (McGuire and Sperling 2016; Sperling et al. 2020). As shown, rural Ugandan seed selection strategies are primarily determined by crop type, and subsequently structured by the various affordances of each channel and the products they offer. For example, maize farmers have specific seed channels to select from, and each affords the individual with a different range of action possibilities; *what* they can buy, *how* they can buy it, etc. In this way, seed channels play a key role in variety adoption decisions. Each channel brings with it a different array of opportunities and risks.

There are a number of reasons why farmers maintain a broad choice of seed channel options (Sperling and Mcguire 2010; Coomes et al. 2015). Seed channels differ along lines of quality, accessibility, availability and the trust that farmers have in them. These dimensions are particularly important given the vulnerable nature of many subsistence farmers. Farmers are also likely to find resilience in the range of choices available to them (McGuire and Sperling 2011; Sperling and McGuire 2012). Views towards these sources appear to be diverse across farmers and in a state of change in Eastern Uganda. To some, formal channels offer the highest quality products, even if difficult to obtain. These groups are making efforts to shift to formal systems, despite the challenges they can impose. To others, informal seed is equally effective in the field, and more accessible. These groups circumnavigate formal systems, drawing instead on informal systems to access goods that originated on the formal sector. This range of choice is important, given the increasing pressures farmers are under to achieve harvests.

Farmers in Sironko describe a sense that rural livelihoods are becoming harder, on account of more challenging growing conditions and increasing prevalence of poverty. This is perhaps unsurprising given changing seasonality and soil fertility and pest pressures across the region (Nyombi 2014; Tenywa et al. 2017; Osbahr et al. 2011; Kisakye, Akurut, and Van der Bruggen 2018; Almazroui et al. 2020). All of these pressures threaten farming as a livelihood. As more smallholders turn to farming as a business to escape poverty, there is a growing need for harvests to deliver despite climate and socio-economic pressures.[1] A key part of achieving these yields will depend on getting useful varieties into farmers' fields. Seed systems are central in this mission.

There is a large literature on the seed systems farmers use (McGuire and Sperling 2016; Adong and Manager 2021; N. Louwaars and Manicad 2022). So far, this thesis has provided new qualitative information into how farmers navigate these spaces to access useful varieties. It has explored the pathways of formal sector supply and provided insights into the environmental features that influence seed system affordances. To build a more robust study of the context, this final results section adds a behavioural economic lens on how farmers choose seed systems.

A smaller body of literature has used quantitative methods to study farmer preferences between seed channels (Bishaw, Struik, and Van Gastel 2010; Mastenbroek, Sirutyte, and Sparrow 2021; Mulesa et al. 2021). For example, Mastenbroek *et al.* (2021) used willingness-to-pay studies to show that information has no causal effect on farmers preference to pay for certified goods. Other willingness-to-pay studies explore how farmers value aspects of new crop technologies, and these provide useful insights into the economic valuation of new crop technologies by farmers (Krishna and Qaim 2007; De Groote et al. 2016; Mukasa 2018 ; Meressa and Navrud 2020). These valuations of crop products are important, but we wish to understand how these investment decisions are made as part of wider preferences for seed channels. To include this criteria, we need an alternative approach that can capture multiple preferences over a range of attributes for seed selection decision-making.

At the time of writing, and to the best of our knowledge, no study uses Discrete Choice Experiments (DCEs) to compare farmers preferences across seed channels. DCEs have a long history of being widely used in medical trial research, but were rare in agricultural research until around 2005 (Breustedt, Müller-Scheeßel, and Latacz-Lohmann 2008; Windle and Rolfe 2005).

[1] And without expanding agricultural area, to prevent further biodiversity loss.

The following decade produced a number of DCE studies, many of which looked at the potential markets for new agricultural technologies (Kolady and Lesser 2006; Krishna and Qaim 2007; Breustedt, Müller-Scheeßel, and Latacz-Lohmann 2008; Ekin Birol, Villalba, and Smale 2009; Čop and Njavro 2022). Some of these studies have sought particularly to investigate farmer preferences for more environmentally resilient cropping strategies (Marenya, Smith, and Nkonya 2014; Smale and Olwande 2014; Schaafsma, Ferrini, and Turner 2019; Ward and Singh 2014). A recent development has been the use of DCEs to identify farmer preferences for crop technology traits, to guide breeding efforts (Arora, Bansal, and Ward 2019; Meressa and Navrud 2020). This chapter adds to this growing literature by using DCEs to understand farmer preferences for factors across seed channels. Doing so provides empirical evidence of how farmers rank these preferences rank in priority. Understanding these preferences can be used to compare with our qualitative findings. The find and guide seed channel design to enable farmers to access useful crop technologies.

7.1 Methodology

Our overall study is a mixed methods design where the quantitative approach described below was informed by prior qualitative research rounds, explored in the previous chapters. This section seeks to provide quantitative evidence of farmer preference between seed channels, which was achieved through a DCE and survey.

7.1.1 Location

Our study took place in Bukiise sub-county, between Sironko and Buhugu districts, in Eastern Uganda. Bukiise was selected on account of the following reasons: it is a rural area with prevalent smallholder farming; the Bukiise agro-ecology and cropping strategies are similar to the qualitative fieldwork locations that informed the DCE; and finally, the area had not previously been visited for this research.[2] Within this area, we randomly selected 10 villages, which happened to fall across five parishes. These villages are the following:

7.1.2 Sampling frame

220 participants were invited to the study. These individuals were selected by randomly selecting 22 people from each of the 10 villages. Lists of all village occupants, ages and sex were drawn

[2] To reduces the chance of contamination effects from previous studies into seed systems.

Parish	Randomly selected village
Nandago	Buyaka
Bukirindya	Zebugyira
Bukiise	Wolugwe
	Naimeni
	Bukomolo
	Natanyo
Busiu	Buwabuyi
Kilulu	Gamaswele
	Bugobelo
	Kilulu

Table 14: Sampling locations

up with the help of village administrators. All households were numbered and invitations were decided by randomly drawing numbers from a bag. Random draws were made in groupings by sex, to ensure equal representation of men and women in our study. As such, the first 11 selected in each village were the main male decision-maker for farming. The next 11 drawn were the same but for female decision-makers. No two respondents came from the same household, to prevent contamination effects. Our study limited acceptance to participants between 18-65 years of age. Invitees were told that no specialist knowledge was required, that the local language would be used and that their decision to attend was entirely voluntary.

Both the DCE and the survey were administered together, with the DCE first. Venues were chosen that were accessible, while still ensuring that respondents had privacy during the experiment. Locations were often a central village location to minimise participant travel time. The experiment was administered by a team of trained enumerators. Respondents spoke individually with enumerator team members. These conversations took place in a separate space to the waiting room where respondents arrived. Enumerators confirmed the identity of the respondent upon arrival. Confirmation involved asking the individual to confirm their name, age and, if suspicion arose, phone number. These checks were used to prevent impostors from joining and derailing random selection.[3]

After respondents passed the identity checks, enumerators explained the research background, experiment outline, team and ethics and if the respondent was happy to continue. Respondents were told that they would be financially covered for their time regardless of their decision to continue with the experiment, to prevent individuals feeling forced to agree. For those who agreed to take part, enumerators took auditory confirmation of consent. Written consent was avoided due to low literacy in the area and previously observed instances of respondents feeling uncomfortable with signing documents they struggled to read. After consent was taken, the enumerator began the experiment.

All data collection was conducted with the support of tablets running ODK survey software, linked with ODK Central servers. The ODK forms were set to randomly choose from a list of question orders for the DCE, to prevent ordering effects influencing DCE findings. A pilot was held prior to the experiment to test the protocol.

7.1.3 Discrete choice experiment

A DCE was used to quantify the effect of distinct attributes on respondents' investment behaviour (Lancaster 1966; Louviere and Woodworth 1983). DCEs have been widely used in economics and healthcare to investigate the factors that influence choices.

In a DCE, respondents are asked to make a choice from between two or more options, say 'option A or B'. Each choice option consists of a number of 'attributes', which in turn are comprised of various 'levels'. For example, if one attribute of a choice might be the *price* of goods, the levels might be the various *prices*. So to continue our example, choice A or B both have the attribute of 'price', but differ on the level (the amount) of that price. The intention is to encourage participants to choose whichever they believe the best choice to be, and thus the option with which they perceive to hold maximum utility for their needs. Respondents make this choice over a number of subsequent choice rounds. Each choice round offers a distinct choice of alternatives, with no connection to prior or following choices. The aim, through observing patterns in how participants choose, is to estimate the conditional effect of each attribute on the choice. The

[3] This sometimes happens for either one of two reasons. Sometimes uninvited individuals try to join out of interest or in the hope that they might receive payment for participation. Other times, mobilisers might not be able to find the randomly selected individual, and send someone else instead.

conditional effect of the different levels is compared against the based level of each attribute (Mangham, Hanson, and McPake 2009). So if we have a base price level, the DCE will investigate the causal effect of changing price values against this base.

There are a number of assumptions with a DCE approach. The first is that individuals will seek to maximise their utility. Our discrete choice experiment assumes that respondents are rational actors, who will try to choose whichever they believe to be the best option (Lancsar and Louviere 2006). This more fundamental assumption with utility theory, that should be kept in mind. To raise the likelihood of observing maximum-utility seeking behaviour, respondents were requested to choose the option that they believe to be the best. This approach however invokes further assumptions. Two related challenges are whether participants accurately understand what will maximise their utility, and how well they are able to perceive this from presented choices (Mangham, Hanson, and McPake 2009; Pearce et al. 2021). This confounding effect might be enhanced given that our experiment works with a sample with limited schooling, asks about hypothetical choices, limits the range of attributes and offers the choice of seed investment in an unconventional way. These elements add levels of abstraction. To aid respondent perception of the situation and choice, a scenario was provided before the experiment that gave an overview of the context and elements of the choice. This scenario, described further below, aimed to be clear and unbiased. To aid respondent understanding in the task, enumerators carefully took respondents through each choice, and ran a 'practice' choice before the experiment began to confirm comprehension.

Our DCE choices were based around the decision of buying maize seed. In particular, we were interested in where farmers prefer to buy seed, what kind of maize seed they prefer and other factors that influence farmers' decisions to invest in seed. For the DCE to be robust and meaningful, these factors must be important for investment decisions, realistic and independent from one another. As such, our DCE design was based on prior rounds of qualitative research[4] on the topic of seed acquisition, that have been reported in the previous chapters. While there are many factors that likely affect seed purchase decisions, presenting all of these to participants risks overloading the individual with information. Doing so risks cognitive overload of the individual, raising fatigue over the course of the experiment, and ultimately risking the quality of responses. As such, we targeted the five most important attributes[5] for seed purchase and kept the fewest levels possible. To reduce the chance of mental fatigue, we limited the number of choices to

[4]Key informant interviews, focus group discussions and observation.

[5]I describe how these five attributes were chosen then following sections.

fifteen (Mangham, Hanson, and McPake 2009).

Each of our attributes were chosen to be independent from one another. This independence is important to avoid multicollinearity, and to ensure that findings are representative for each attribute in isolation (Coast and Horrocks 2007; Mangham, Hanson, and McPake 2009). The DCE choice, and their rationale for selection are discussed below.

7.1.3.1 Choices

Our choice experiment offered farmers with choices of two kilogram bags of maize seed, of a hypothetical modern variety that the respondent has not used before. The table below summarises the attributes and levels included in the DCE. This selection was based on our research focus, subjects which farmers say are important for seed investment. I describe the rationale for these attributes and levels below. I also include rationale of potentially relevant attributes and levels that were omitted. All selected choices were piloted and found to be well-suited to the seed investment decision. Any confusions over wording were amended before the actual experiment.

7.1.3.1.1 Seed source Seed source is a fundamental attribute in the DCE for a number of reasons. The first is because of its importance in seed acquisition, from both a farmer behaviour and policy point of view. The second is because farmers are expected to change their seed systems of choice over the next two decades (*Uganda Vision 2040* 2013; Adong and Manager 2021; Bagamba et al. 2023). As such, there is a timely relevance to understanding how and why farmers choose seed sources. Finally, comparatively little literature exists that offers qualitative data on smallholder preferences between seed channels, and this therefore represents a gap in seed system research. Consequently we included seed source as an attribute, and the rest of this section explains how we decided upon the levels.

We sort to understand farmer preferences between priority seed channels. Seed supply channels are diverse but can often be grouped into three types: formal, informal and government (McGuire and Sperling 2016). In prior qualitative work, Sironko smallholders regularly spoke about four main seed channels: agro-dealers, local stores, local markets and farmer exchange. Agro-dealers belong to formal channels while the remaining are considered informal channels. Government channels were mentioned as another potential challenge, but these are unpredictable[6] and subsequently were not seen as priority channels. Travelling salespeople were also omitted for the same reason. Another potential seed channel that was deliberately left out was that of farmers.

[6] Both in terms of availability and quality.

Attribute	Level
Source	Agro-dealer
	Local store
	Local market
Price	4,000 UGX
	6,000 UGX
	8,000 UGX
	10,000 UGX
Seed type	Traditional variety
	Mwaka moja
	Quality Declared Seed
	Certified seed
Recommendation	Has not heard of this variety
	Radio
	Agro-dealers
	Extension worker
	Other farmers
Local presence	No-one grows
	Neighbours
	Few locals
	Widely grown

Table 15: Attribute and levels.

A great deal of seed purchase behaviours occur between farmers, and I share reasons for omitting this channel in the wider source selection rationale sections below.

Agro-dealers are positioned as the main output channel for modern crop breeding innovations across Africa (Chinsinga 2011; Odame and Muange 2011; Domínguez et al. 2022). They are also tasked with the expansion of the formal sector and modern varieties across rural Uganda. Farmers in interviews had a range of feelings towards agro-dealers. Often they were associated with new, but expensive, certified seed. Farmers knew that agro-dealers are central in bringing in new varieties but were dubious of the quality of the products they offer. These thoughts echo the research of others who have found issues with quality and counterfeiting in formal seed supply (Bold et al. 2017; Boef et al. 2019; Access to Seeds Foundation 2023). But, as discussed in the previous chapter, farmers are interested in *products* that originate from agro-dealers. Including agro-dealers in our choice experiment therefore allows us to separate out how farmers view agro-dealers as separate from the products they sell.

Local shops, local markets and farmer exchanges are all important sources of seed for farmers, and widely mentioned in both the qualitative research and the literature (McGuire and Sperling 2016; Sperling et al. 2020). There were however differences in how farmers reported these different channels. Local shops tend to be more long-term businesses, through which farmers might develop trust with the owner. Conversely, local markets tended to be more mercurial. While local market locations provided hubs where seed could reliably be sourced, market sellers themselves were more varied, changeable and less consistent in their products. While much literature bundles informal seed systems together, including both local shops and local markets as separate levels offers a chance to compare channels which farmers treated differently. It also offered the opportunity to compare both sources with agro-dealers.

A notable seed channel omission is that of local farmers. Local farmer exchange is a given seed source and originally included in our list of channels, but was removed as a level for methodological reasons. Two core components of the DCE approach is for choices to be realistic and for the attributes to be independent of one another (Lancsar and Louviere 2006; Mangham, Hanson, and McPake 2009). Clearly, in reality, farmers seed sources are both of these but including farmer exchange in our DCE caused conflicts with levels within the price, recommendation and local presence attributes. For example, while in reality prices levels fluctuate across our other channels, it would have seemed unrealistic for a farmer to charge the highest price attribute level (explained later) for seed in all but the rarest of cases. Further, the farmer seed channel clashed with the ‘has not heard of this variety’ and ‘no-one grows’ levels in the seed presentation and local presence attributes, respectively. Both of these baseline levels are likely for new modern varieties to an area but become paradoxical when seemingly offered by the same local farmers who reportedly do not grow them or know about them. Omitting farmer exchange is subsequently a necessary sacrifice to keep our choices as plausible, but the overall impact of this omission should not be overstated. Our discrete choice experiment primarily seeks to understand farmer seed acquisition preferences to guide the delivery of modern varieties for farmer uptake. From this lens, farmer exchange is unlikely to be a primary channel in the same way that the other levels could be.[7] Farmer exchange might be a more likely seed channel if our design included integrated seed system channels, but maize is currently not sold by integrated channels in Uganda (Mastenbroek, Otim, and Ntare 2021a).

7.1.3.1.2 Price Price is a major component in seed acquisition decisions, and one with particular influence on seed accessibility dimensions (Biemond 2013; McGuire and Sperling 2013; McGuire and Sperling 2016). Price was the main attribute that farmers spoke about when discussing seed, and a lens through which to frame returns on investment. For example, many farmers argue that highly-priced seed is beyond their economic capacity, but farmers would also debate on whether higher value seed resulted in more profitable harvests. In Sironko, seed prices fluctuate with the type of seed, but also the time of year. Seed prices significantly escalate for the start of the planting season, but also greatly reduce outside of those periods.

Our prices were based on real-world prices in Ugandan Shillings (UGX). All prices were made against a baseline amount of the approximate price for two kilograms of saved seed at the planting season (4,000 UGX). Subsequent levels were then set at x1.5, x2, x2.5 and x3 this amount (6,000, 8,000 and 10,000 UGX). This top price correlates with the price of certified seed from agro-dealers, although prices can vary with specific varieties, time of year or changes in local demand (Mastenbroek, Sirutyte, and Sparrow 2021). Price levels were restricted from going higher to maintain a realistic price option for certain levels in the seed type attribute; which includes traditional varieties and certified seed. The top price level is high for locally saved seed, but not completely unheard of under situations of short supply and high demand for a specific variety. It would however be unrealistic for traditional varieties and *mwaka moja* to be sold for more than the highest price level, even under extreme circumstances. In contrast, certified seed

[7] Although that does not exclude the real-world function of farmer exchange as secondary channels for new varieties through selling *mwaka moja*.

is unlikely to be sold at the baseline level, but this could be possible under specific circumstances, such as market sales, off-season selling or subsidised prices. Going below this price point however seems unrealistic for certified seed and therefore influenced our price levels.

We therefore include price as an attribute due to its essential role in seed acquisition, and design levels which allow for the price dynamics of traditional and certified seed levels. These prices become less conventional at the extremes, but not beyond the realms of possibility.

7.1.3.1.3 Seed type Seed type refers to the format of the product and includes the way in which it is presented to the farmer at the point of purchase. Ugandan policy has echoed African Green Revolution initiatives across the continent in focusing on promoting certified seed over locally saved and traditional seed (Akroyd 2005; *Uganda Vision 2040* 2013; Ntare 2015; Adong and Manager 2021). A more recent addition has been the introduction and policy advocacy behind QDS, produced by LSB groups (Bonny 2021; Astrid Mastenbroek, Otim, and Ntare 2021b).

In prior qualitative research, farmers regularly mentioned the differences between certified seed purchases versus those for saved and traditional varieties. For example, farmers spoke of the sealed and treated presentation of certified seed, as opposed to the open bags of traditional and *mwaka moja* seed. These differences changed how farmers could interact with the seed and the flexibility around sold quantities. As such, the type and presentation of seed influenced how farmers could judge reliability of seed; whether they trusted formal regulation or preferred their own. There was therefore a trade off of trust in formal regulation versus agency to check informally produced products. These factors are also part of the 'seed type' component to seed acquisition decisions.

We select four levels for seed type; traditional seed, *mwaka moja*, Quality Declared Seed (QDS) and certified seed. Combined, this selection provides a range of seed types available to farmers. Traditional seed refers to older varieties that have been locally adapted and saved by farmers. Traditional varieties were present but rare for maize across our qualitative research.[8] A potential challenge for the realistic component of our DCE comes with a clash with one recommendation level, 'has not heard of this variety' given that traditional varieties are often locally conserved. During qualitative work however, farmers mentioned the option of travelling to other districts to access other locally conserved varieties. In these instances, it is not outside the realms of

[8]Although generally common for other crops of importance locally.

possibility that a new variety might be brought in that is a traditional variety from another location. In this sense, the respondent might not have heard of the new variety. Another potential realism challenge is with the combination of agro-dealers recommending or selling the traditional varieties. Officially, agro-dealers do not sell informal seed, making it doubly unlikely that they would recommend traditional seed. In practice however, prior agro-dealer surveys in this thesis showed that around half sell informally sourced seed alongside certified seed. This suggests that agro-dealers could sell traditional seed, if there is demand for it. This also raises the possibility of agro-dealers recommending such products. This same argument can be made for *mwaka moja* seed, which differs from traditional varieties by being distinct as of formal sector descent. *Mwaka moja* was included as a level to investigate if and how farmers might see this type as separate from traditional varieties.

QDS is separate to informal seed in that it is produced as part of the integrated seed sector. Its inclusion in this DCE was deliberately made to test how farmers perceive it against informal and formal seed choices. Technically, QDS in Uganda is not planned for maize seed, as LSBs are positioned to complement the formal seed sector's production rather than compete (Bonny 2021; Mastenbroek, Otim, and Ntare 2021a). Still, we wished to test if farmers would hypothetically be interested in LSB produced maize. While this might appear to break the reality concept of the DCE, QDS was not currently produced in our field area at the time of study.[9] Farmers had not heard about QDS, and so this provided the opportunity to describe the rationale behind QDS and observe an initial response. Including QDS in this way allowed us to compare farmer initial perception for this seed type with preferences for our other seed types.

Our final seed type is certified seed. Certified seed has already been well described and its inclusion in Ugandan maize seed preference testing is apparent. Its potential concern when combined with the lowest price level has been discussed above. Certified seed was included to test its causal effect on farmer investment, versus the other informal and integrated seed levels.

7.1.3.1.4 Recommendation Information about a technology is often considered to influence adoption (Shikuku 2019; Van Campenhout 2021). The same is also thought to be so for crop technology, although information about a potentially useful crop does not always alter uptake (Mastenbroek, Sirutyte, and Sparrow 2021). Two related components are where the information comes from and who endorses it.

[9]This was confirmed through combining ISSD records with interviews and focus group discussions.

Smallholders are bombarded with information about varieties from various sources (Hammond et al. 2023). These sources are further increasing with the rise of mobile technologies and apps that seek to provide farm support (Misaki et al. 2018). Another increasingly prevalent area is the rise of crop technology advice with loans and agricultural insurance programmes (Greatrex et al. 2015). Despite the publicity on these more recent advisory channels, farmers in our discussions focused on a narrow range of information sources for crop recommendations. These sources are; radio stations, agro-dealers, extension workers and other farmers.

Radios are a regular feature throughout rural Ugandan locations. They are found playing in town areas, shops and households. Agricultural advertisements routinely run between radio channels, and these frequently advise farmers to select crop varieties from specific seed companies (Hailu et al. 2017). Farmers in qualitative stages often mentioned hearing about new varieties on the radio, although some cautioned that this information source might not reach the poorest households. Regardless, we included radios as a level to test how these advertisements and talk shows influence farmer preferences for varieties.

Agro-dealers were frequently mentioned as a source of agricultural advice. Many farmers mention that a benefit to purchasing from agro-dealers was that they can find out the best varieties for their growing conditions, along with growing advice. As such, they provide an important channel for varietal recommendations. These views were however not held by everyone, nor held for agro-dealers uniformly. Some felt that agro-dealers are business people with the sole interest of making money. As such, their recommendation was not to be trusted, as it was not made with the farmers' best interests at heart. Others took a more nuanced view of whether to trust agro-dealers or not based on the owner. For example, some farmers would repeatedly return to a specific owner, even if it meant travelling further, because they trusted that individual. These same farmers were however generally reluctant to trust agro-dealers. Our choice experiment therefore tests to see how much the recommendation of a variety by agro-dealers influences the decision to adopt. An aforementioned potential clash with this level might occur where agro-dealers are recommending traditional or *mwaka moja* seed, but as mentioned earlier in this thesis, it was found to be common practice for agro-dealers to sell saved seed.

Similarly to agro-dealers, farmers spoke of growing varieties based on the recommendation of extension workers. These experiences occurred through face to face interactions, or following the recommendations given at demonstration plots. Farmers enjoyed interactions with extension workers and generally advocated for more of them. It was generally felt around Sironko that agricultural extension workers are giving fewer demonstrations, and farmers would welcome more interactions. Part of the reason farmers liked these demonstrations was that they provided guidance on particular crops and their cultivation. Demonstration plots were seen as a way for farmers to discover new varieties in the locality, and observe how they develop over the growing period. Farmers were concerned that new varieties might not be adapted for their agro-ecologies and so demonstration plots provided useful evidence on the potential of new germplasm. Extension workers also seemed to be seen by farmers as a useful conduit between local needs and technologies developments. These individuals were trusted as providing unbiased information, partly due to their apparent separation from the private interests of selling crops.[10] Agricultural extension workers we met appeared to be well-known and warmly welcomed by farmers. Such individuals might have personal connections to areas, increasing the trust and understanding they had with the area. Interestingly, we also found that agricultural extension workers did occasionally recommend traditional varieties to farmers, where they believed them to be of use.[11] We were therefore not concerned where this level appeared with saved seed rather than QDS or certified seed.

The most common source of crop information that farmers mentioned as important was that of other farmers. This is unsurprising given that farmers surround each other on a daily basis and tend to farm in similar ways. As such, their recommendations of what to grow or not, were often well-suited to local needs. Further, farmers were trusted as their farms are highly visible to others, providing a transparency that could confirm recommendations. Sironko farmers often ask local farmers which varieties they are growing and where they sourced the seed. This is particularly the case for farmers that were either respected locally, or those who were observed to have highly-performing fields. For these reasons, we included farmers as an important recommendation level.

When testing the importance of a recommendation on decision making, it is also worth considering the absence of a recommendation. This is different to a negative recommendation. When a new crop variety enters an area, it seems plausible that few will be able to provide a recommendation on account of neither having heard about it or used it. Therefore, as we consider the importance of where the recommendation comes from, it is worth using a base level of no recommendation. Doing so allows us to compare the recommendation of any source against the absence of a

[10]Although we did come across cases of extension workers who sold seed so recommendations may not always have been made without conflicts of interest.

[11]Although this was mainly for crops other than maize.

recommendation. Such findings can inform where advertisements of new technologies are targeted, to encourage uptake. As such, we include the base level of having not heard recommendation of the variety before. This was carefully worded so as not to appear as a negative review of the variety. For example, "variety A is not recommended" could be misunderstood as 'advised against', rather than the absence of a recommendation. We deliberately omitted negative reviews of varieties. Including an additional level of 'this variety has been advised against' seems likely to be influential, but has little explanatory power as to how this varies with source. It also makes for more abstract grounds for decision making, as it does not specify *who* has advised against the variety. The alternative would be to have positive and negative recommendations for most of the recommendation levels.[12] Consequently, the number of levels would almost double, adding to the complexity of the experiment and requiring additional choice rounds and subsequent mental fatigue. Finally, there were few priors to include such negative reviews of crops. While it seems extremely likely that numerous sources advise against varieties, farmers in qualitative discussions specifically mentioned positive recommendations being influential to their choices. For these reasons, we do not include a negative review of a variety in our DCE, but further research could investigate the influence of these negative reviews from different actors on adoption decisions.

There are two unavoidable but notable assumptions in this attribute and its levels. The first is that we do not specify the details on which the recommendation is made. For example, we do not expand on *why* the recommendation is made or *how* it is recommended. In reality, a recommendation is usually made for a reason; i.e. Buy variety X because it is better in droughts or variety Y because it tastes nice. Our interest with the recommendation attribute focuses on the potential role of the information source on the decision to purchase. As such, we omitted the exact reason upon which the recommendation was made to ensure the focus was on the *source* of the recommendation. An alternative might have been to say that each level recommends the variety as 'higher yielding', but this assumes farmers' interest in yield, and ignores how respondents might compare how sources might differ in the perception of yield. For example, what farmers say is a good yield might differ from other sources. There may however be numerous reasons why a farmer might generally recommend a variety over agro-dealers, which respondents innately know. Omitting the reason for the recommendation allows respondents to formulate their own plausible reasons of why different groups might recommend a variety, keeping the choice focused on the source of the recommendation, rather than the subject of the recommendation itself.

[12] e.g. "the radio/agro-dealer/extension worker/local farmers recommend you do not use this variety".

A challenge with our recommendation attribute is the implied homogeneity of actors within a source. While it is useful to separate out these different sources of recommendation, in reality, respondents likely break these groups into more granular detail. For example, some agro-dealers might be trusted over others, or some farmers might be known to offer better advice than others. While our experiment investigates general patterns of where respondents find recommendations influential, respondents likely rank individuals within and across these groups, to different degrees. Our experiment provides general findings at the aggregate level, but seems likely that individuals might break their own recommendation groupings for remarkable recommendation sources.

7.1.3.1.5 Local presence Farmers watch what those around them grow, and keep track of how varieties perform. Qualitative respondents regularly mentioned which varieties grow around them, and how adapted they appear to their local agro-ecology. A concern throughout conversations of new varieties, particularly from the formal section, was the fear that newer varieties would not be suited to their growing conditions, causing their investment to perform poorly in the field. Choosing varieties that already grew around them therefore removed this risk. This same behaviour however inhibits the uptake of new varieties to an area, despite the potential value they might offer. This behaviour likely has a socio-economic dimension to it, whereby poorer or more marginalised farmers are more likely to invest in technologies with evidence of local performance, over newer ones that might be better but have greater uncertainty of success. This scenario is particularly relevant for new crop technologies that seek to offer benefit to the poorest community members, such biofortified crops (de Brauw et al. 2018). In this attribute, we sought to investigate how varying levels of local production influence the decision to invest.

Our base level was that no-one is growing the variety. This situation is likely to occur when new crop varieties are developed and enter the area. For innovative respondents, these new varieties might present an attractive option for experimentation. For others who might be part of early or late majority adopters, the presence of other growers might encourage investment, as well as provide evidence that the variety is viable in local conditions (Rogers 1962). We add a local proximity to this by including the levels of 'neighbours growing' and 'some local farmers growing'. Here we test to see if respondents differentiate between the behaviours of those immediately around them, versus others more generally close by. We also test to see if there is a difference in choice behaviour informed by a small number of farmers growing in comparison to a larger number. In theory, a small number of farmers growing a new variety demonstrates the variety's local performance. Some however might place greater confidence in a wider number of farmers adopting a specific variety, as this might signify widely experienced returns.

A slight clash comes between the level of ‘not grown locally’ and the recommendation attribute level where farmers recommend the product. In this scenario, the challenge to plausibility is why farmers would recommend something they do not grow. Two possible examples exist for how this situation could happen in reality. The first is that the seed is not available locally despite previous farmers use. This was observed during fieldwork where certain bean varieties were well-liked and sought-after but had failed in the previous year due to a climate shock. Since these bean seeds were entirely sourced on informal systems through annually restocking, no seed existed in the area. As such, farmers were recommending a product that they were not currently growing. Another alternative could be when farmers recommend a new variety that they have heard to perform well, but do not currently grow themselves. This was also observed during fieldwork where farmers recommended new Kenyan maize hybrids on account of their growing reputation, despite having not grown these varieties personally. Therefore the potential combination of farmers recommending a variety that they do not grow is not beyond the realms of possibility.

Our local presence attribute therefore contains four levels; no-one grows, grown by neighbours, grown by a few local farmers, widely grown.

7.1.3.2 Omitted attributes

A number of attributes and associated levels were considered as a result of the qualitative rounds of research, but ultimately omitted from the DCE. The following attributes are those that have been mentioned in our qualitative discussions or the literature as important for farmer decision-making. I describe the rationale for omitting each attribute below.

Crop type: Our DCE investigates how farmers choose between seed sources. Crop choice is a relevant attribute that determines where farmers buy seed. For example, some sources might be associated with high-quality varieties of some crops, but be less reliable for others. We could therefore have included crops within our choice experiment to see how the choice of crop influences farmer decision-making between sources. Including crop type as an attribute however brings multiple challenges for the DCE design. Overall, crop type clashes with multiple other attributes and makes for complex choices. The first challenge is that farmers across our sample area may grow different crop types based on local agro-ecologies. This therefore might create the scenario where a crop type is offered to a respondent who lacks the environment to grow it. As such, the individual might be choosing options based on fundamental criteria that are not included in the DCE. The uniformity of maize cultivation across the sample avoided this challenge. Another challenge is that respondents may perceive different utility from different crops, and that these differences overrule other attributes. For example, a farmer may always choose maize over cassava, regardless of the other attributes. Further clashes come when trying to create realistic levels with other attributes. For example, plausible price levels for maize differ from those for beans, cassava or other crops. As a result of these challenges, the DCE focused on maize, so that all choices were from the perspective of a single crop, and one which all farmers grew. Restricting the DCE to one crop also allowed the other attributes and levels to be set as realistic levels to that crop type.

Distance. The distance that farmers travel to obtain new varieties is mentioned as important in the literature on accessibility grounds. For instance, agro-dealers are reported as being distant from rural areas where seed is needed. Similarly, ensuring that varieties reach 'the last mile' has become common in agricultural development vernacular (Minten, Koro, and Stifel 2013; Mabeya et al. 2020; Barikore et al. 2022). Overall, seed channel distance is seen as influential to adoption, and posed as being particularly felt across gender, age and socio-economic dimensions (McGuire and Sperling 2011; Sperling and McGuire 2012). Subsequently, our DCE could provide empirical data on the conditional effect of distance to seed channel on investment. Yet, despite the regular appearance of these topics in the literature, distance to seed source seemed to be of limited or lesser importance to farmers in qualitative research. Respondents mentioned preferring to travel shorter distances, as this saved them both time and money. Some women also felt that their household responsibilities restricted their travel. Despite this, many farmers of different genders spoke of deliberately travelling further distances to obtain better planting materials. For example, Sironko rice farmers preferred to travel to distant markets in other districts on the belief that they sold better seed. For these reasons, distance appeared to be a relevant, but lower priority reason to decide where to purchase seed from. An additional challenge with distance is the methodological approach in which the levels might be presented. For example, farmers spoke of distances in physical lengths or travel times. Offering either form of distance as levels seemed abstract for farmers to base decisions upon. For example, physical distances (e.g. miles) might be more or less readily travelled depending on other factors such as public transport or road quality. The alternative of providing distances as travel times gave more consistency between levels, but seemed more abstract to how respondents viewed travelling to a range of locations. A final option was to offer three physical locations of differing distance, but this risked bringing in external factors as to how respondents choose to travel to those locations or associate them as good sources of crop varieties. Overall, the lower priority of distances than other choices and methodological challenges caused us to omit distance from the DCE design.

Pest and disease resistance. Pests and diseases limit crop productivity. A number of qualitative interviews mentioned that farmers are unlikely to experience large returns unless they spray pesticides. Pesticides however come with an additional cost that can be a barrier to smallholders. Even the farmers that can afford pesticides must spray multiple times in the growing season to protect their harvests. Due to the costs involved in pesticides, many Sironko farmers reportedly either do not, or only partially, spray their crops, raising the chance of greater pest damage. Modern varieties do however exist that incorporate resistance genes to pests and diseases.[13] This innate resistance means that the crop would be protected without the need for farmers to spray pesticides, while also raising harvests by preventing losses. Varieties with these kind of resistance traits are likely offered to farmers. Our DCE could therefore investigate which forms of innate resistance might raise the likelihood of investment. Doing so could provide breeders with priorities for resistance trait introgression. It might also demonstrate where markets might exist for improved resistance varieties. There was however no specific pest or disease that farmers mentioned in interviews.[14] This lack of clarity over exactly which pest and disease pressures farmers wish to protect their crops against poses challenges in both setting attribute levels, and communicating those effectively in choice experiments. Further, this shifts the focus of this DCE more towards plant breeding questions rather than seed source. For these reasons, we have omitted the presence of pest and disease resistance from our investigation. Other studies may wish however to explore these topics.

Climate Resilience. Farmers regularly mentioned the importance of varieties that are resistant to climate shocks, such as droughts and floods. This is unsurprising as weather patterns are changing across Uganda (Tenywa et al. 2017; Kisakye, Akurut, and Van der Bruggen 2018; Dosio et al. 2019). Farmers are aware of these changes and many spoke of how the once predictable rains, upon which many rely, are now a point of uncertainty. Consequently, climate resilience in varieties could offer grounds upon which farmers choose varieties. This however comes with some challenges to pose as attribute levels in a way that would both be unrealistic to offer, and of limited value for variety selection. The first challenge is that simply offering drought or

[13] Such as bt eggplant or Xanthomonas wilt-resistant banana (E. Birol, Smale, and Yorobe Jr. 2012; Tripathi et al. 2017).

[14] Although many spoke of struggling with weevils in post-harvest storage.

flood tolerance as levels to farmers is abstract. DCE levels should be clear and distinct to assist farmer choices. Listing a level as drought/flood tolerant provides little tangible comparison of how much more or less resistant it is to climate shocks. While it might be useful to observe if flood or drought tolerance influences the decision to adopt, reporting this has limited value when climate tolerance is already a major breeding objective. Part of the challenge also lies in the broad ways in which a plant might be more or less tolerant of climate extremes. What exactly makes something more flood or drought tolerant is varied. For example, it could mature earlier and subsequently require less weeks of water. Alternatively, it could grow differently, to sustain itself despite drought periods. Including both dimensions in the same attribute seems awkward as well as they might be distinct depending on the farmer's views and surrounding land. This also shifts the focus of this study more towards crop breeding rather than extension.

Complementary inputs. A common critique of modern varieties is their dependence on additional inputs to provide adequate returns. For example, modern varieties are often designed to rapidly assimilate the additional nitrogen levels provided by fertilisers. This response allows them to achieve higher yields, under high-nitrogen conditions. The challenge however is that many African soils are depleted of nutrients, and many smallholders lack the finances to apply nitrogen fertilisers (Nyombi 2014; Woniala and Nyombi 2014; Tully et al. 2015; Dimkpa et al. 2023). Selecting plants that perform well under high nitrogen levels does not necessarily mean the plants also perform well under lower nitrogen conditions (McGuire 2005). Under these conditions, modern varieties may perform the same, or worse than local varieties, despite the higher prices of certified seed. Sironko farmers were well aware of this situation. They were cautious about modern varieties requiring additional inputs to yield well on account of the associated costs; both time and money. Farmers mentioned this cost both for fertiliser and pesticides. It should however be noted that this situation is not unique to modern varieties. All of the varieties farmers were growing would benefit from these inputs to a degree. Further, as explored in the previous chapter, local seed systems generally offered the same varieties as certified options. Subsequently, there is no major genetic difference why one requires inputs over the other. The main difference here is that farmers need better yields from certified seeds to achieve a reasonable return on investment that recuperates the higher costs of certified seed. Still, some farmers maintained the view that certified seed requires additional inputs that they could not afford and that influences their seed acquisition decision. This could possibly be tested in a DCE by including levels such as 'requires fertiliser' or 'doesn't require fertiliser'. An additional level component might be the amount of fertiliser or the number of applications. In reality however, all of the maize plants offer would likely return higher yields in response to standard fertiliser applications. The converse is also likely. It therefore seems unrealistic to offer farmers with maize varieties that do not require inputs. Further, this does not seem like a realistic choice that farmers would be presented with for maize seed.

Maize variety type. A great deal of literature argues on the suitability of hybrid or open-pollinated varieties for smallholder farming (Warburton et al. 2010; Mastenbroek, Sirutyte, and Sparrow 2021). The inference is that smallholders will continue to rely on the resulting saved seed, and that hybrid varieties lose their 'trueness' to type (as explained in previous chapters). As such, hybrid progeny can quickly lose the valuable traits on which they were originally purchased. This incentivises farmers to repurchase seed, rather than facing reducing yields for those who cannot afford to repurchase. This same arrangement is used by private seed companies to raise the likelihood of repeat purchase. Open-pollinated varieties (OPVs) on the other hand have a greater likelihood to maintain their desired traits in the subsequent generations.[15] As such, our DCE could investigate the conditional effect of hybrid or OPV type varieties on farmer adoption choices. In qualitative research stages however, farmers were aware of the change in hybrid progeny but did not seem to use this as a major driver for decision-making. It was generally felt that all 'new' seed, freshly purchased from agro-dealers or local shops, was most productive for the following season or two before needing to be replaced. Farmers however seemed to treat this more as a fact of life, with no-one claiming to decide which variety they chose based upon it. An additional consideration is how this attribute would have clashed with the plausibility of traditional varieties being sold as hybrid varieties. For these reasons, we decided against including a variety type as part of our DCE.

Previous experience. A common theme in interviews was farmers repeatedly purchasing the same variety. Farmers often chose varieties and seed sources they previously had good experiences with. They were cautious about those that they had not tried before. This scenario makes sense given that many farmers are risk averse, and the reassurance of using something that worked previously reduced an element of uncertainty. This same behaviour however discourages the purchase of new varieties, despite the chance of them offering improved technology. Understanding this effect could therefore feed into how new varieties are offered in an area. DCEs could test the conditional effect on seed investment depending on whether the individual had, hypothetically, used the seed variety before. This could have been presented as a binary level of having

[15] Although this chance reduces with each additional generation and is dependent on the surrounding maize varieties on wind pollination.

used the variety before or not. Alternatively, additional levels could be added to include how well the variety performed if purchased before. For example, 'purchased before and gave a small/moderate/high yield'. This suggestion however becomes methodologically awkward to offer in practice. Previous experience with the variety could be offered in two ways. The first might be to frame the variety as an existing option that the individual has used before (e.g. Longe-10). This is however clearly problematic given farmers may have unique experiences or views towards particular varieties that influence what they choose. The challenge therefore is that farmers choose a variety in the DCE based on prior experience and not on the criteria within the choice experiment, reducing external validity. The other approach would be to use hypothetical varieties throughout, but ask respondents to imagine that they have used one before. This imagined personal experience seemed tricky to be plausible and depends upon significant willingness to engage from the participant. The request is also a poor emulation of a realistic choice. Asking an individual to imagine they've used a variety before is clearly different to the actual experience that comes with having used a variety. Clearly the experience of having grown a variety before is important for farmers, but part of the reason for this is on account of reducing uncertainty of how well the variety performs locally. As such, our other attributes of recommendations and local presence offer some of this same information for respondents. Consequently, we decided to omit the choice of having grown the variety before, and instead rely on our current attributes to investigate the effect of local performance uncertainty on adoption decisions.

7.1.3.3 D-efficiency

The robustness of a DCE relies upon a balanced design across choices (Mangham, Hanson, and McPake 2009). Offering participants a combination of all attributes and levels would be lengthy and reduce choice data quality due to mental fatigue. Such an approach is referred to as a full factorial design, and would involve a large number of choices for our experiment. Instead, we used a measure of design efficiency (D-efficiency), to reduce the number of choices offered to participants, while still maintaining quality across the choice design. D-efficiency gives a fractional factorial design and as equal as possible representation of all attributes and levels across our fifteen choices (Mangham, Hanson, and McPake 2009; Street and Burgess 2007). Put another way, D-efficiency aims to balance the number of attributes presented to respondents with minimal overlap (Mangham, Hanson, and McPake 2009). This approach sought to give an orthogonally balanced design, to aid estimation of separate utilities (Carlsson and Martinsson 2003). Here, the utility of each alternative in a choice set is equal, where utility is based on prior information about the attribute parametres (e.g. from the prior qualitative research). The overall aim is to maximise information that can be gained from the choices presented to respondents. As such, it seeks to raise the precision of parameter estimates and the statistical power. The advantage of this approach is that it provides the chance to measure the effect of many attributes, over a smaller number of choices, reducing the mental fatigue effect on the respondent.

The D-efficiency formula is as follows (Carlsson and Martinsson 2003; Hole 2017):

$$[\ |\Omega|^{\frac{1}{k}}\ ]^{-1}$$

Where Ω is the variance-covariance matrix and k is the number of parametres in the model. The output of a D-efficiency approach is a matrix of attribute levels. This approach can result in illogical or unrealistic combinations of attribute levels. As stated above however, attribute levels were planned with the intention that no combination appeared beyond the realms of possibility, but this was confirmed with the outputted D-efficiency suggested matrix. STATA 17 was used to create the D-efficiency matrix, using the `dcreate` command.

Our design included 15 estimated effects, which is given by the total number of levels across the 5 attributes (20 levels) minus the reference category for each of them (5), as they are all indicator variables. In our case, the full fractal design matrix has 960 rows (3x4x4x5x4). Using our D-efficiency approach, we can reduce this to 15 choice pairs. The D-efficiency value of our final matrix design is 1.

7.1.3.4 Analytical framework

Our model for the analysis of the DCE responses follows the Random Utility Theory (RUT) framework developed by McFadden (McFadden 1974). Here, the utility of an alternative presented to the individual is decomposable into a observable component, specified as a function of the attributes of the alternatives (term ν in equation 1), and a random element ε_{ij}, representing the unobserved variation in preferences (de Bekker-Grob, Ryan, and Gerard 2012).

$$U_{ij} = \nu_{ij}(A) + \varepsilon_{ij} \tag{1}$$

Where ν_{ij} is the measurable utility of alternative j of attribute A for individual i. The decision maker will then choose alternative j over k if:

$$\nu_{ij} + \varepsilon_{ij} > \nu_{ik} + \varepsilon_{ik} \quad or \quad \nu_{ij} - \nu_{ik} > \varepsilon_{ik} - \varepsilon_{ij} \tag{2}$$

The probability of choosing alternative j conditional on the attributes and choice set C can be written as follows:

$$P(j_i \mid A, C = P_i j = P[\nu_{ij} - \nu_{ik} > \varepsilon_{ik} - \varepsilon_{ij}] \forall J = k \tag{3}$$

The probability of choosing alternative j is given by the probability that the difference in ε_{ij} (the error term) is smaller than the difference in the observed utility (McFadden 1974; Ryan and Gerard 2003). We use a standard normal cumulative distribution function for the cumulative distribution function as we use a random effect probit model (REP) for analysis.

A REP was used to estimate conditional effects due to its long-established use in discrete choice experiments and the design of our experiment (Ryan and Gerard 2003; de Bekker-Grob, Ryan, and Gerard 2012; Clark et al. 2014; Soekhai et al. 2019). A REP is particularly suited to experiments of binary choices, where participants do not have the choice to 'opt-out' of the choice (de Bekker-Grob, Ryan, and Gerard 2012). Further, we use a panel structure for the group, with each participant making fifteen choices, and therefore a total of 30 alternatives (Ax15 + Bx15). A REP is also useful as it does not make Independence of Irrelevant Alternatives assumptions (IIA). The IIA means that the relative probabilities of choosing between two choices (say, A or B) are unaffected by the presence of other alternatives (C and D). Here, the odds of choosing between A or B are the same whether C and D exist or not; which may not hold true in real-life choices. IAA arises because multinomial logit models use a closed-form mathematical expression to represent choice probabilities. A REP on the other hand does not rely on the same mathematical assumptions and uses a different cumulative distribution function that does not require IAA. Instead, a REP adds subject-specific random effects to account for repeated choices by each respondent. This provides more flexibility and allows REP to avoid making IAA assumptions (McFadden 1974; de Bekker-Grob, Ryan, and Gerard 2012).

The latent relationship between the utility of the alternative and its two components is assumed to be linear (as shown in equation 1 above). This relationship takes the following form in our application:

$$U_{ij}^{*} = \alpha + A_j \beta + \chi_i \delta + \varepsilon_{ij} \tag{4}$$

Where U_{ij}^* is the latent utility of alternative j for individual i, which is not observed and is instead represented by bivariate Y_{ij} that takes value of one if an option is chosen, or zero if not. A_j is a set of bivariate variables which define the attributes of every alternative j. These include the source of maize seed, price, seed type, recommendation and local presence. χ_j includes the individual level controls. The overall model of our choices is:

$$U_{ij}^* = \alpha + \beta_1 source_{ij} + \beta_2 price_{ij} + \beta_3 type_{ij} + \beta_4 rec_{ij} + \beta_5 presence_{ij} + \varepsilon_{ij} \tag{5}$$

Where i refers to the respondents, j refers to the choice alternatives and ε_{ij} is a random error term.

All data analysis was conducted in STATA 17, with the REP conducted using the `xtprobit` command.

7.1.3.5 Experiment protocol

Enumerators conducted the DCE through face-to-face interactions and guiding respondents through physically printed choice cards. There were fifteen choices in total, which involved thirty printed cards. Each choice had a 'variety A' and a 'variety B' that respondents were asked to compare and choose between. The choice number and A or B variety is listed at the top of each card (Figure 26).

Choice cards depicted one level for each of the five attributes, displayed vertically in a grid. Each level had both a written and visual component, to aid communication of the differences. This was particularly important given that literacy levels are low in our selected location.

Enumerators guided respondents through each level, one by one, on each card. This worked by completely describing the levels of variety A, before doing the same with variety B. After completely explaining all levels on both cards, the enumerator requested respondents to choose which proposition they believed to be the best choice. Respondents were able to hold each card when comparing the choices. If requested, the enumerator clarified differences between compared attribute levels. Enumerators were however careful not to suggest any ranking or their own preference in comparisons. As such, enumerators described all choices, attributes and levels as of equal importance for decision-making. Once the respondent decided upon a preference, enumerators recorded this choice on tablets running ODK survey apps.

Choice order deliberately varied slightly with each respondent to prevent ordering effects. Five

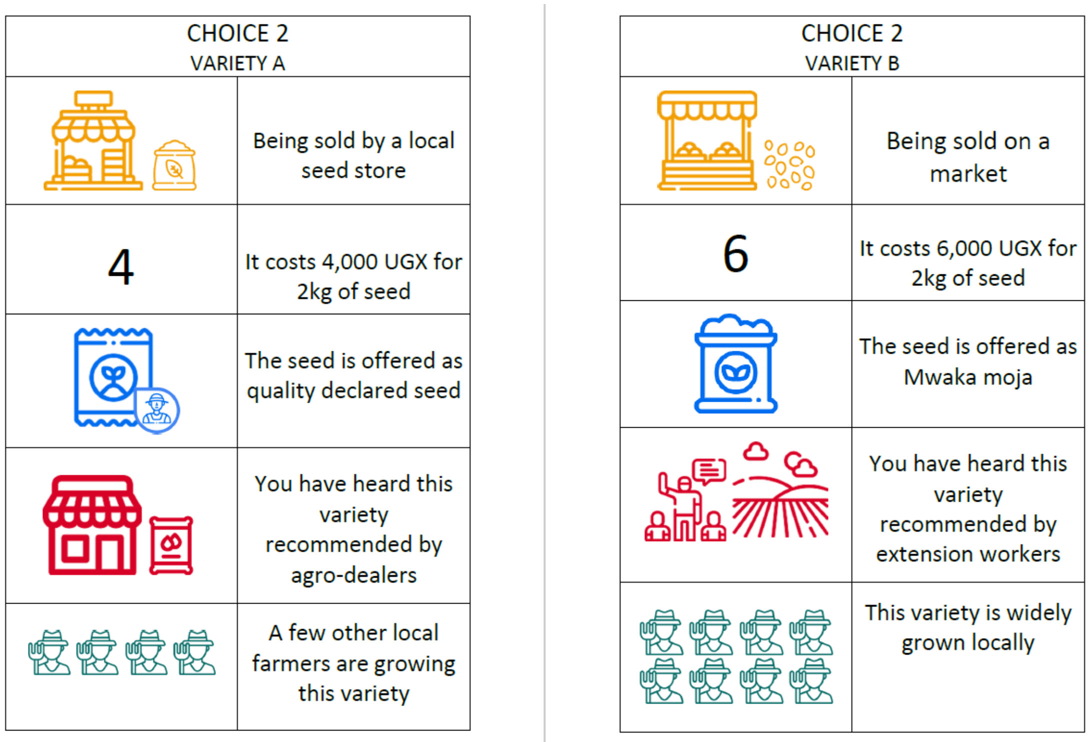

Figure 26: Example of the printed choice cards. The choice number shows the number, which ran between one and fifteen.

different orders were created for the fifteen questions. Upon commencing a new participant, the ODK software randomly selected which question grouping for the enumerator. This order was made visible to the enumerator by the choice number on the screen. When the respondent made their choice, the enumerator recorded this as A or B and the tablet prompted the enumerator the number for the next choice. Each question showed an image of the choice cards on the tablet screen, to help enumerators confirm that the printed card matched the tablet question.

Before implementing the DCE, participants were asked to reflect on seed acquisition. This reflection included reminding participants:

- That there are different seed channels to purchase from.
- Seed comes in different forms: locally saved, certified and quality declared seed (QDS).

These reflections were designed to remind, but not lead, participants into making a particular choice. The following section of text was be read out to each participant before the DCE started:

DCE scenario text

Thank you for joining us today.

We would like you to imagine the following situation. Suppose that it is approaching the first planting season and you want to buy a new variety of maize seed. The seed that you plan to purchase will be the main variety of maize that you grow for the season ahead, so the choice is important to you.

Before we offer you some choices to select from, we would like to remind you of a few important factors when choosing good seed.

Firstly, you have a range of places that you could buy seed from. Some of these places include agro-dealers, local seed stores and markets. Agro-dealers are the stores that focus on selling improved varieties, as well as fertilisers, pesticides and other farming products. Local seed stores are the next type. These seed stores sell a range of new and recycled seed and might also sell other farming or general goods. Another seed source is from markets. These markets might bring together lots of different sellers who sell a wide variety of products.

You can find a range of maize varieties at each of these seed sources. However, the way the seed is presented can also come in different forms.

For example, you could buy maize seed sold in open bags as local traditional varieties or 'mwaka moja'. These kinds of seed have been stored from farmers' previous harvests locally. Because the bags for these types of seed are often open, you can check the seed before deciding to buy. However, the yields from these kinds of seeds can be less predictable. These types of seed also do not have formal quality checks and you might be uncertain about how they have been stored which is important for germination.

Other types of seed are sold in sealed bags. There are two types of sealed seed that we would like to remind you about.

The first is certified seed. Certified seed is improved maize that has been produced by seed companies. It has been certified as high quality by government regulatory agents. These quality checks confirm that the seed has been stored carefully by the company, that the seed will germinate well and will produce healthy plants. Certified *seed will not be released for sale at agro-dealers unless it passes these checks. Certified maize is also treated and dyed to protect it against pests before it germinates. You cannot normally open certified seed bags to check it before purchase. You can however check the expiry date on the package to confirm if the seed is old. Mwaka moja is the offspring of certified seed, but it does not have the same quality or storage checks.*

Another type of seed that we will introduce is Quality Declared Seed. This is a new type of seed that is starting to be sold across Uganda but is not commonly found in the Sironko District yet. Quality Declared Seed is produced by local farmers who are trained in how to produce and store high quality seed. When the seed is ready for sale, it is checked by local agricultural extension agents for quality before it is sold. These checks confirm that the seed is healthy, has not been damaged and has been stored carefully.

These checks are different to certified seed which relies on companies and the government to check the quality. This is different to the trained farmers and extension agents who check quality-declared seed.

Today, we are imagining that you are choosing between two new seed varieties that you have not grown before. We will share some potential options and we would like you to choose which seed seems like the best option to you, based on the information you are provided with.

First, we will have an example. I'm going to show you two cards that show these two different seed choices. I will go through all the ways in which the two choices are different.

Variety A is being sold by an agro-dealer shop. It costs 10,000 UGX for 2kg of seed. The seed is offered to you as mwaka moja seed. You have heard this variety recommended on the radio. You know that a few other farmers locally to you are growing this variety.

Variety B is being sold at the market. It costs 7,500 UGX for 2 kg of seed. It is being sold as quality declared seed. You have heard this variety being recommended by agricultural extension workers. No-one you know of is growing this variety.

Which out of those two varieties sounds the best to you? If you are unsure of any features, I will explain the differences again. Once you are happy you understand *how the two choices differ, please can you tell me which you prefer?*

Enumerators conducted the DCE by guiding respondents through the printed choice cards. Enumerators then went through an example choice with the respondent, asked them to make a choice and then asked questions to confirm if they understood the process. The DCE started once the respondent confirmed they understood the task. The following points of clarification were given to respondents, if requested:

- All seed refers to maize seed.
- The choice is always for 2kg of seed.
- Seed prices are in relation to maize seed prices in late February-early to March (just before the first planting season).
- The respondent has not used either variety before personally. All seed is of Ugandan origin.

7.2 Results

198 respondents took part in our experiment, with near equal representation of men and women. The table below outlines socio-economic data across the sample. Where possible, this has been disaggregated by sex.

The wealth index was calculated by a sum of respondents reporting to: use a tractor, have electricity at home, have a television, have a fridge, use mobile money, have piped water, have a concrete floor and have a mobile phone. Groups were intended to be made by stratifying the lowest and highest 25% of the sample. In practice, low variation in the index meant that the poorest make up 37.3%, the middle 40.4% and wealthiest 22.3% of the sample. This wealth index was used to disaggregate how our sample varies over other socio-economic areas.

The highest level of education for the majority is primary school. Around 67% of our sample have primary school education level or less, and this is higher for women, at around 80%. Around 30% achieve secondary education and only around 3% reach tertiary education.

Wealth index grouping shows that the poorer community members tend to have less education, while wealthier members tend to have higher levels of education. Despite this, primary school education was the most common level for all three groups.

Farming is overwhelmingly the main source of household income. The majority of household

Variable	Women	Men	Sample
Proportion	48.19%	51.89%	
Age	37.04	40.09	38.6
Household head sex	2.44%	97.56%	
Education:			
No education	13.98%	5%	9.33%
Primary	65.59%	52%	58.55%
Secondary	19.35%	38%	29.02%
Tertiary	1%	5%	3.11%
Household assets			
Function phone			88.08%
Smartphone			12.44%
Has electricity			20.73%
Has piped water			6.22%
Has cement floor			6.27%

Table 16: Sample characteristics.

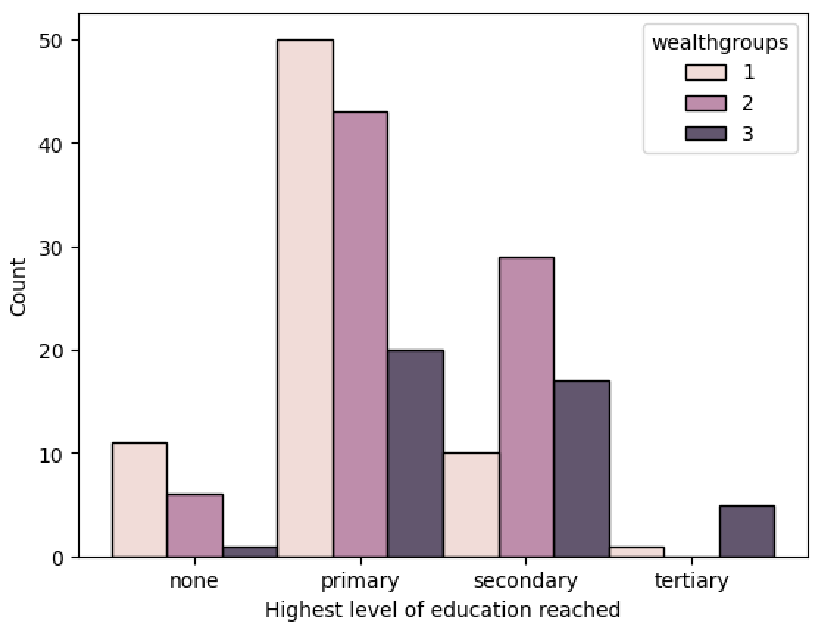

Figure 27: Highest level of education reached.

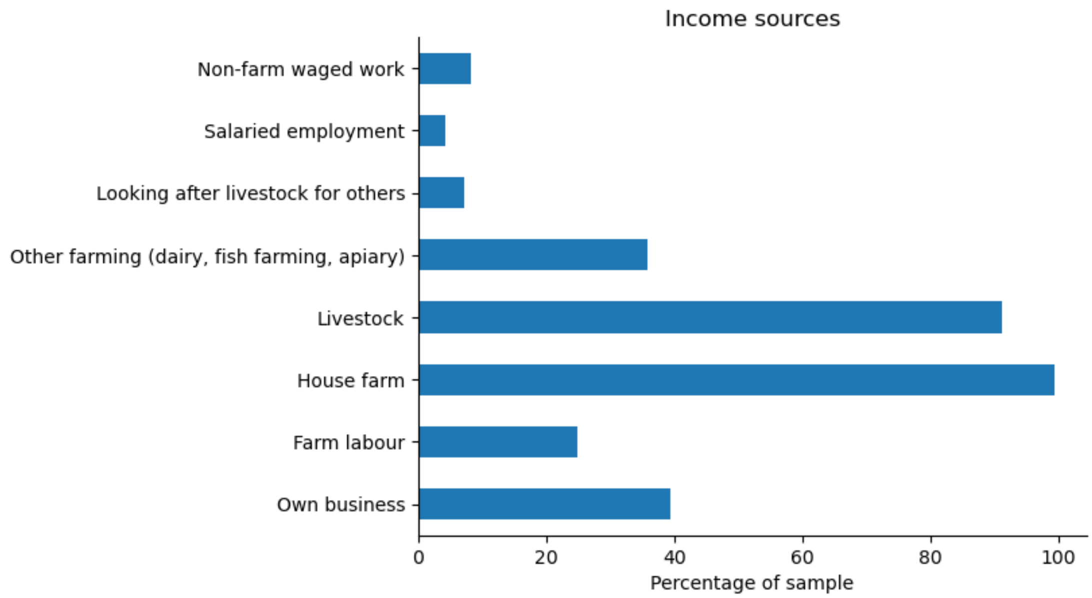

Figure 28: Income sources.

incomes come from the house farm and livestock, but other forms of farming are also common. Around 40% of the sample also rely on a household business. Livelihood options became less common outside these main areas, with farm labour work mentioned as the most important income source outside of household production. Other off-farm and salaried work are less common sources of household income. These estimations were made for the household, and both genders answered almost identically. These figures also show a relatively high homogeneity in how local households source income.

Farmers cultivate just over two acres of land on average, and 0.85 acres of this is rented in on average. Around 35% of the sample do not rent land, relying instead on their own land. Education is associated with a slight difference in cultivated land area, but is only significantly different where those with secondary and tertiary education cultivate more than those with no education. Those with no education cultivate an average of 1.15 acres, while those with secondary and tertiary education cultivate 2.71 and 3.08 acres respectively. Middle wealth and wealthier farmers cultivate similar size areas, but both groups farm significantly more area than the poorest. The poorest cultivate around 1.5 acres. The middle and wealthier cultivate 2.5 and 2.8 acres, respectively.

A surprising feature is how limited crop diversity is amongst farmers. Nearly everyone grows

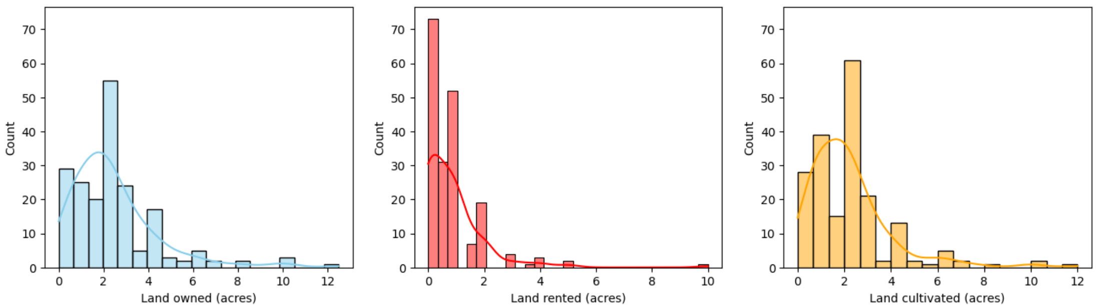

Figure 29: Land owned, rented and cultivated.

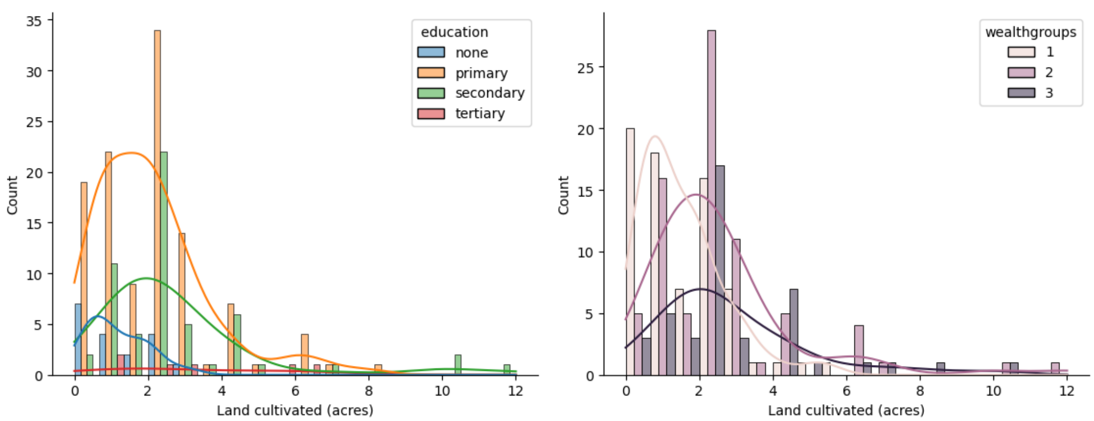

Figure 30: Land cultivated, by education and wealth status.

two crops, maize and beans, with tomatoes being the next most commonly grown crop for 31% of the sample. Crop diversity is low outside of these three choices, although a range of crops can be found across the whole sample. These figures demonstrate how important maize and beans are for household cultivation. Similar findings can be found in a recent FAOSTAT study (2020) where just maize, beans, millet and sorghum account for 92% of Uganda's harvested area (Mabaya et al. 2021)

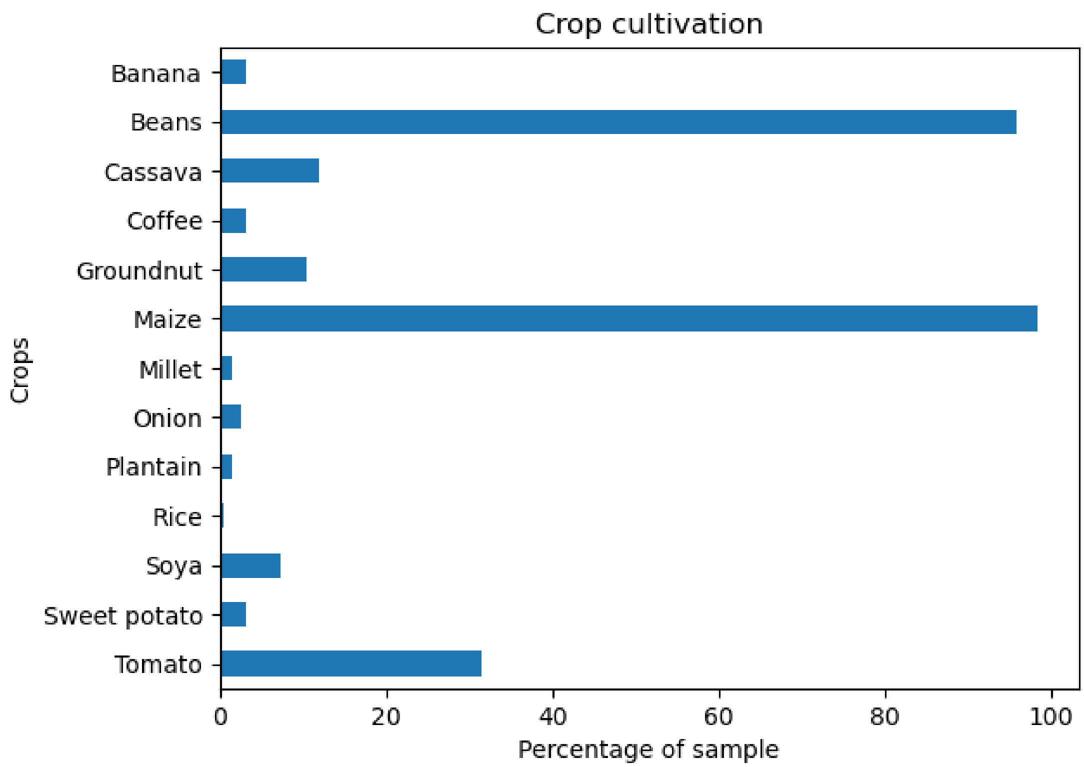

Figure 31: Choice of crops.

Over 80% of farmers report buying seed from agro-dealers in the last three years. Around 62% of the sample have purchased from local shops in the last three years and only around 25% reporting to buy from local markets. There is a temporal dimension to this preference. 61% of respondents report to be buying more from agro-dealers than in the past, with 21% buying the same amount. The picture is more nuanced with local shops and local markets. 39% of those who have purchased from local shops in the last three years are buying less than they used to, and 28% have stopped. Only 18% report to be buying more and 13% are buying the same amount. The pattern is similar for local markets, with 42% reporting to have stopped and 33%

buying less. Only around 23% report to be buying the same or more seed from local markets than in the past.

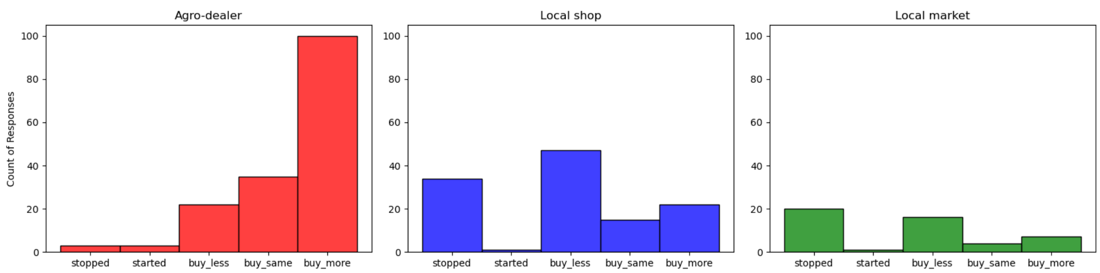

Figure 32: Changes in buying behaviour from seed channels. Note that Y values are counts, not percentages, to give an overall picture of the number purchasing from each source.

Respondents choose agro-dealers for different reasons than local shops or markets. Of those who choose agro-dealers, 94% do so for high-quality products and 77% choose them due to the better varieties they offer. Those who buy from agro-dealers see them as the most reliable source of seed, with 48% giving this as a reason why they purchase from this channel. Interestingly, although many seem to value the high-quality products at agro-dealers, only 7% say that good prices are a reason for purchasing from this channel. It seems therefore that farmers appreciate the quality of goods at agro-dealers, but still see these prices as high. Despite reports in previous qualitative work that agro-dealers can be a useful source of agronomic advance, only 12% see this as important in their investment decision. Around 17% of the sample also shop at agro-dealers due to the social status it implies.

There were however also reasons why respondents avoid agro-dealers, and it is clear to see the relationship between these reasons. Of those who avoid agro-dealers, 67% do so because of high prices and 60% because they see agro-dealer seed as inaccessible. Despite recent studies into counterfeit seed in formal seed supply, only 3% avoid agro-dealers due to counterfeit seed. Similarly, despite concerns that agro-dealer seed is poorly adapted to local conditions, only 7% avoid agro-dealers because of poor varieties and no respondent reported poor quality as a reason to avoid agro-dealers.

Respondents choose local shops and local markets for different reasons than those for agro-dealers. Despite the differences between these informal seed sources, respondents perceive them similarly in terms of reasons to choose or avoid them. Those who buy seed at local shops and markets, do so for good prices (72% and 75%) and easy accessibility (43% and 42%). 21% chose local shops and markets for the choice they offered, but a higher number saw shop varieties as slightly better (18% vs 10%) and more reliable (23% vs 6%).

There were many reasons why respondents report to avoid purchasing seed from local shops and markets. As with reasons to choose these channels, reasons to avoid these two channels were similar. Of those who avoided local shops and markets, the main reported reasons for this choice were counterfeiting, poor quality seed and poor varieties. 57% avoid local seed shops due to counterfeiting and this number is even higher for local markets, at 65%. 69% avoid local shops because of poor quality seed, higher than the 56% reporting this for local markets. This pattern was the same for varietal quality, with 60% avoiding local shops and 46% avoiding local markets. More generally, some feel that local shops and markets are unreliable, and likely to be unstaffed.

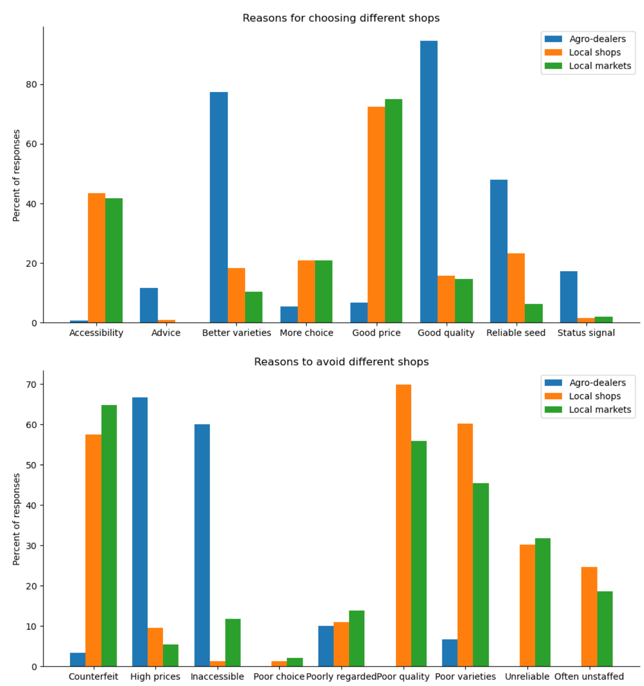

Figure 33: Reasons why respondents choose or avoid seed channels.

Seed channels of choice vary with the crop. 55% of respondents reported agro-dealers as their main source of maize seed. 30% report local shops as their main maize seed source and only 5% see local markets as the most important maize seed source. Only 13% report their own stores as their main source of seed for maize. This ranking of seed source is notably different for beans, the second most important crop for Sironko farmers. For beans, own-saved seed is the most important source (43%), followed by local shops (35%). Conversely to maize, only 19% see agro-dealers as the most important bean seed source. Similarly to maize however, local markets remain low in ranking, with only 6% seeing these channels as a major source.

As with seed channel choice, inputs vary between the two priority crops. Counter to qualitative reports of low input use, 85% of our sample report to apply fertilisers. This number decreases to 24% with beans. This reduction makes sense, given that legumes have the ability to access their own nitrogen source through a symbiotic relationship with nitrogen fixing bacteria. There are still however soil nutrients that legumes rely upon, such as phosphorus and potassium and so different doses of fertilisers make sense. Respondents reporting to purchase improved seed for maize and beans (49% and 12% respectively), echo similar numbers reporting to purchase from agro-dealers for both crops. A large proportion of respondents use pesticides for maize (83%), and this is mirrored in beans with 60% applying fertilisers. Few report to use no inputs for maize (9%), but around 31% report not to use inputs for beans.

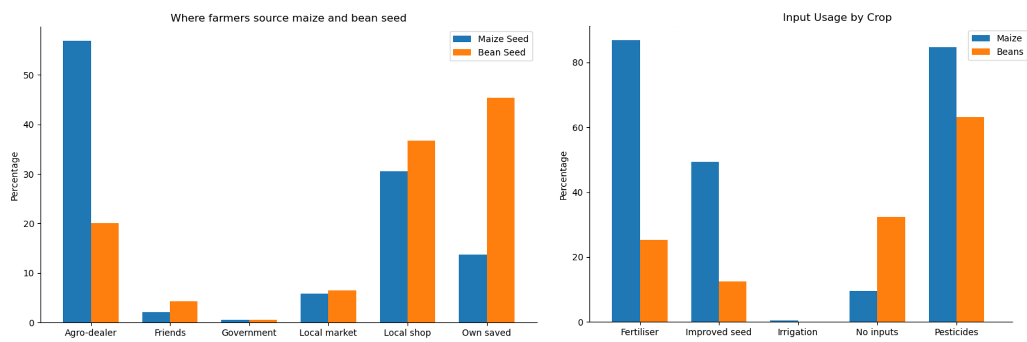

Figure 34: Source and input by crop.

Looking further into perceived quality on seed channels, 80% believe that agro-dealers sell high-quality seed. The next highest channel for good seed quality is other farmers, at 17%. The picture is however less clear for other seed channels. 29% feel that local shops sell low quality seed, while 46% believe this is the case for local markets. The slight majority felt that seed from local shops and other farmers is mostly average (33% and 27% respectively). A reasonable proportion of respondents feel unsure or that seed quality is mixed across most sources, except for agro-dealers. The most uncertainty is felt around travelling seed merchants, where 52% of respondents are unsure of the quality of seed on this channel.

54% of respondents report to sell seed at some point and 65% of respondents see this as, at least sometimes important for household income. Of those who sell seed, 88% sell to other farmers. Only around 12% of those who sell seed, sell to shops.

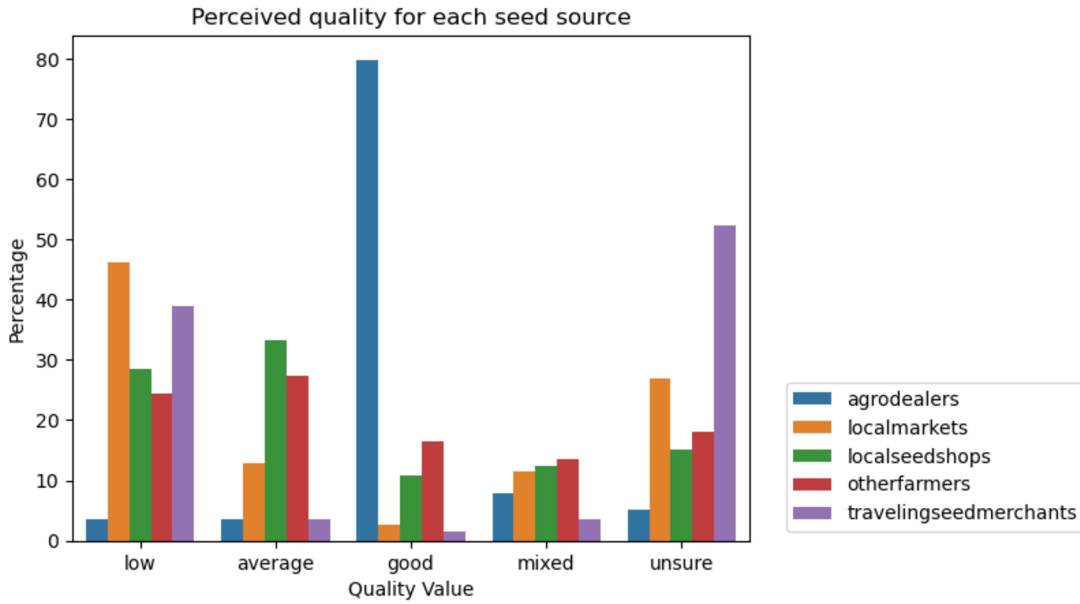

Figure 35: How farmers perceive quality across seed channels.

Most respondents believe that there are some seed counterfeiting issues locally. 53% of respondents believe that counterfeiting is sometimes a problem, and a quarter of respondents believe that it is often a problem. Views were mixed with regard to the counterfeiting source. 37% believe that local shops were to blame and 30% thought that travelling salespeople might be involved. Further to demonstrate a lack of certainty of counterfeiting sources, 17% of respondents were too unsure to suggest any particular source. Counter to previous qualitative, few believed the formal seed sector and business people to be a source of counterfeit goods (2% and 4% respectively). Related to counterfeiting, the majority of respondents had experienced seed failing to germinate. 61% reported that seed germination failure sometimes happens, and 14% felt this happens often. Around a quarter of respondents however had not experienced seed failing to germinate.

Demand for certified seed appears to be changing. Respondents perceive more local people buying certified seed than in the past, and expect this trend to continue. The below graph shows estimates respondents gave for the number of farmers out of ten growing certified seed five years in the past, at the current time and five years in the future. Five years ago, farmers estimate that around farmers out of ten purchased certified seed. This has now risen to an estimated six out of ten farmers purchasing certified seed currently. By five years time in the future, respondents estimate that eight out of ten farmers will buy certified seed. Therefore, respondents estimate

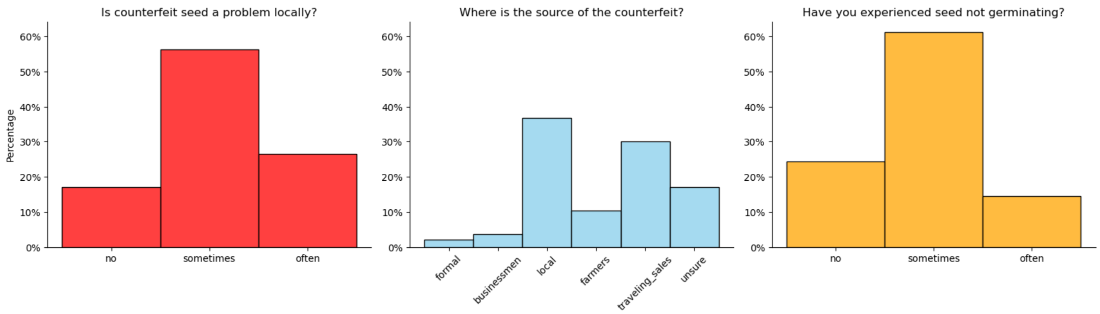

Figure 36: Counterfeit seed.

that the number of farmers buying certified seed will have almost doubled over ten years.

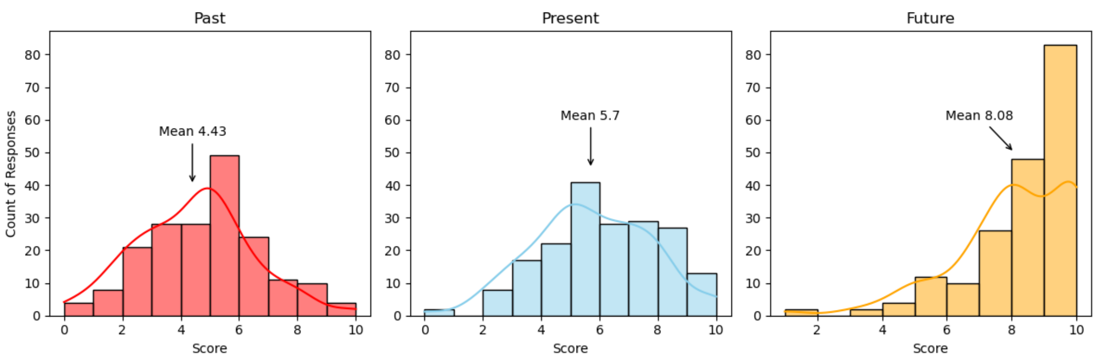

Figure 37: Estimates for buying certified seed.

7.2.1 Survey summary

Sironko respondents come from limited education and rely on arable and livestock farming for income. They cultivate around two acres of land, which is nearly entirely devoted to maize, beans and tomato crops. Crop diversity is limited beyond these three. Agro-dealers are the most popular seed channel and this demand has risen in recent years. Conversely, people are buying less or ceasing to buy from local shops and markets. People choose agro-dealers for high quality products and better varieties. Those who avoid agro-dealers do so because of high prices and the inaccessibility of stores. Local shops and markets are viewed similarly in terms of advantages and disadvantages. Both are favoured for accessibility and good prices. Both are avoided because of concerns of counterfeit seed, low quality products and poor varieties. Counterfeit seed is seen as a local problem. Local seed vendors are seen as the source of fake products. The majority of farmers sell seed at least sometimes. These sales are almost entirely made to other farmers. Local demand for certified seed is rising and this trend is expected to continue.

7.2.2 Discrete choice experiment

Our discrete choice experiment asked respondents to make choices comprised of five attributes:

1. **Seed source:** where the seed is purchased from.
2. **Price:** how much the seed costs.
3. **Seed type:** what kind of seed it is offered as.
4. **Recommendation:** who recommends the variety.
5. **Local presence:** how commonly grown the seed is locally.

The results of this work are visualised in figure 38 below. Colours differentiate attributes. Each attribute is compared against a base value. "*" indicates significance at the p = 0.05 level and "**" at the $p < 0.01$. These findings are detailed in table 17.

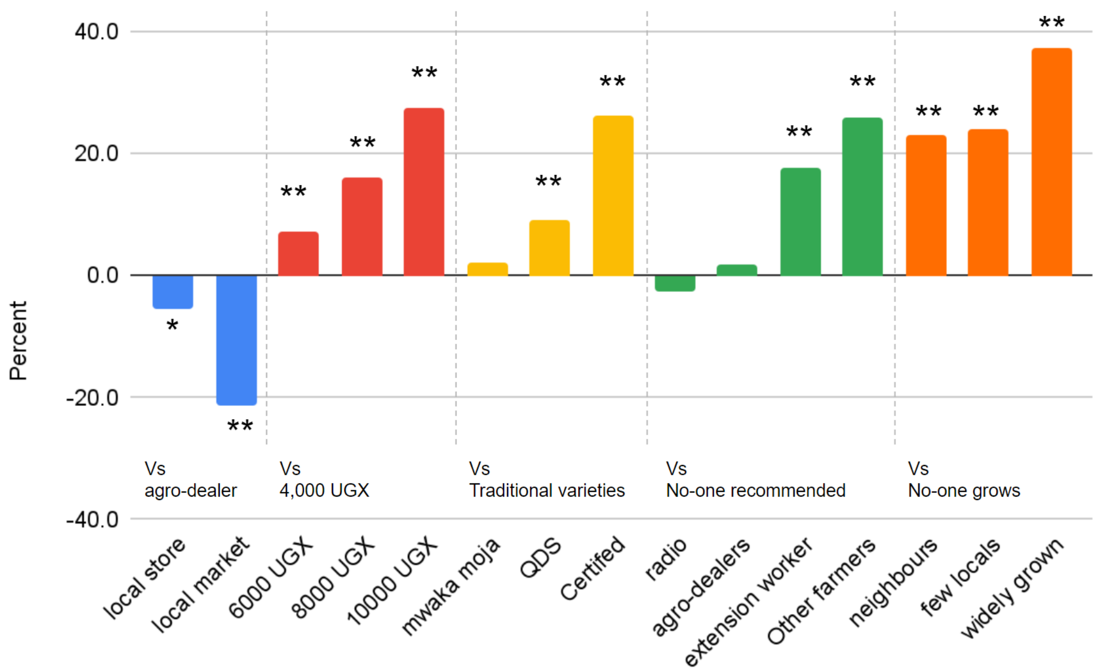

Figure 38: Respondent preferences across attributes.

A number of these findings are surprising and contrast with wider literature and our previous qualitative research. I give some explanations for this in the attribute sections below, and expand

Attribute level	Coefficient	SD	Z	P
Agro-dealer *(base)*				
Local store	-.055*	0.023	-2.42	0.015
Local market	-0.213**	0.022	-9.89	0.000
4,000 UGX *(base)*				
6,000 UGX	0.072**	0.024	3.02	0.003
8,000 UGX	0.161**	0.029	5.57	0.000
10,000 UGX	0.274**	0.028	9.99	0.000
Traditional seed *(base)*				
Mwaka moja	0.022	0.025	0.84	0.398
QDS	0.093**	0.028	3.35	0.001
Certified seed	0.26**	0.029	8.86	0.000
No recommendation *(base)*				
Radio	-0.025	0.026	-0.99	0.324
Agro-dealer	0.019	0.023	0.81	0.420
Extension worker	0.178**	0.026	6.74	0.000
Local farmers	0.258**	0.024	10.96	0.000
No-one grows locally *(base)*				
Neighbours	0.231**	0.028	8.35	0.000
Few locals	0.239**	0.027	8.70	0.000
Widely grown	0.373**	0.028	13.44	0.000

Table 17: Conditional effects of attribute levels on seed investment choices.

upon the wider implications in the following discussion section.

7.2.2.1 Seed source

Respondents are most likely to buy seed from agro-dealers. Respondents are 5% less likely ($p=0.015$) to purchase from local seed shops and 21% less likely to purchase from local markets ($p<0.001$). It seems therefore that respondents are marginally more likely to purchase seed from agro-dealers than local shops, and much more than local markets. These preferences align with the survey findings on source purchasing where the majority of respondents report to purchase maize from agro-dealers. These findings also demonstrate a perceived difference between local shops and local markets. While attitudes in the survey seem to treat both similarly, DCE results suggest that respondents are much less likely to choose new maize varieties from local markets, despite their popularity across rural areas.

Preference for agro-dealers contrasts with other seed system studies which find that sub-Saharan smallholders tend to rely on informal seed systems (McGuire and Sperling 2016; Sperling et al. 2020; Mastenbroek, Sirutyte, and Sparrow 2021). Smallholder reliance on informal systems is a major subject for sub-Saharan policy documents and critiques of the Ugandan formal seed sector (*Uganda Vision 2040* 2013; Joughin 2014; Agra 2017; Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019). The overwhelming narrative from these documents is that farmers are not choosing agro-dealers and instead prefer informal channels. Preference for agro-dealers also contrasts with earlier qualitative research undertaken as part of this project (as mentioned in previous chapters). In interviews and focus group discussions, farmers regularly spoke of not trusting agro-dealers, suspecting their goods to be poor quality despite the high prices they charge. Farmers in these instances said they preferred to acquire seed from local shops and farmers, on account that they trusted these actors and so they could conduct their own quality checks. These qualitative reports are also counter to survey findings, where respondents associate agro-dealers with high-quality products, and safe from counterfeiting. It therefore seems that there are nuanced views across respondents towards seed channels. There are a number of explanations that might explain such contrasting views.

The first point to make is about the specificity of maize. Maize is the most important crop in the area and happens to be one of the few major crops that the formal seed sector offers. This means that farmers might rely on informal channels for the majority of their crops, but choose agro-dealers for maize. In this sense, it could be that respondents in qualitative research were speaking about the formal seed sector more generally, rather than specifically for maize. Given the findings from the survey, it seems highly likely that farmers might have held a different preference for seed channels had the DCE been asking about crops other than maize. This is however not a perfect explanation. Conversations about *mwaka moja* were nearly entirely about maize. So too were complaints about certified seed presentation preventing farmers from running their own checks. Finally, and most glaring, focus group discussions regularly ranked agro-dealers as a lower priority seed channel for maize (see chapter 2). This paradoxical response suggests another possible reason for our DCE seed source results.

Another explanation is that our research has captured a time of change in how smallholders view and interact with formal seed channels. While a wealth of evidence suggests that informal seed systems have been the priority for many Ugandan smallholders, this could be shifting (Sperling et al. 2020). While informal shops were the seed channel of choice, perhaps farmer preferences for maize are shifting to agro-dealers. The very start of this research began around 2018 and finished in the summer of 2023. Survey respondents suggested that within the same time period, more people locally are shifting to purchasing from agro-dealers. As such, the preference we captured for agro-dealers could be a sign of changing demand. Other findings from this survey give plausible reasons as to why farmers might prefer agro-dealers. For example, farmers believe agro-dealers offer better varieties, high-quality seed and are more reliable. Local shops and markets on the other hand are seen as offering accessible, but lower quality products.

A plausible reason for the difference between qualitative and quantitative findings of this work could perhaps be explained by the locality with which shifting demand is taking place. Both rounds of research were in the same district, but still separated over large rural areas. It could therefore be that where farmers are changing seed source, that these changes are happening over relatively small areas at first. We later explore the DCE attribute of surrounding farmers on seed adoption but the important point to make here is that it appears to have a strong causal effect on investment decisions. If many farmers in the local area are shifting to agro-dealers, this could encourage large homogeneity in response. This argument can work both ways. In areas where local seed shops are preferred, the pattern might be the reverse. Thus it could be that our rounds of research have taken place in areas with binary opinions towards seed channels. Continuing this research across more areas would confirm or disprove this possibility.

A final, more concerning, suggestion is that this result was primed by our methodological approach. As described above, a script was read before the DCE, as a way to remind the respondents about the topics of the experiment. Doing so could reduce the chance of respondents choosing between alternatives without clear understanding of what all the attributes and levels are. Having respondents choose without this baseline understanding could reduce the explanatory power of the choice experiment. For example, respondents might be influenced to choose based on the topics they understand (or do not understand), rather than their preference between those choices. This is however a step that is different from the qualitative research. In interviews and focus group discussions, respondents were informed of what we are interested in talking about, but were not given explanations of the topic area. While we have tried to remain unbiased in our DCE scenario and present the situation fairly, it could be that respondents were either convinced to choose formal sector options, or that our research teams wanted them to choose formal sector options. An important factor to consider here is that researchers, government agencies and NGOs regularly operate across Eastern Uganda. These actors often thank respondents for their assistance by gifting bags of certified seed. Since certified seed is associated with agro-dealers, this might also have led respondents to believe that we, like other visitors, support the formal seed sector. Two counters to this suggestion can be found in the survey responses. Firstly, there is a great deal of homogeneity across seed source responses. If our presence did influence respondent actions, nearly all appear to be influenced in almost exactly the same way, and across multiple questions. This seems unlikely that our brief introduction could result in such consistency over a range of respondents and over separate locations. For instance, this homogeneity not only applies to the reasons why respondents choose seed sources, but also the nuanced ways they dislike them or avoid them,. As such, while our presence will have influenced the experiment, such consistency suggests widely held values across our respondents, likely formed from real-world experiences. Next, the details within this survey data paint a clear picture of why respondents believe agro-dealers are different, and potentially a better choice than local shops or local markets. While we believe our pre-test scenario to give a fair and non-leading description of the different seed options, if it did influence farmers, it still makes no comment on many areas related to agro-dealers where farmers showed further consistency in answers. For these reasons, we should be mindful of any bias but still consider the findings within this attribute.

Overall, it is worth considering the size of the conditional effect of seed channels on respondent choice. While agro-dealers are the preferred option, this is only by around 5% more than local shops, which traditionally have been a favoured seed channel. While all results are significant, this does perhaps suggest that the choice between agro-dealers and local shops is not a major determinant on seed investment alone. The literature, our qualitative work and the findings in survey have all mentioned reasons for why agro-dealers might be inaccessible (Chinsinga 2011; Odame and Muange 2011; McGuire and Sperling 2016). It seems however that respondents are interested in agro-dealers as a seed channel, at least in the absence of other factors. This might mean that in reality farmers are open to purchasing from agro-dealers, but might still be put off by other factors, such as price. Therefore, these findings could suggest that farmers would like to purchase from agro-dealers in theory, and real-world cases of choosing otherwise might be on account of other dimensions of the seed investment choice. With this thought in mind, we move on to the attribute that was most frequently mentioned throughout qualitative research.

7.2.2.2 Price

Price was regularly given as a reason why farmers choose between seed options. Since the majority of smallholders in our location are subsistence farmers, low prices are likely to be enabling and high prices seen more as barriers. That predication is however the opposite of what our DCE finds. We find that respondents are more likely to buy seed the more expensive it becomes. Respondents were 27% more likely to choose the most expensive seed against the cheapest ($p<0.001$). We find an escalating preference to choose seed which each level increase in price. These findings go against a wealth of literature that report high prices as barriers to farmer investment (Odame and Muange 2011; Smale and Olwande 2014; Bold et al. 2022; Chivasa et al. 2022). Other reports have found that even when provided with information on the potential benefits and return on investment modern varieties can offer, Ugandan smallholders remain unwilling to pay the higher prices (Mastenbroek, Sirutyte, and Sparrow 2021). Price was consistently mentioned in our qualitative research stages as a major driver for purchase decisions. High prices are seen as inaccessible and a barrier to investment. Low prices however were seen as enabling investment. Similarly, survey findings show that respondents choose informal seed sources on account of low prices, and see the prices at agro-dealers as inaccessible. This is worth considering in combination with Mastenbroek (*et al.*, 2021), which demonstrates that overcoming information barriers with modern varieties was only sufficient to raise willingness to pay to half that of certified seed prices. Mastenbroek's conclusion is that *"information is not the key constraint in the adoption process of yield enhancing products"* (Mastenbroek, Sirutyte, and Sparrow 2021, 197). The DCE preference for higher prices therefore suggests a number of possibilities:

The first possibility is that price was associated with quality. Our top price levels represent the prices associated with certified seed bags. When comparing which variety to pick, respondents might have associated higher prices as indicators of better quality or higher performing products. This compliments our survey findings; that sources associated with the highest quality varieties are also associated with high prices. This same suggestion was offered by a Ugandan field researcher we met during our research, who added that higher prices might also indicate authenticity, rather than counterfeit goods. As such, price and quality might be linked in respondents' decision-making. This presents two challenges. The first is that the data reflects a more hypothetical choice, rather than a real-world one. Respondents might be using price to identify the variety that they believe to be the best, but they might not be willing to choose this variety if they have to pay for it. If this is the case, our other results might be viewed through the lens of what respondents prefer in an ideal world. Since higher prices would be more associated with those for certified seed, respondents could be choosing prices that imply they are certified (Mastenbroek, Sirutyte, and Sparrow 2021).

The second challenge of the hypothetical choice is methodological, as it implies that price is not a distinct attribute. Ideally, each attribute should be separate from one another. This is not the case if prices are being used as a proxy for something else (e.g. quality) as well as the finances required for purchase. This challenge was partially expected, as seed prices are associated with different sources, but price had to be included as an attribute on account of its importance for purchasing behaviour. The consequence of price potentially having multiple implications comes in interpreting whether the attribute reflects attitudes toward financial amounts, or preferences for something else. The latter seems plausible given that there were no suggested varietal performance differences suggested between alternatives in our model. As such, additional rises in prices could potentially be seen to offer a lower return on investment. Alternatively, it could be that in the absence of yield estimates encouraged respondents to use prices levels to approximate differences in return. If so, this suggests an interesting way in which respondents might rely on prices as indicators of quality, even if they may not have the finances to always purchase seed of the highest price.

Another, more challenging, possibility for why respondents choose the highest priced seed might be that they believed they would be given their chosen seed option for involvement. This seems unlikely given that participants were told that they would be financially reimbursed for their time, and no mention was made of gifting seed. Further, all choices were introduced as having no impact on their reimbursement. It is however worth noting that it is common practice for many research and government projects in Uganda to gift seeds in exchange for participation.

Despite our introduction, respondents might have chosen an option on the chance that they would receive after the experiment. Since price is widely reported as a barrier to seed purchase, this might have encouraged choosing the highest option, in the hope of receiving it for free. If true, this has knock-on effects to the interpretation of the DCE findings. On one hand, this could have little effect beyond price. For instance, it might mean that respondents' views are less hypothetical about the other attributes, as they hope to obtain the product at the end. In this light, the factors beyond price would remain safe to interpret as real-world choices. On the other hand, if respondents sought higher-end, less regularly accessible options, the literature would predict they choose expensive seed from agro-dealers. For these same reasons, they might also avoid the more easily accessible local seed and local sources for this same reason. These predictions would align with our results and so could suggest such 'rarity-seeking' behaviour would affect the conditional effects for multiple attributes. Still, findings from the survey show why respondents are shifting to agro-dealers, so it seems unlikely that respondents are choosing the most exclusive option alone. It is also hard to see how this potential respondent strategy would affect the other attributes beyond real-world importance to the individual.

Ultimately, our DCE tries to capture what smallholders believe the best seed choice to be. Our findings for the price attribute suggest that respondents are making exactly this choice, but that this might be in a hypothetical or gamified way. Either approach suggests that respondents could see price as quality, even if real-world reports suggest that they may not always purchase the highest price in practice. Part of this reason not to purchase higher price maize might be explained by financial capacity. If farmers do however see higher prices as useful indicators of quality, further study could confirm if farmers are more likely to buy higher price products as they become wealthier. I however find no significant difference on this result when interacted with our wealth index. A final consideration here is how these findings might be influenced by seed subsidy scheme, which have been used in other African countries to reduce the barriers to certified seed (Erenstein and Kassie 2018). If farmers associate price with quality, subsided products might signal a lower-quality good.

7.2.2.3 Seed type

We presented four different types of seed to farmers. We find that respondents are 9% more likely to choose Quality-Declared Seed (QDS) and 26% more likely to choose certified seed over traditional seed ($p \leq 0.001$). *Mwaka moja* is equally likely to be picked as traditional seed, suggesting that the difference has no conditional effect of choice. These findings for certified seed are consistent with the survey results of preferring to purchase maize from agro-dealers; who mainly sell certified seed. Again, this contrasts with literature and qualitative research that finds that Ugandan smallholders are predominantly choosing saved seed, rather than certified seed. Contrary to farmer reports in the previous chapter, here respondents seem to prefer certified varieties and see little value in *mwaka moja* in comparison. If however we continue the hypothesis in the previous attribute (that respondents are choosing the hypothetical best option), that might also explain why farmers reported preference for *mwaka moja*, as it signifies that it comes from certified seed but without the accessibility barriers. These results however suggest that if farmers were in an ideal world, they would choose certified seed.

Our findings for QDS are new and potentially promising for the future of the integrated seed sector. QDS did not exist at our field site at the time of study, meaning that respondents likely learnt of this seed type in the pre-DCE scenario. Technically QDS will not be used for maize, since policy around it positions it for non-cash crop use (Mastenbroek, Otim, and Ntare 2021a). The aim here is for QDS to support formal sector crops, rather than compete with these markets. QDS is however still emerging in Uganda and has seen significant growth across the country for many other crops, such as beans and sweet potato. Our findings suggest that, on a brief outline of the concept alone, respondents see QDS as different from *mwaka moja* seed, and would be more likely to buy it. This is interesting as, in theory, the practice of producing *mwaka moja* and QDS sound similar from our brief introduction. Both rely upon the saving and storing of seed by farmers. Clearly however, respondents see something different between these types of seed, and that one is more attractive than the other. Further study could seek to understand how farmers seek QDS as different from locally saved and sold options.

The lack of significance between traditional varieties and *mwaka moja* is surprising for two reasons. The first is that many respondents in interviews spoke highly of *mwaka moja* as a more accessible way of accessing useful varieties from the formal sector. This qualitative finding suggested that farmers see *mwaka moja* as a specific strategy to access modern varieties. Further, *mwaka moja* has largely replaced traditional varieties across Sironko. Very few farmers in the area grew traditional maize varieties. Those who did, grew small amounts in addition to their main maize crop. This demonstrates that farmers not only claim to value *mwaka moja* over traditional varieties, their fields are living empirical evidence of this preference. The DCE result is therefore surprising as respondents do not appear to be actively choosing *mwaka moja* over traditional varieties. There could be a number of reasons for this. The first might be that respondents did not understand or simply do not see a difference between traditional varieties and *mwaka moja*. This seems unlikely given that farmers know which variety names are associated with agro-dealers and the formal seed system. It could be however that respondents view both traditional varieties and *mwaka moja* as the same in another regard; they are both farmer-saved. In this sense, traditional varieties and *mwaka moja* might be seen to farmers as similar products and hence the lack of differentiation when farmers are offered a range of options. Still, these findings complicate the reports of farmers who prefer *mwaka moja* seed over traditional varieties and even certified seed. Here it seems that farmers have the greatest preference for maize seed in the form of certified seed.

7.2.2.4 Recommendation

Farmers are surrounded by a large number of sources that are reported to recommend crop varieties. We find that recommendations from extension workers and other farmers have a conditional effect on seed investment decisions, 18% and 26% respectively ($p<0.001$ for both). These preferences complement earlier qualitative findings of where farmers report to value advice. Farmers reported to value extension worker insights and requested more of these interactions through field demonstration days. The importance of agriculture extension workers' recommendations here demonstrates their role as a conduit between farmers and useful technologies. This role is perhaps particularly important in Ugandan given the decentralised government, and pluralistic extension systems that have more recently come into effect (Kuteesa, Kisaame, and Barungi 2018; Namyenya et al. 2022). These findings demonstrate the importance of investing in agricultural extension workers as a way to inform and encourage farmers to access new and useful varieties.

Respondents' investment decisions are most influenced by the recommendations of other farmers. This aligns with qualitative work where farmers regularly reported to observe and seek the agricultural guidance of other local farmers. These other farmers are well-placed to compare ideas with as they share the same agro-ecology and may have hands-on experience of the technology. Furthermore, these farmers are unlikely to have vested interests that bias the kinds of advice they give. These forms of peer to peer effects on knowledge exchange and technology adoption are well known. As Van Campenhout describes it for a recent study with Ugandan rice farmers' information becomes more effective if it can be discussed among peer farmers" (Van Campenhout 2021, 31). This seems to be particularly the case where farmers identify with those they are asking (Benyishay and Mobarak 2014).

We find that radio and agro-dealer recommendations are no more likely to influence choices than no recommendations at all. These results are surprising and contrast with the qualitative findings. In focus group discussions, radio stations were commonly mentioned as a way to learn of new varieties. This could be observed in the field, as radio stations were regularly playing in village areas and shops. When farmers sought a new variety, many learnt of it from the radio. This is to be expected given that more than 80% of households in rural Ugandan areas are thought to have access to radio stations (Tenywa et al. 2017). Radio stations tend to be broadcast in local languages, reach across remote rural areas and provide a line of information for illiterate individuals. For these reasons radios have frequently been targeted as a way to build awareness around agricultural information (Hailu et al. 2017; Kaahwa et al. 2019). We find however that, although these stations are well-known as sources of agricultural information, their recommendation of a variety does not have a causal effect on respondent choices.

Interviews found that farmers appreciate the advice agro-dealer give about varieties and cultivation. The DCE results however suggest that this advice is equally influential on the investment decision as no advice at all. These findings are consistent with the survey, where only 9% felt 'advice' is a reason to shop at agro-dealers. This result is however surprising given the DCE result that agro-dealers are the most preferred seed channel. Similarly, our survey shows that agro-dealers are associated with the best quality goods and that more farmers are shifting to purchase from agro-dealers.

All of these signs would suggest that respondents might value the recommendation of agro-dealers but this appears not to be the case. This could perhaps be due to the vested interest that agro-dealers have in selling their products. It could therefore be that respondents are reluctant to believe the recommendations agro-dealers give. This scenario would be consistent with farmer views in qualitative rounds of research, where agro-dealers were seen as untrustworthy, and primarily interested in selling their products rather than ensuring farmers achieve high yields. Alternatively, it could be that respondents see agro-dealers as purveyors of good products, but still as primarily business people, and lacking in the agricultural experience to give a reliable recommendation. A final possibility is that an agro-dealer recommendation is not bespoke, and that agro-dealers recommend all of their wares. In this scenario, a variety recommended by agro-dealers might be unremarkable, because agro-dealers might recommend many products. Regardless of the exact reason, this finding correlates with findings in the first results chapter that agro-dealers actually have remarkably little influence on encouraging farmers to purchase new varieties. Instead, they cater to farmer demand, which is largely towards older, familiar varieties. Together these findings demonstrate that while agro-dealers are the main interface for crop innovations from the formal seed sector, they may have limited ability to encourage farmers to adopt new varieties.

We caveat these recommendation findings by highlighting a notable methodological challenge with our recommendation category. Our results here demonstrate that the information alone of whether a variety is recommended by agricultural extension workers or farmers is sufficient to cause a conditional effect on respondent behaviour. What this choice unfortunately does not cover is the *way* in which the recommendation is made. While we find that news of recommendations on the radio or agro-dealers have no causal effect on investment, it could be that the way that a product is recommended by either of these sources could have an effect. For example, what happens when the radio station programme broadcasts farmers recommending a variety? Our results demonstrate where recommendations appear to have the most influence, but some might still be swayed by the way in which radio shows or agro-dealers advise the best crop. Another feature to note is that some farmers are more active in seeking recommendations than others (Giroux et al. 2023).

7.2.2.5 Local presence

The relative local presence of the variety had the largest conditional effects on respondent choice. Respondents are increasingly more likely to choose varieties with each additional level of local presence. Every level of local presence was preferred against a variety that hasn't been grown locally before. Varieties grown by neighbours, a few locals or widely grown raised choice likelihood by 23%, 24% and 37%, respectively ($p<0.001$ for all). Interestingly, the effect is also identical for whether a variety is grown by neighbours of the respondent, or other locals more generally. It therefore seems that the proximity of neighbours or other local farmers is weighted similarly by respondents in this instance. Neither wealth or education status appear to influence the effect of local presence on the decision to adopt. Both were tested as wealthier or educated individuals might be more inclined to experiment with new varieties but our data suggests no such patterns with this prediction.

These findings complement qualitative reports of farmers worrying about purchasing new varieties which are not locally adapted. This concern makes a great deal of sense given that many of the local farmers in our sample area are vulnerable to shocks and have few safety nets. Consequently, the risk of missing the growing season could be potentially disastrous. Smallholders in this same position are commonly found to stick with the varieties they know (Holden and Quiggin 2017; Mukasa 2018) Thus, our local presence attribute demonstrates a key factor on how farmers gauge risk. Those varieties that are not grown locally present either a gamble of local suitability (e.g. 'new and unknown'), or the potential that their absence is a result of other farmers choosing not to grow the variety (e.g. 'known and avoided'). In either case, the relative number of other farmers growing the crop in an area appears to be a metric with a strong causal effect on respondent adoption. The more people are said to grow a variety, the more likely respondents are to adopt it. Thus, there appears to be a herd mentality to local farmer choice that encourages others to adopt and reinforces the overall effect in a form of positive feedback. This is not dissimilar to the diffusion of innovations concept of (Rogers 1962), whereby the majority of actors will not adopt a technology until those around them do.

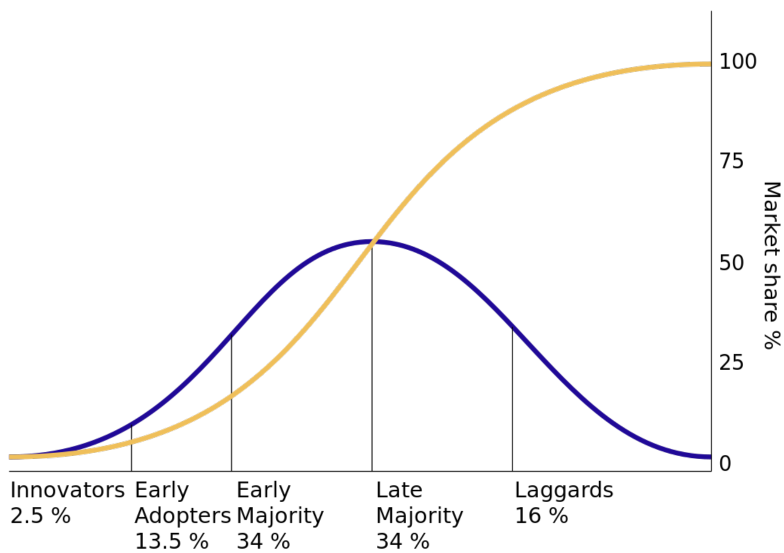

Figure 39: The diffusion of innovations according to Rogers (1962). The blue markers successive individuals adopting the technology, while the yellow line shows market saturation.

The system likely works for smallholders on some grounds, as it would be irrational for a large number of farmers to grow a failing crop. This same behaviour might however encourage farmers to stick with average but well-established varieties, when better but rarer options exist. This behaviour is therefore particularly challenging in that it could discourage investment in new varieties to the area, despite their potential value. So on one hand, siding with the majority might protect the individual against unknown threats, but it inhibits the kind of risk-taking behaviour required to discover potentially useful innovations. These findings are important challenges to consider can pest, disease or climate adaptation strategies that require large proportions of a community to rapidly switch to new, previously unused varieties. With that said, informing smallholders of wider adoption might further encourage uptake.

A point to consider in this experiment is that we are asking respondents to make one choice. This is useful to understand the factors that affect that choice. However, in reality, a farmer is likely to choose more than one variety, and experiment with what works on their land. It therefore makes sense that a respondent would choose their main crop based upon local presence of the variety, but they may still be willing to trial a smaller area for lesser known varieties.

7.2.3 In conclusion

Our results find that respondents prefer agro-dealer sources of maize seed over local shops and markets. Smallholders marginally prefer agro-dealers over local shops, but a negative effect size is noticeably larger for local markets. It therefore seems that respondents would prefer to purchase maize varieties from agro-dealers, compared to informal channels. Respondents were most likely to pick varieties of a higher price as the best choice. These findings are surprising given that our sample is mainly comprised of research-poor farmers. Prices are regularly seen as a barrier to adoption on accessibility grounds, and this tends to be particularly so for subsistence farmers. We therefore suggest that farmers are using the attribute of price as an indicator of quality. This could perhaps be informed by the apparent exposure Ugandan smallholders have experienced to low-quality and counterfeit goods, whereby higher prices might indicate better quality products (Bold et al. 2017, 2022; Barriga and Fiala 2020).

The main challenge to this hypothesis is that many of the studies on poor quality seed are associated with formal seed products, which tend to be comparatively higher on price than informal options. Surveys suggest however a general feeling that formal sector goods are of higher quality and more reliable than informal options. These findings echo recent study, where farmers report to be satisfied with the quality products from agro-dealers (Van Campenhout and De 2023). Surveys that show preferences for formal channels, respondents are more likely to choose QDS and certified seed over traditional and *mwaka moja* options. The preferences for more formal seed types over locally conserved options are counter to prior qualitative research, but in-keeping with surveys that suggest farmers are shifting to formal sector products. Maize seed investment decisions are most influenced by recommendations from other farmers or agricultural extension workers. These findings are in-keeping with qualitative findings that farmers trust other farmers, and welcome interactions with agricultural extension workers. These findings support others reporting farmers to prefer technologies they can source information on from those they identify with (Benyishay and Mobarak 2014; Van Campenhout 2021). Recommendations from radios and agro-dealers however have no more effect on the maize seed choice than no recommendation at all, contrasting other studies that find promise in these information outlets (Ssalongo 2011; Hailu et al. 2017). These reports regarding agro-dealers seem particularly surprising, given that other attributes and survey results suggest farmers value agro-dealer products (Van Campenhout and De 2023). Finally, respondents prefer to choose varieties that are locally established. Each level above not being grown locally has a positive causal effect on the choice decision, with respondents being most persuaded by varieties that are already widely adopted.

7.3 Discussion

Our DCE and survey findings paint a clear picture of Sironko farmer preferences. Respondents would prefer to buy new maize varieties from formal channels, and use prices as an estimate for quality. Respondents prefer what other farmers recommend and are known to grow. Overall it seems that respondents are shifting to formal seed channels and products, and perceive this behavioural change across other farmers. Conversely, informal channels are seen as an accessible way to access new technologies, but subject to more variable quality of products.

These DCE findings are revealing in their own right, and complementary when compared with earlier qualitative work. I break this discussion section into two parts to explore these findings. The first compares and contrasts farmer seed purchase behaviour between our affordances and utility theory approaches. The second section draws specifically on what these DCE findings present, and the wider implications for changing seed systems around Ugandan farmers.

7.3.1 Contrast

A striking feature of the DCE results is how they contrast with the findings from our affordances approach. Farmers and key informants in qualitative research seemed to push back against formal seed systems. Qualitative research participants saw formal systems as expensive, untrustworthy and ultimately, an unnecessarily expensive way to obtain useful varieties. Informal sources on the other hand afforded greater action possibilities to farmers, as they sought the best seed strategy for their livelihoods. These views seem almost completely counter to those suggested by the DCE and survey. Both elements add to a more nuanced and robust view of how farmers view and navigate seed systems. Here I discuss some of the possible reasons for contrasts in our findings, which might give deeper insight into the situation.

The first reason is that our affordances lens investigated seed system landscapes for the entire portfolio of farmers crops. Our DCE on the other hand looked specifically at maize. This is important as the Ugandan formal seed system is almost entirely focused on the sale of maize seed and oil seed crops. It therefore makes sense that interview participants are critical of formal channels generally, as they play a limited role in seed supply. Thus, while our DCE study suggests a shift to formal seed sectors, this must be made with the caveat of the special case for maize. While it is possible that buying maize from formal sectors might indirectly encourage the same shift for other crops, our DCE findings alone cannot be conflated with a more general shift. Thus, our DCE shows a specific case with maize and our affordances lens captures a more general feeling towards seed systems.

Clearly, however, another point of contrast is how farmers in both rounds of study frame maize seed systems. Many qualitative discussions were critical of formal maize channels and certified seed in particular. These reports stand in stark contrast to DCE findings, especially with regard to *mwaka moja* seed. One potential way this could be understood is that farmers would like to purchase certified seed in an ideal world, but ultimately certain dimensions to the investment decision, such as accessibility, mean that farmers have frequently chosen informal channels. This distinction of 'the best' and 'what is used' is critical. During our affordances research, participants were asked to share what cropping strategies they make, and why. In the DCE, respondents were asked to select *the best* option from a hypothetical situation. Thus our affordances responses might be giving a more representational picture of what crops smallholders currently use and why. These conversations might therefore naturally draw out more of the challenges involved in these choices that constrain or enable farmer choices. DCE results on the other hand offered a more controlled study of a specific set of variables. This approach gives us insight into what farmers perceive as the best choice, but that does not mean that farmers always make this same choice in practice. Put another way, our DCEs might be more hypothetical, and maybe even aspirational. The challenges here are perhaps of both contextual behaviour and cognitive dissonance.

Contextually, respondents in qualitative discussions are likely to draw upon a broader range of social elements than the array of choices within our survey design. Our affordances lens relies on deeper qualitative approaches, which might capture greater complexity of social trust and networks that underpin informal systems. For these reasons, our affordances research might have provided the space for farmers to share greater insight into informal channels, and the array of social actions that comprise them. Our DCE lens on the other hand is more focused on quantifying a particular set of preferences. As such, it may not have fully captured more of the social nuances surrounding informal seed practice. Another contextual component includes the clear experiential difference for respondents discussing topics in focus groups compared to one-to-one surveys. This is not to say the two are completely separate, as our DCE and survey design was influenced by the content in qualitative discussions. The strength in having both is that our overall findings include the broad findings from qualitative discussions, and use DCEs to more precisely test what appear to be key dimensions for decision-making. These different contexts could however influence which topics are focused on, especially for emotive or socially sensational topics; such as stories of seed failing or counterfeit seed from formal channels.

Cognitive dissonance could play a role in contrasting results whereby farmers may prefer formal seed features in theory, but choose informal systems for the accessibility, distrust or social elements outlined in the affordances research (Chen 2008; Harmon-Jones and Mills 2019). This suggestion echoes other studies that find choice experiments to be informative, but not always a true reproduction of how actors behave in reality (Verschoor, D'Exelle, and Perez-Viana 2016). We therefore suggest that our DCE lens gives perspectives into Ugandan smallholder decision-making, but that our affordances lens provides reasons of why not all all actors may make these same choices in the field.

Finally, contrasts in findings could be as a result of geo-spatial and temporal differences. Our research appears to have studied seed systems at a time of change. These changes could perhaps be rapid but extremely localised. For instance, it could be that some communities are rapidly shifting to formal seed suppliers for maize, while others are more reluctant to change. For example, some areas might have greater proximity to agro-dealers or higher relative affluence to purchase formal sector products. While our samples appear similar in socio-economic background, DCE results show how highly influenced individuals are by local adoption choices. A potential explanation for different views towards seed channels might therefore be a result of which communities have suddenly shifted to formal channels, and which continue to use informal channels. While this seems unlikely, further study across Uganda might serve to confirm this.

Overall, these differences remind that farmer preferences can be dynamic and multi-dimensional.

There appear to be good reasons why farmers chose formal and informal systems, and these reasons are not as binary as expected. Further research can seek to understand how preferences manifest across larger areas, and socio-economic groups. These differences also have policy implications. The contrasts we find can guide agricultural policy design to build trust and quality perceptions in the formal sector while recognising importance of informal systems in seed security. Doing so can offer a more nuanced framework for developing interventions to support seed systems and new variety adoption.

7.3.2 Changing seed systems

Perhaps the most striking finding from this research is how quickly maize seed purchasing is shifting to agro-dealers, and that this is expected to become prevalent. These findings provide a snapshot of how actors are changing seed channel preferences, against a backdrop of rising farming pressures and government advocacy for formal seed supply. While these figures concern maize particularly, and other crops may have a different channel association, they nod to a widespread social shift in how Ugandan smallholders purchase crop varieties. This shift is important as it is contrary to how the majority of African smallholders currently source seed (McGuire and Sperling 2016; Sperling et al. 2020). These findings suggest that the new norm for Sironko farmers is to purchase maize from agro-dealers, and that farmers expect this prevalence will become near universal.[16]

The critical question is what this transition actually means for farmers. The logic of the Ugandan vision and other African Green Revolution groups suggest this transition will result in a maize productivity increase in Eastern Uganda in the coming years (Agra 2017; Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019). It is important to consider on what grounds these predictions are made with respect to our research.

A transition to agro-dealers does not necessarily mean that farmers shift to the latest varieties, as agro-dealers mainly sell older "well-known" varieties. Even more critically, this transition might not even mean farmers *change* the varieties they grow, as our previous chapter demonstrates that farmers appear to be choosing formal varieties from informal systems. Finally, our DCE results show farmers prefer locally-known and widely-grown varieties. Changing channel is unlikely to change this preference. Combined, these factors suggest that a shift to purchasing from agro-dealers is unlikely to result in farmers growing new varieties. So if maize productivity

[16] With only 2 of our 10 farmers expected to buy seed from informal sources in the future.

increases do not come from new varieties, how else might this transition raise harvests?

A transition to formal channel purchasing will change the number of farmers who rely on certified seed. To be more precise, it will raise the number of farmers dependent on formally produced and regulated seed. Proponents of a shift to formal seed channels argue this will improve the quality of seed products farmers purchase (Mennel et al. 2014; Bold et al. 2017). This predicted greater assurance of quality is hoped to protect farmers and lead to greater yields. Currently, the majority of farmers rely on the quality checks of other farmers, informal sellers and their own tests prior to purchase. In shifting to formal systems that block these local tests, purchasers will rely more heavily upon formal regulatory standards and the conditions in seed supply (Barriga and Fiala 2020). As explored in this thesis, this raises some concerns over whether there is regulatory capacity in formal seed supply to ensure farmers purchase high quality goods. The status of quality on seed channels remains hazy (Miehe, Sparrow, and Spielman 2023). Formal reports find poor quality products in formal supply (Bold et al. 2017, 2022; Barriga and Fiala 2020). Farmers in our qualitative research shared these experiences with formal systems, but DCE respondents rank formal sources as the most reliable. Generally, it seems like the quality of formal products remains an area for government investment, to protect farmers and encourage repeat purchase.

7.3.3 In conclusion

We find that smallholders in Eastern Uganda prefer agro-dealers and prices that associate with those for certified seed. These findings might be indicative of a general social switch of seed system choice for maize, whereby the majority of seed is sold by formal seed sources. While this change aligns with government ambitions for seed purchasing, the impacts of such a change remain unclear. We do however caution that the qualitative research informing this work shared multiple benefits of informal seed systems, which are likely to be of particular importance to marginal farmers or during times of shock. We therefore suggest these findings can improve the design of formal seed systems for farm engagement. For instance, we find that farmers are moving to certified seed, and they are most likely to choose these varieties when they are recommended by extension workers and other farmers. This is particularly important for new varieties to an area as farmers are more likely to choose what is already widely grown. With that said, these findings also demonstrate the importance for plurality in seed systems to best protect farmers (Mastenbroek and Menya 2015; Mulesa et al. 2021). While it seems farmers are shifting to formal seed systems, this change is limited to maize. Beyond maize, a range of informal seed sources are essential to ensure farmers can meet their livelihood and nutritional needs. These results therefore remind of the ongoing importance of supporting a range of seed systems for local economic and food security.

Chapter 8

Conclusions

Global agricultural systems are under great pressures to change. Some of these changes are from environmental and public health needs (Campbell et al. 2017; Schwingshackl et al. 2017; FAO et al. 2020). These include needs to reduce the impact of the food system on biodiversity, while also achieving nutritious diets for all (Brondizio et al. 2019 ; Benton et al. 2021; Wentworth and Latter 2023). Other pressures to change stem from an increasing demand for food production, despite the pressures of climate change and rising consumption (Campbell et al. 2017; Ortiz-Bobea et al. 2021). Seasonality changes, and associated pest and disease fluctuations, have already reduced harvests and these pressures are expected to intensify (Barzman et al. 2015; Ortiz-Bobea et al. 2021). A major part achieving future food security depends on raising harvests of healthy food despite these pressures, and doing so on reduced overall agricultural area (Conway and Shah 2012). A key part of how we overcome these challenges, depends on how we support farmers to adapt.

As we have explored, raising agricultural productivity has become a central policy theme in Uganda. In a country where two thirds are employed in agriculture, suffer from yield gaps and have limited adaptive capacity, the Ugandan productivity mission outlines a vision for *transformation.* Transformation here means changing smallholder farming to a Green Revolution formula that has raised yields across continents (*Uganda Vision 2040* 2013). The plan is to proliferate modern varieties and inputs across smallholders' fields, which promise higher, more resilient and nutritious yields. This is posed as a solution to the current varieties rural Ugandans grow, which are seen as constraining productivity. Put simply, shifting to modern varieties is expected to reduce the risks Ugandan smallholders face from climate and nutritional security pressures. Bioscience has many examples of how modern varieties can offer resilience to productivity pressures. There are however also concerns for the new risks such changes might expose farmers to.

Shifting Ugandan smallholders to modern varieties also means changing the main system by which farmers access seeds. The formal seed model of officially regulated, certified seed, sold by agro-dealers marks a significant adjustment from the informal system farmers depend upon. These changes not only affect the type of material products, but also the wider social structures which order how farmers perform seed technology. The livelihoods of many depend upon the same systems that transformation policies seek to replace. This study has therefore sought to understand how farmers navigate seed systems to reduce risks and support livelihoods. Learning from these strategies can inform systems to help farmers access useful varieties.

In this thesis, we have explored how formal seed operates in practice, how farmers navigate the seed systems to source useful varieties and how the conditional effects of seed channel attributes influence farmer behaviour. I summarise the findings on these themes below, before considering how changes in seed systems and their products affect the risks that Ugandan smallholders face. Following this, I reflect on the methodology of this research, and outline areas for future research.

8.1 Main findings

This thesis shares natural and social science findings that influence seed systems and farmer decision-making. In this section, I explore some of the main findings for ongoing seed system development and plans to help farmers access new varieties. These findings are as follows.

8.1.1 Our methodology gives a nuanced understanding of the context

This thesis provides an interdisciplinary study into seed systems, using integrated mixed methods approaches to understand the context. Both natural and social science approaches were used to understand the broad context of seed technology, as well as the integral actors, behaviours and social structures. As mentioned in the epistemology of this thesis, combining these disciplines was challenging, requiring significant time for learning, feedback, reflection and adjustment. These stages demonstrate the additional investment required to design interdisciplinary research. Drawing these perspectives together however, gave a dynamic lens through which to consider how changing Ugandan seed systems might enable or restrict smallholder livelihoods.

The natural sciences components of this research allowed confirmation of the high germination rates of seed shipped from companies, while also demonstrating how these germination rates deteriorate in smallholder planting conditions. Such findings show that seed can be both of high viability and yes give low germination rates when grown under smallholder conditions. Our natural science work also served to identify the hidden environmental risks to seed health in formal supply systems, and hint at first challenges in agro-dealer storage. These findings offer new insights into the widespread reports of counterfeiting across Uganda being the source of seed that fails to germinate.

A key social science component of this research involved combining two complementary methods of studying behaviour and perceived utility. Here, we combined the theory of affordances with discrete choice experiments. Both approaches offer frameworks to explore different aspects of smallholder decision-making. Comparing these methodologies provided meant we could analyse farmer patterns for utility seeking behaviour, based within an environment of changing action possibilities. Here we study seed investment from both individual rationale, and the changing individual-environment affordances. The result provides a greater frame of reference upon which to consider seed technology in rural Uganda.

Perhaps the most notable insight from our combined approach is the contrast in how farmers view changing seed systems. The landscape of seed technology behaviours from both technographic and affordances perspectives notably diverge from those using a purely rational utility theory approach. Some difference should perhaps be expected, given that both approaches emphasise different components of human behaviour and environmental interaction. Still, the degree of contrast presents a complex and more nuanced view of the situation. We find reasons why farmers are reluctant to shift to agro-dealers, as well as why they are shifting.

Some of these differences can be explained due to general views towards seeds in certain cases, compared to views specifically for maize seed (such as in our DCE). Even within the particular case of maize however, our affordances research finds clear reasons why farmers avoid and distrust certified seed, while our DCE shows almost the opposite. Both groups are of similar agro-ecologies and socio-economic status, so potential differences in the sample population cannot adequately explain differences in response. Instead this demonstrates that there are complex views around the shift to formal seed systems.

It is important to note that using either approach alone would have led to more direct recommendations from this thesis. For example, DCE results suggest that farmers see a shift to agro-dealers would improve the quality of seed they purchase. Using only this approach however would have missed the ways in which farmers use their agency to access modern varieties from agro-dealers as part of wider seed security strategies. Combining findings from both offered a more rounded understanding of the context, to influence seed system development plans in ways that support the range of farmers who depend upon them. More generally, the interdisciplinary nature of the research provides a broader picture to the context. It allowed testing and understanding of the physical components of seed and variety technology in combination with the social components of crop technology performance. Both dimensions are critical to the overall delivery and performance of seed sharing and the mobilisation of useful traits.

Our approach demonstrates the richness of findings that can come from combining the decision-making of the individual, within the environment of relational action possibilities. It elucidates how actors perceive value in seed attributes, and how changes in the environment influence agency. Informal channels afford farmers with greater agency to explore new seed technologies. Formal channels restrict the range of these action possibilities, but farmers may be willing to sacrifice this agency where other factors have a causal effect on their preferences.

Overall, this gives a sense of complexity and dynamism in smallholder preferences. These results demonstrate how farmer seed preferences are not static or one-dimensional. They are nuanced and formed through a dynamic interplay of economic, social, and individual factors. These results also demonstrate the potential for these preferences to vary even within the same community. Through investigating the reasons for such contrasts, we can draw new insights into Uganda. This can also offer a more realistic and grounded framework for developing interventions to improve seed system choices and adoption rates of new crop technologies.

On these grounds, I encourage wider studies to consider this combined approach of decision-making theories. Doing so might capture the greater nuance in how actors perceive and act as part of technology developments. This rounded view seems particularly important for complex changing systems, such as those taking place around Ugandan seed sector developments. Such changes will affect a range of actors over a myriad of ways. This is compounded given the range of ways the individuals might make choices and their respective openness to risk in change. The findings outlined below are a result of this combined methodology.

8.1.2 Gaps remain in formal seed supply capacity

The Ugandan formal seed sector aspires to replace the informal seed sector, but we uncover capacity shortfalls that make this replacement seem unlikely. Until these capacity shortfalls are amended, the formal seed sector seems unlikely to become the main seed channel across crops.

The first capacity shortfall is that the formal sector simply does not supply the range of crops households rely upon. Instead, formal systems focus on a limited portfolio of nearly entirely maize varieties and oilseed crops. While it is true that formal systems can offer other higher-value crops, such as tomatoes, we find little evidence of most smallholders generally relying on formal channels. Modern varieties do exist for a wider array of crops, but they are either unprofitable for seed companies to market or too comparatively costly for most smallholders to purchase compared to informal alternatives. This limitation is a combined result of the private business model of formal seed systems, and the additional costs in seed production that influence modern variety prices. These challenges are the result of path dependency, whereby the formal sector is bound[1] to operate in a certain way based on historically made decisions (McGuire 2005; McGuire 2008). It is therefore difficult to see how the formal sector could feasibly support wider Ugandan agriculture in the short-term, given that its model struggles in the context outside of a narrow range of crops. This same business model makes it unclear how formal systems could enable modern variety deployment of less market-focused crops, despite their importance for household nutritional security.

The wider ramifications of this are that it is unclear how modern breeding innovations in nutritional but lower value crops could be sustainably deployed to smallholders on formal systems. For instance, seed companies would struggle to compete with informal systems to offer biofortified sweet potato to farmers, despite the nutritional benefits such varieties can offer to poorer families. Resource-poor farmers are unlikely to pay formal seed costs for crops that bring in little money. Given that this is the situation for the majority of Ugandan farmers, it is hard not to see the formal seed sector as designed for a different context. This fundamental business model challenge therefore undermines more dogmatic views that transitions to formal seed systems will ensure a general productivity increase. Formal systems offer productivity increases for a limited range of crops, but struggle beyond those high-value crops.

A related assumption is that the formal sector has the capacity to supply new crop innovations to farmers. A common narrative is that switching smallholders to formal seed systems brings

[1]By pre-existing management, infrastructure, staffing roles and investment responsibilities.

the latest varieties from modern breeding platforms to farmers (Agra 2017; Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019). These scenarios give the sense that formal seed systems control the demand farmers have, helping to point farmers in the directions of newly improved varieties. On the contrary, we instead find that agro-dealers respond to demand of farmers, who prefer well-known varieties that have worked in the past. This preference for familiar crops might explain why many of the most popular modern varieties of maize in Uganda are decades old, despite countless varietal innovations in the same time (Mabaya et al. 2021). Since the business models of both agro-dealers and seed companies depend on catering to smallholder supply for older varieties, the formal seed sector appears to have difficulty encouraging the update of the newest varietal innovations. These findings demonstrate how a shift to purchasing from agro-dealers does not automatically result in farmers purchasing the latest varieties.

Another capacity component examined in this research is the ability of the formal sector to achieve the regulatory standards it prides itself on. As shown, shortfalls come in the form of both the current regulatory staffing capacity, and the capacity of seed system supply chains to reliably supply seed products. A commonly described narrative is that the formal seed sector offers high quality and dependable products on account of its production standards and regulation. These officiated regulations are valourised as protecting farmers from low germination rates and poorly performing products, thereby reducing adoption risks and ensuring a good return on investment. In theory, such assurance is critical to subsistence farmers who are particularly dependent on their seed investments performing each season. In practice however, certified seed is still associated with poor quality products. Reports of poor quality certified seed has led many to search for counterfeiters (Mennel et al. 2014; Bold et al. 2017; Barriga and Fiala 2020). Such suggestions shift the blame from the formal sector, suggesting that if formal sector products are failing to perform, they must not be authentic products (Bold et al. 2017). We however join others in investigating the potential for quality issues with genuine formal system products (Barriga and Fiala 2020).

I find high germination rates in bags of seed immediately leaving seed companies, suggesting that poor quality seed does not stem from production centres. I find that environmental conditions in seed bags are hot and humid during the first days of seed supply. While the effect size is small, this shows that storage conditions in the first days of seed supply affect germination rates. These results suggest that adverse environmental effects experienced over longer time periods throughout supply chains could have a greater effect on seed performance. This is especially the case given that we find agro-dealers to have limited storage capacities to protect seed.

It is hard to estimate the risk to farmers from certified seed being poorly stored over longer periods of time. In some regards, longer storage might be less likely with certified seed, as delays in production and supply make it more likely to reach remote agro-dealers just before the growing season (Chinsinga 2011). On one hand, this might make for shorter periods of time between seed delivery, purchase and planting, reducing the chance of seed spoilage due to adverse conditions. On the other hand, farmers may have already purchased seed in preparation for the growing season by this point. In these cases, last-minute certified seed bags may remain at agro-dealers over longer periods, such as until the next growing season. The current delivery scenario of the formal seed sector could therefore be contributing to a situation of surplus, higher risk certified seed.

Some may argue that seed on informal seed systems also pose quality risks due to storage concerns. This is true, but as shown in this research farmers find it easier to conduct their own forms of regulation on informal seed. In contrast, the sealed bags of treated seed in certified products prevent seller and farmer regulation along the supply chain. The negative cost of purchasing poor quality seed is also more greatly felt with certified goods, on account of the higher prices and time demands they require in purchase than informal seed alternatives. It seems therefore that the formal sector promises highly regulated products, but there are staffing, infrastructure and operational capacity limits that have subsequent impacts on certified seed. The risk to farmers is that they purchase spoiled seed that fails to grow. Since certified seed blocks farmer methods of quality control, instead they must rely on regulatory branding that promises high quality - but fails

If certified seed purchase is expected to increase, more investment is required in seed regulatory capacity and handling, to scale quality checking with demand.

8.1.3 We have a clearer understanding of how informal seed systems operate in Eastern Uganda

Informal seed systems host a diverse range of channels that farmers navigate to access seed technologies. We add to the literature by exploring the composition of these seed sources, and the ways in which they differ. An overall observation is the beneficial accessibility and availability opportunities that these systems offer to farmers. Farmers are surrounded by these channels, which provide more affordable and more flexible ways of buying seed. These dimensions make farmer seed systems an important source through which to quickly source, test and compare potentially useful crops. These accessibility components also made informal channels a valuable part of seed security for more marginalised farmers.

We find that informal systems cater to the entire range of crops that farmers require. When conditions changed or varieties were not performing, it was often through informal systems that farmers were able to adapt to changing circumstances. These systems therefore offered farmers with a flexibility to trial potentially useful crops, and a resilience to farming challenges and changing market demands. These systems not only preserved culturally valued crops *in situ*, they also provided a more accessible way of acquiring modern varieties. The majority of farmers we spoke to access modern varieties through informal channels, rather than from agro-dealers.

We find four main groups of informal sellers, they are: informal seed shops, local markets, local general stores, travelling sellers and other farmers. Each of these channels have developed as a result of local customs, community norms and traditional practices around the process of saving and exchanging seed. While past seed exchanges involved neighbours sharing or as payment for labour, today we find that the vast majority of transactions on these channels use cash. An unexpected finding is that seed exchange between farmers has become a less common form of seed exchange. While farmers did describe buying and selling to one another, this channel was consistently seen as a low priority seed source. This differed by crop, with some crops[2] sometimes being freely given to one another. Generally however, it seems that farmers have shifted to a more commercialised model of buying from vendors.

Of all the informal systems, farmers hold the most trust for informal seed shops. These sellers tend to be locally known, buy from known farmers, have better infrastructure than farmers for storing seed and are careful to sell viable seed. Consequently, farmers trusted these sellers to provide authentic and quality seed, arguing that their seed business would quickly collapse if they became known for selling poor quality products. Social capital, and its role in determining future purchases, therefore maintained reliable products on these sources in the absence of formal governance. For these reasons, informal seed shops were a priority channel by which farmers access a diverse range of crops.

This same level of trust is not given to travelling sellers or market traders. Social capital could again explain some of this situation, as often these sellers might be unknown individuals or people passing through. As such, farmers felt that they had less reputational risk of selling lower

[2]Such as cassava stems.

quality products. With that said, markets could offer farmers with good deals and the added convenience of purchasing seed while purchasing other goods. Farmers at markets might also have just sold their goods, meaning that they had the cash to hand. We find generally however that farmers are moving away from these channels, and concerns about seed quality is part of this.

8.1.4 QDS offers great promise to bring varieties to farmers

An exciting seed development in Uganda is the rise of the integrated seed sector. Supported by the ISSD group, QDS seed is now recognised in Ugandan policy and produced by LSBs across the country (Mastenbroek, Otim, and Ntare 2021a). LSBs are strategically designed to complement formal seed sector products, focusing instead on crops with lower market price and greater household nutrition value. LSBs can focus on these crops, due to their comparatively lower operating costs that subsequently lack the higher recuperation costs of the formal sector. The resulting products are regulated by local agricultural extension, supported by the development of new mobile technologies to assist coordination.

The LSB we met as part of this research provided a two-way conduit to bring new varieties to farmers, and share valuable traits with breeders. This combination meant that the LSB was able to operate as a sustainable business, while also leading in a form of local participatory breeding.

Unlike agro-dealers, the LSB played an active role in encouraging farmers to grow new varieties. Part of this occurred as a result of the LSB building demand for their varieties. This demand creation took place through field days where the LSB shared innovative ways to prepare each of their products. Farmers visiting this event were invited to try a range of products and were guided through the strengths of each of the varieties for different products. This helped consumers to understand the benefits of new varieties, and encouraged them to try new and different varieties. This approach encouraged farmers to try new products. It also appeared to offer a more effective way to build farmer interest for new varieties than the traditional selling approach used by agro-dealers.

The LSB also served as a form of knowledge exchange to unlock knowledge flows back from end-users to breeders. Through extended dialogue with farmers, the group was able to capture locally-valued traits and bring these to breeders for introgression into modern varieties. This process worked through farmers using QDS, and collaborating to share ways that the crop could be improved for local actors. Since this process also brought locally-valued traits to breeders, it served as a pathway to conserve local genetic diversity for future breeding.

The number of LSBs in Uganda has dramatically risen in the last decade (Adong and Manager 2021; Mastenbroek, Otim, and Ntare 2021a). If supported, they offer a powerful mechanism by which to proliferate useful varieties with farmers, and bolster breeding efforts. What's more, they have the capability to focus on a far wider range of crops than simply high-value crops. LSBs therefore offer a strategic investment alongside formal seed systems, as a pathway to getting better varieties into farmers fields.

8.1.5 Many farmers already grow modern varieties without buying from agro-dealers

A major justification made by formal seed sector advocates for shifting farmers to formal seed systems is to achieve greater harvests through adopting modern varieties. The underlying logic here is that modern varieties are deployed on formal systems, while informal systems circulate traditional varieties. Changing farmer seed system purchasing therefore implies that farmers will also change the varieties they grow. I find little evidence to support this assumption.

Throughout qualitative discussions, farmers regularly reported to grow modern varieties, regardless of their seed channel of choice. Counter to much literature, we found traditional varieties of maize to be rare on informal systems. Informal systems mostly traded saved modern varieties, sold as the special class, *mwaka moja*. While many farmers spoke of considering a change to agro-dealer suppliers and certified seed, most intended to grow the same varieties that they purchased on local channels. It is therefore hard to see how shifting farmer purchasing to certified seed would transform local maize variety choices from what farmers currently grow.

A counter-argument to the above is that certified seed progeny is different to the F1 generations agro-dealers sell. Indeed, shifting farmers to certified seed would potentially reduce the number of farmers growing the subsequent progeny of hybrid and OPV lines. Doing so would better ensure that smallholders are growing seed that is true to the type that was intended upon purchase. This however might be less dramatic change than that of shifting from traditional to modern varieties. It also remains unclear how much difference this might make in performance, especially when grown under the often limiting growing conditions in subsistence farming. All of these arguments are perhaps also unfair to the potential for traditional varieties *and* the saved progeny of modern varieties. Traditional varieties might yield less than highly improved modern counterparts, but could also be more adapted to local extremes or offer alternative farming strategies and cultural values (Westengen et al. 2014; Westengen et al. 2018). A more radical theory could be that concurrent saved progeny of certified seed could breed with other local varieties and become more adapted to local conditions (Westengen et al. 2014; Coromaldi, Pallante, and Savastano 2015).[3] In either case, the point is that farmers mainly grew modern maize varieties across Sironko, and these were the main products on informal seed channels.

8.1.6 Farmers are actively transitioning to formal seed systems for maize

Farmers in Eastern Sironko are already shifting to purchasing maize from agro-dealers, and farmers expect this choice to become commonplace. This finding is surprising given the body of literature estimating that agro-dealers serve a small minority of farmers (Odame and Muange 2011; Marechera, Muinga, and Irungu 2016; Mastenbroek, Otim, and Ntare 2021a). Here, we find that farmers are rapidly shifting to purchasing seed from agro-dealers. Farmers expect that approximately 80% of smallholders will be buying certified maize seed in five years time. It therefore seems that Ugandan maize farmers are in the midst of the transition that agricultural policy has been pushing for. Further studies across wider areas of Uganda could confirm how widespread this pattern is across the country.

We also find insights into why farmers are changing. DCE results suggest that farmers see agro-dealers as the best seed channels and seed sold at certified prices as the best products. As far as we are aware, these are the first results that share conditional effects of farmer preferences between seed sources. Combined with our survey findings, it seems that farmers are switching to agro-dealers as they perceive them to sell high quality varieties and reliable seed. These findings closely align with the aspirations of the formal seed sector, and might be evidence that smallholders are persuaded by the changes agro-dealers are bringing in. While we also find that many remain suspicious of agro-dealers, it seems that the overwhelming majority see them as the seed channel of preference.

Conversely, smallholders appear to be reducing and stopping purchases from informal channels. This is particularly the case for informal markets. While informal channels are seen as beneficial on accessibility grounds, farmers are uncertain of seed quality on these channels. A slight caveat to these findings is that smallholders are only around 6% more likely to purchase seed from

[3] Although this is dependent on chance and we personally have no evidence from fieldwork to support this theory, possible through it may be.

agro-dealers over local shops. Further, respondents made these choices between seed sources more generally. At this small effect size, it could well be that interpersonal connections with staff, or the price differences could still sway individuals to choose particular agro-dealers or informal stores either way. For these reasons, it seems likely that many Sironko farmers will continue to use informal systems they have connections to, or a mix of both informal and agro-dealer sources. Overall however, it seems that the majority are shifting preferences to agro-dealer seed sources.

A final caveat is to remind that these results are for maize specifically. We found little evidence to suggest that farmers are transitioning to formal seed sources more generally. One could imagine that individuals who purchase maize seed from agro-dealers might be tempted to purchase other crops from this source. This may be so, but we also find that farmers strategically chose seed channels at the crop level. These sources vary greatly with the crop, influenced by the crops' market value, use and local availability.

8.1.7 Farmers are influenced by what others grow and recommend

Farmers are surrounded by sources of information advising them what to grow (Shikuku 2019; Mastenbroek, Sirutyte, and Sparrow 2021; Van Campenhout 2021; Hammond et al. 2023). We find however that farmer variety investment decisions are most influenced by the recommendations of other farmers, and how commonly grown the variety is locally. These dimensions likely influence one another as it seems likely that farmer-recommended varieties might also be grown more widely. Farmers also value the recommendations of agricultural extension workers, but less so than the word of local farmers. There are two important points to note with this finding. The first involves the route by which many varieties are advertised. The second is the wider implications of this behaviour for the uptake of new varieties.

While the formal sector is seen as a mechanism to encourage uptake of new varieties, we find that farmers see the advice of agro-dealers as equally persuasive to hearing no advice at all. It seems that despite being a channel designed to bring modern varieties to remote rural areas, few are convinced by agro-dealer suggestions of which variety to grow. This finding triangulates with other literature and our survey results from agro-dealers stating that they primarily source varieties based on the requests of farmers (Domínguez et al. 2022). It appears overall then, that rather than agro-dealers having a push effect on farmer varietal purchase, farmers have more of a pull effect. Until farmers show demand for a new product, agro-dealer are unlikely to sell it to them. This same demand behaviour likely also cascades back to seed producers, influencing their chosen catalogue of varieties.

This situation of farmers copying each other and going with what is locally popular has wider consequences for the general adoption of new crop technologies. Given the increasingly unpredictable nature of the growing season and the high potential cost of failure, copying what works well for others is a sensible strategy. This 'crowd-mentality' behaviour also could explain why the most popular modern varieties are those that have been in circulation for many years, rather than newer and improved options. It seems rational that subsistence farmers with few safety nets may be more inclined to stick with varieties that they have grown successfully before. This might be especially so given that many worried about purchasing new varieties that could perform poorly in local growing conditions. The wider effect of this crowd mentality behaviour could either inhibit change or enable it. For example, a sudden change of a number of farmers could encourage much wider adoption. Conceptually, this could be thought of as a tipping point, where new varieties face resistance for adoption, until they reach a critical mass where enough farmers and grow and recommend the variety that others copy this behaviour in a snowball effect (Juberg et al. 2016)

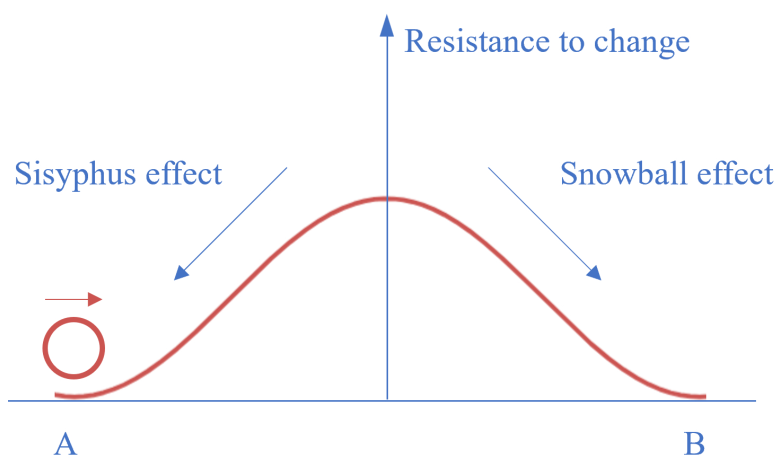

Figure 40: A potential tipping effect to new variety adoption with smallholders, adapted from Juberg *et al.* 2016.

The importance of this effect is particularly relevant when there is a need to rapidly shift farmers to new varieties. For example, this could be encouraging new resistant varieties to an emerging disease before incidence in an area. Another example might be shifting farmers to climate smart crops in areas expecting significant seasonal changes. A potential benefit to this form of crowd mentality is that it offers the potential for rapid acceptance of new varieties, once the tipping point is breached. The challenge therefore comes with the initial investment by more risk-embracing farmers. Our findings show that agro-dealers and radios are unlikely to persuade farmers in making this change. The recommendations of agricultural extension agents however might provide an initial catalyst to encourage to get enough initial farmers to inspire further change.

8.1.8 Uncertainty in smallholder farming includes modern varieties

Switching farmers to certified seed is suggested to raise yields as a result of planting better varieties and more reliable products. We find however that such arguments do not necessarily hold true in practice. As mentioned, we sourced certified seed directly from the producer, and used germination tests to confirm high germination rates. We then planted these seeds using the same methods as smallholder farmers.[4] We note that these local planting methods resemble the advice of extension workers who visit the area. Our planting methods also matched those of the smallholders surrounding the field site and our site was planted by locally hired farm labourers. The purpose of this approach was to study seed performance in a way that is representative of the farmers who are intended to shift to certified maize seed. This included a fertilised and non-fertilised side, as not all apply fertilisers. Even the application of fertiliser was delivered in the same way as local planting practice.

We find that field germination rates fell to 33%. These results were from the same seed batches that recorded around 83% germination under lab conditions. We also found that fertiliser made no difference to the overall harvest.

The purpose of this example is to highlight the uncertainty of growing conditions in subsistence farmers' fields. Clearly this is a result of a single trial, and therefore could be attributed to a shock event. Repeating the test, and in separate locations would serve to confirm this. The point to make here however is that technically our field trial did everything farmers are advised to do. We used certified seed, prepared the farm following extension advice, added fertilisers (at an additional cost) and planted on time. Despite doing everything 'correctly', 67% of our seeds did not grow and fertilisers did not improve yields. The general uncertainty of seasonality, pest pressures and others make it difficult to understand *why* performance remained low, making problem solving extremely difficult. This example demonstrates the problem of assuming modern

[4]Aside from our plotted system of farming for measurement purposes.

varieties and fertilisers automatically translate into reduced yield gaps and better harvests in subsistence farming. Had we been a subsistence farmer, it is clear to see why we might not purchase certified seed again, given its price at between double or triple the price of locally saved options.

8.2 How these changes affect the challenges farmer face

Our discussion so far gives a snapshot into the current situation of seed system change in Uganda. As we have seen, historically decided pathways in how formal and informal systems operate have influenced the current state of how companies, merchants and smallholders practise seed technology. These traditions and inherited practices influence how seed technology has been officially constructed, and how it informally operates in practice.[5]

Ultimately, the majority of Ugandan farmers are smallholders, with limited resources for investment. These farmers depend upon seed systems for their livelihoods, and historically have relied upon informal seed systems of farmer exchange and local markets. The Ugandan government seeks to transition from these systems into a newer one of specialist breeding, privatisation, formalised production, and the deployment of crop innovations and associated inputs. Such replacement is justified by examples of higher productivity and subsequent economic gains made by other countries who have followed the same model (Evenson and Gollin 2003; Stevenson et al. 2013; Agra 2017 ; African Development Bank 2022). It is a revolution that has started many times in sub-Saharan Africa, but never been sustained (Scoones and Thompson 2011). It has fed global populations, but also brought great costs to biodiversity and public health.

There are multiple and complex changes that this new system imposes. Some elements promise an opportunity to reduce the risks farmers face. Others could bring new risks with them, or change the type of risks that farmers are exposed to (Clay and Zimmerer 2020; Mkindi et al. 2020). In the penultimate section of this thesis, we reflect upon our findings to consider how modern varieties and seed systems affect the risks farmers face.

[5]For example, the regulation upon which certified seed is legitimised as high quality in formal arenas, versus the limits of this regulation in practice.

8.2.1 Changing the seed systems farmers are dependent upon

Perhaps the most obvious risk exposure concern is that of changing something fundamental to the livelihoods of vulnerable people. The majority of farmers in Uganda are smallholders, with many dependent upon each harvest to sustain them until the next. These harvests provide both incomes and nutritional security. Seed composition and acquisition are a fundamental part of how these systems work. Changing the systems that grant access to seed could therefore have powerful knock-on effects to the risks farmers face. Better varieties and uptake methods could unlock improvements to better resilience, nutritional and economic returns. Conversely, problems with seeds and their proliferation could put families in crisis. In a similar way to how we consider the multi-dimensional aspects of food security, we should consider the range in which changes to seed systems affect the seed security upon which farmers depend (McGuire and Sperling 2011).

Today, the majority of farmers in Uganda find seed security in informal seed systems. These systems are accessible, available across remote areas and fast to circulate new varieties (Coomes et al. 2015). They help farmers reduce risks on investment by providing the chance to check the variety source, if it has performed locally before and for farmers to conduct their own quality tests. Where these seeds come from informal seed stores, the seller's livelihood depends upon their customers yielding successful harvests. As such, the purchaser often confirms the performance of the variety in the field prior to sale. These precautions allow farmers to protect themselves against a major risk that many speak of fearing that their seed fails to germinate.

As we have seen, certified seed blocks and asks farmers to forgo the risk reduction systems upon which they have become reliant. Instead, farmers must place trust in formal regulatory systems, while also increasing the price of investment. Such moves ask farmers to diminish the agency and control they normally have on informal systems, while at the same time adding access barriers. When nearly every farmer group we spoke to was able to share stories of certified seed failing to grow, it clear why many farmers are not willing to take the risk. Many farmers were suspicions of agro-dealers and we find evidence in seed supply of spoilage risks to seed germination. Another factor is that agro-dealer varieties are sometimes new to the local area, risking that farmers purchase seed that struggles in local agro-ecologies. This risk is one that is particularly associated with formal crop improvement, on account of the varieties being designed in distant places, and under different growing conditions. Local suitability was a commonly held concern in farmer groups, suggesting that such events are widely known and do happen. More recent concerns with certified seed include counterfeiting, shortfalls in regulatory staffing and reports of poor quality products. With all these concerns in mind, it does seem risky to encourage subsistence farmers to buy from agro-dealers - particularly with the additional financial requirement.

A common argument is that formal systems can reduce the risks farmers face by providing an important link to modern breeding innovations. This argument makes sense given that modern breeding methods have unlocked staggering productivity increases and the opportunity to make more nutritious and resilient crops. Recent advances in genetic understanding and phenotyping technologies promise even greater refinement of useful traits, and faster pipelines to deployment (Watson et al. 2018; Watt et al. 2020). Helping farmers access these innovations may prove critical in benefiting livelihoods, while protecting rural communities against productivity risks. At present, formal seed systems offer the main link between bioscience innovations and farmers.[6] On these grounds, transitioning farmers to formal seed channels could provide more diverse crop strategies to reduce risks to farmers. The promise of this argument should be however contextualised, given the limited crop viable portfolio currently on formal systems. There are varieties that could reduce the risks farmers face, but these are not available for the entire range of crops smallholders rely upon. Therefore a shift could help farmers access varieties to reduce their risks, but is limited beyond the main market crops. Some might argue that these market crops are the most important for smallholder livelihoods, which going by our survey results, is generally the case with the exception of beans.

If the Ugandan government wants potentially vulnerable farmers to become dependent on formal systems, it must invest more in regulatory capacity and minimising risks to seed quality throughout formal seed supply (Joughin 2014; Bold et al. 2017, 2022). A clear solution is simply increasing the number of regulatory staff to increase seed testing capacity. Recent innovations in the integrated seed sector of using mobile tools to assist with regulatory coordination might also benefit formal sector regulators (Kumar 2021). Another potential area for improvement from this research could be the training and support of seed couriers and agro-dealers to improve seed storage infrastructure and practice. The Uganda Seed Trade Association (USTA) and Uganda National Agro-lnput Dealers Association (UNADA) could play a role here to operationalise these projects with seed companies and agro-dealers (Joughin 2014). A final area for consideration here to reduce risks to seed quality in supply could involve seed packaging. Some of this is already underway with anti-counterfeiting packaging (Mennel et al. 2014). Another potential area that arose out of this research is the potential for smart packaging that signals when it

[6]Although promising developments are being made with integrated seed systems, as mentioned earlier.

is in unfavourable environments.[7] These kinds of innovations could help seed suppliers and farmers identify seed spoilage risks, and might be combined with anti-counterfeiting measures. Combined approaches such as these might better ensure that farmers who do invest, can do so in the confidence that they are purchasing high quality products.

A more existential risk is that of the loss of informal seed traders with a shift to formal seed systems. Informal seed systems have persisted in Ugandan and are unlikely to disappear soon (Coomes et al. 2015). Studies have found however that informal seed systems can be undermined by sudden shifts in farmer seed acquisition behaviour (Sperling and McGuire 2012). These shifts might come from poorly planned seed aid to an area, or a sudden shift to formal agricultural inputs (Eicher 1995; Alumira and Rusike 2005; McCann 2001). This seems to be particularly problematic where farmers transition to predominantly hybrid varieties, which quickly become unpredictable in their beneficial traits with each successive progeny. Such examples warn us that informal seed systems can be disrupted. Where these systems have been lost, it also appears to be difficult to rejuvenate them. Losing these systems entirely is of particular risk to marginalised members in the community, who rely on the greater accessibility to seeds that informal channels offer (McGuire 2007; Sperling and McGuire 2012; Sperling et al. 2020). Related to this, examples from Zimbabwe demonstrate how a loss of informal systems and reliance on hybrid varieties can be particularly risky in shock years (Eicher 1995; McCann 2011). In such events of low harvests, farmers struggle to recuperate their costs and may lack the funds to purchase certified seed. In the absence of informal channels, vulnerable members in the community may struggle to access seed.

Another risk of shifting to formal systems comes in the form of conservation (Dempewolf, Krishnan, and Guarino 2023; Westengen, Dalle, and Mulesa 2023). As mentioned, the purpose with certified varieties is to limit genetic variation across the field. It is a shift towards monocultures, and the predictability they can offer. Where farmers shift to monocultures, they tend to replace more genetically diverse crop populations (Westengen, Dalle, and Mulesa 2023). This is particularly the case where monocultures replace landraces and traditional varieties. Our findings suggest this replacement is already taking place, with many traditional varieties of maize becoming uncommon in the areas we visited. This may also be the case with other high-value crops that the formal sector stocks.[8]

[7] An example of this system can be found at https://seedsentry.systems.

[8] Such as other cereals or oil crops.

While the genetics of modern varieties are generally stored for future preservation in *ex situ* collections, the same is not always certain for local varieties. There is therefore a risk that once these varieties are gone from the field, they are lost forever. The rate at which local varieties can disappear from an area is surprisingly fast. For example, respondents spoke of a popular local bean variety that people wanted to grow but a shock season caused a previous harvest to fail. As a result, no-one in the area was able to grow these beans the following year. While this situation was the result of a shock event, it demonstrates how quickly traditional varieties that are annually restocked can disappear from an area. Climate change is further increasing the incidence of these shock events (Schlenker and Lobell 2010; Ortiz-Bobea et al. 2021). Such impacts present a loss on cultural grounds, where communities lose access to specific varieties of local heritage. These forms of genetic erosion have broader plant improvement grounds, where these locally-valued and potentially useful traits become lost to future breeding efforts.

Overall, it is difficult to quantify the immediate threat of these diversity losses to farmers. For instance, how can one meaningfully estimate the loss of a cultural variety to a community, or the loss of a variety that *might* have had useful traits for future breeding objectives? For the latter, breeding resilience is often made possible by drawing on diversity, making conservation essential for future adaptation. Thankfully, there are numerous methods to preserve varieties. *Ex situ* conservation could target areas where farmers are shifting to modern varieties, collecting locally valuable accessions to long-term storage in genebanks (Westengen et al. 2018; Argumedo et al. 2023; Dempewolf, Krishnan, and Guarino 2023). The Plant Genetic Resources Center (PGRC) of NARO, where the Uganda National Gene bank (UNGB) is based, is already playing a key role in this area. These *ex situ* projects need to be combined with *in situ* conservation, to ensure farmers maintain access to culturally valuable crops (Otieno, Kiwuka, and Mulumba 2017)

Another potential risk to farmers from a widespread shift to formal systems comes indirectly from habitat degradation (Reich 2001; Tully et al. 2015; Branthomme et al. 2023). This habitat degradation comes as a result of increased agricultural use (Emana, Gebremedhin, and Regassa 2010; Branthomme et al. 2023). Modern varieties are often bred to respond well to synthetic fertilisers. Due to the higher costs of certified seed, farmers are encouraged to apply insecticides and fungicides. Our survey demonstrates that farmers are using these inputs particularly with certified maize seed, although some also use them for other crops. All of these inputs risk detrimental impacts on local ecosystems (Masso et al. 2017; Tang et al. 2021). Synthetic fertilisers are highly water soluble, with the majority of applied nitrogen being washed away from the plant and into local bodies of water (Dimkpa et al. 2023). This eutrophication leads to booms in algal blooms which produce toxins and block sunlight. The result is the collapse of the ecosystem below the algae. Another more chemical hazard with excessive nitrogen fertiliser use is the reduction of soil pH, reducing the bioavailability of nutrients for plant roots. Farmers in these situations often mistake affected plants as requiring more fertiliser, causing further nitrogen, and a worsening of the problem (Zhang et al. 2020). Applications of pesticides can cause off-target damage, destroying local biodiversity and damaging soil health (Tang et al. 2021). Agro-dealers are trained, and profit, from the sales of these inputs. It therefore seems likely that as farmers shift to modern varieties and seed systems, they will increase the applications of such agricultural inputs. Doing so will increase the required investment, but it does offer the potential for higher yields.

In the short-term, input applications will likely benefit farmers, but the longer-term implications of successive biodiversity damage could affect agricultural systems in profound ways (Zhang et al. 2007; Sato and Lindenmayer 2018). Global species collapse as a result of agricultural systems is well reported, but the exact threats this poses to Ugandan farmers is harder to say (Almond et al. 2022). Still, the overwhelming sense is that this does pose significant risks to habitats, and more needs to be done to protect ecosystems and healthy soils. As such, agricultural extension and agro-dealers should be careful to encourage controlled input application to prevent environmental impact. Ironically, while shifts to modern varieties could raise input applications, some new varieties offer traits that replace the need for inputs (Jones et al. 2014; Haskett et al. 2022; Jhu and Oldroyd 2023). For example, varieties with innate resistance to biological pressures reduce the need for pesticide applications.

A shift to monocultures brings potential challenges to local suitability. As mentioned, farmers are particularly worried about purchasing varieties that are not suited to their growing conditions. Part of this suitability challenge stems from the heterogeneity in growing conditions and the homogeneity within modern varieties. This contrast means that a particular modern variety might perform well in some contexts, and not others. Where these varieties perform well, they can be a benefit to farmers due to more predictable performance across the field. Such predictability helps farmers in estimating cropping needs, timings and harvests. This same reason of limited genetic diversity however also means that certified seed varieties may be unreliable in some farms, or unpredictable across farmers with diverse agro-ecologies. The main risks to farmers here is that they purchase seed that fails to perform, which could be disastrous to the household.

The uncertainty of local suitability can however be easily managed where farmers are able to trial modern varieties in small amounts, with therefore lower investment requirements and lower costs of failure. The genetic uniformity of modern varieties also means that farmers can quickly and confidently test the suitability of a variety to their growing conditions. Some might argue that the minimum size of two kilograms of seed might already be a large purchase for farmers to risk on testing a new variety that fails to perform. One solution might be to provide smaller packages for farmers to trial plots with. Our findings however suggest that farmers use *mwaka moja* as a flexible and low-cost way of trying modern varieties. Once farmers confirmed that a variety worked in their field, they were likely to continue to grow it. A slightly surprising suggestion might therefore be for the formal sector to be supportive of trialling varieties through *mwaka moja*. Doing so might provide farmers with a low-risk way of trying varieties that could encourage later investment in certified seed versions.

Narrow genetic diversity across the field also can put farmers at greater risk from the spread of pests and diseases (Dalin, Kindvall, and Björkman 2009). While many modern varieties are bred to have enhanced biotic stress tolerance, their near identical genetics means that organisms that overcome innate resistance can spread rapidly across large areas (Ekroth, Rafaluk-Mohr, and King 2019). This risk is particularly great in Africa where continuous cropping over connected arable areas increases the potential for pest or diseases to spread (Bokil et al. 2019). The problem is compounded by limited disease surveillance and porous borders across sub-Saharan Africa (Sileshi and Gebeyehu 2021; Mulema et al. 2022). Examples of how quickly such pressures can spread can be seen in wheat rust outbreaks, the western spread of Cassava Brown Streak Virus or Maize Lethal Necrosis Disease (Alicai et al. 2019; Prank et al. 2019; Boddupalli et al. 2020). The catch twenty two challenge is that modern varieties are continually being released with increased resistance to these kinds of diseases, but ongoing monocropping also creates the selection pressure for these diseases to adapt and spread. A greater diversity of crop genetics raises the change of local resilience, but this is not a certainty.

The changing space around formal seed systems brings a risk to farmer ownership and sharing of technologies (Thompson 2012). The formal seed system depends upon the creation and ownership of crop technologies through intellectual property and plant-breeders rights (Louwaars, Tripp, and Eaton 2006; Tansey 2011; Kock 2021). This change marks a departure from informal systems where useful varieties are bought, grown, traded and resown without legal ownership of the technology itself. These changes affect farmers in multiple and complex ways. At its most basic, the addition of plant breeders rights often results in higher prices as companies seek to profit on their ownership (Tansey 2011). Such price rises pose particular challenges to smallholders, who arguably might be most in need of the technology improvements. If followed as intended, variety ownership also makes smallholders dependent upon private companies (Kloppenburg 2017). This poses risks to farmers where companies change products, fall short on production or go under, taking the technology with them. Perhaps most importantly, farmers may be unaware of these restrictions, what they impose and the legality of how they are expected to (Wattnem 2016). This is particularly the case when rules around rights differ to long-held cultural norms of seed sharing and conservation. As our findings demonstrate, the challenge is pressing given that modern varieties are the most common choices on informal seed exchange. Technically, these practices are illegal, with the law on the side of powerful companies (Jonge 2014). While it is hard to imagine how the informal system might currently be policed for breaking plant breeders rights, it lays the foundation for future bindings of who controls potentially important technologies, and who doesn't have rights. Such rights have wider implications for who builds power and profit in food systems (Tansey 2011).

Ultimately, the risk to farmers is that monopolies over ownership lock farmers out of exchanging important crop technologies (Tansey 2011; Wattnem 2016; Kloppenburg 2017). These same systems help farmers adapt in times of shock, and are of most value to the vulnerable. A risk of shifting to formal seed systems brings the entrenchment of intellectual property (IP) rights. A related concern where farmers share local varieties for breeding efforts is where farmers lose sovereignty over those traits (Thompson 2012; Wattnem 2016). The problem is compounded by the fact that most farmers would struggle to engage with IP, which requires specific knowledge and infrastructure which are often rare in rural areas. In a capitalist system, it is clear why plant breeders rights give breeders the confidence to invest in creating new technologies and ensure they see a return on this investment (Jonge 2014). The challenge is that these same systems risk locking farmers out of the technologies they rely upon, contributing to a loss of food sovereignty and further power inequalities. An alternative approach would be open IP systems and protecting farmers indigenous crops to reduce smallholder dependency solely on commercial seed systems (Kloppenburg 2017). A final closing comment on this section is to caution against treating formal systems as controlled and informal systems as egalitarian. Informal seed systems still involve the movement of scarce resources, controlled by markets and social institutions (Coomes et al. 2015). While these systems to not have the same legal ownership of technologies, they still may offer unequal access and control over how seed resources are dispersed.[9] A potential way to support smallholders in this emerging space might be to develop local dialogues about farmer rights, plant breeders rights and areas for cultural protection. These could include capacity-building programmes advising on seed selection, saving, and adaptation topics from across seed systems.

A somewhat surprising risk to farmers comes with the assumption that high productivity is effective at fixing food security challenges, or even that it is always a good thing for farmer empowerment. A major selling point for modern varieties is the promise of higher productivity. The value of this productivity boost is that farmers have more food and can sell more products. There are however some challenges here. The first is the oversight on how productivity translates into labour. This additional work burden can overload smallholders who are already overburdened with tasks and this concern has a gender dimension (Devereux and Longhurst 2010; Rao, Pradhan, and Roy 2017; Addison, Ohene-Yankyera, and Aidoo 2020). Women tend to lead on much of the weeding and ongoing labour of the plot and this must be done in competition with household tasks and raising the family. Mechanisation can take some of this burden, but often this is out of reach of smallholders. Another option is hiring labour, but this comes with an extra cost which therefore questions whether it is worth upgrading from lower productivity but less outgoing costs.

Another challenge to the productivity argument comes from an economics point of view. We find that smallholder farms are homogeneous in crop choice across local areas. Increasing the amounts of these crops therefore risks saturating the market with a supply-side boom. A common prediction in such situations would be that local market prices for the product fall in response. For example, between 1949 and 2000, field crop prices declined by 40% (Alston, Beddow, and Pardey 2009; Cock et al. 2022). A similar situation was reported in 2018 in Uganda, with maize prices falling following a bumper harvest, leaving farmers struggling to recuperate investments (Tajuba 2018). So while rising harvests increases the amount of produce sold, the overall cost per product would decrease. The degree of this effect depends upon access to local markets, but these market links tend to be limited for smallholders (Montalbano, Pietrelli, and Salvatici 2018; Hill et al. 2021). This is particularly so for individuals who face barriers to travel. Helping build access to markets might help reduce these effects and provide greater rewards for higher harvests.

Some might argue that higher levels of crop production still lowers the chance of local food

[9] An example in our field experience was an individual who had improved cassava varieties, as a result of being the kin of the village chief who was given the varieties by extension workers.

insecurity. This might be true, but this scenario is influenced by time. Some major challenges for smallholders (including our respondents) are food waste and post-harvest loss (Sheahan and Barrett 2017; Mvumi 2019). Many rural households struggle to protect food from pests and spoilage. These waste losses contribute to the rising prices of food with time since the harvest. Productivity increases offer the chance to make food more available, but this does not tackle the temporal challenge of providing food over longer periods of time. Silos, hermetic bagging technology and community storage structures all offer methods that can improve preservation of raised harvests, helping raised productivity benefit household food security (Manandhar, Milindi, and Shah 2018). A final point to consider from a nutritional perspective is that Ugandan modern varieties tend to focus on crops with high calorie content, but little micronutrient diversity (Lowe 2021). Therefore, suggestions that switching farmers to formal seed systems may still leave nutritional security gaps. New biofortified modern varieties are however being developed with greater bioavailability of nutrients, and encouraging uptake of these technologies could reduce the risk of hidden hunger in communities (de Valença et al. 2017 ; Siwela et al. 2020).

A final remark in this section cautions on the over-promising of what modern varieties alone can offer. Maize yield gaps are often used to support shifts to modern varieties, but yield gaps can still occur *with* the adoption of these varieties (Abate et al. 2017). Part of the issue is that Ugandan smallholders are practising farming under challenging conditions; for example, the lack of irrigation or the pressure of declining soil fertility. Modern varieties and input applications can raise the potential for larger harvests, but our field trial experiment demonstrated that this is not enough alone (Coromaldi, Pallante, and Savastano 2015). While modern varieties hold promise, their returns will be boosted by more holistic support for farming infrastructure and improved cultivation practice.

8.2.2 The risks with informal seed systems

Discouraging transitions in Ugandan seed systems also brings risks. Perhaps the most obvious risk is that it gambles on informal seed systems alone providing varietal solutions to rising demand, changing seasons and outbreaks of new pests and disease (Vurro, Bonciani, and Vannacci 2010; Atlin, Cairns, and Das 2017; Ristaino et al. 2021; Sileshi and Gebeyehu 2021). As shown, informal systems already supply modern varieties, but this process is a more indirect pathway from modern breeding outputs. This indirect pathway brings potential risks in the quality, genetic consistency and authenticity of products. There is also a risk that repeated resowing of modern varieties without careful observation risks losing the precise genetics that might make it useful. This is particularly likely with varieties which do not have a clear phenotype. For example, resistance genes to known diseases, or biofortified crops without visual cues. This concern is that farmers grow these varieties believing they are protected against a risk, when that may not be the case. These factors make informal seed systems a risky strategy to deploy varieties that are heavily dependent on being true to type.

As our survey results show, informal seed systems appear to suffer from quality issues which pose risks to farmers. What is less clear is how these risks manifest across different crops. For maize at least, it seems quality issues in informal supply are encouraging farmers to shift to certified seed, which is seen as more reliable. There is a seed channel dimension to these quality challenges. The risk of purchasing low-quality seed appears to be particularly associated with local markets, where farmers have less assurance that the individual can provide quality goods. It is for this reason that farmers in Eastern Sironko are shifting to certified seed. On these grounds, a change to agro-dealers might ensure farmers are more likely to access high-quality products.

A benefit of purchasing from agro-dealers is that farmers might gain access to greater technical support and resources. Access to these resources may help farmers make more informed decisions about their farming strategies, or hear of new technologies that could assist them. The guidance and products at agro-dealers should in theory align with local agricultural extension advice. It is however worth recalling that smallholders seem unpersuaded or distrustful of agro-dealers as points of advice.

Clearly farmers also share technical advice between one another on informal systems (Van Campenhout 2021). These kinds of advice tend to be based on experiences, and specific to the context. A challenge with over-reliance on local knowledge systems however is their capacity to advise on more technical dimensions of genetic performance, heritability, disease resistance and wider environmental implications for practice. Both formal and local information sources clearly have the potential to inform farmer decision-making. Encouraging both sources offers farmers a greater range of information and technologies to act upon.

8.3 In summary

Changing the seed systems that smallholders rely upon brings with it complex changes to the risks farmers face. Overall, it seems that farmers in Eastern Uganda are already choosing modern varieties for maize, and this has been the case for a number of years. Initially this shift to modern varieties took place through farmer agency on informal seed systems channels to access new technologies. More recently however, farmers are choosing agro-dealers and certified seed as their primary maize source. This trend is well known locally, and expected to continue. It therefore appears that from the farmers' perspective, this transition is a viable livelihood strategy, and one that reduces the risks they face in choosing where to invest.

What is less clear, is how the awareness of risks associates with switching to monocultures, losing traditional varieties and leaving informal systems behind. There are also wider questions of how breeders rights over modern varieties will influence their sale on informal seed systems. These informal channels are critical for marginalised farmers or more generally following shock events. Losing such seed systems presents the loss of a safety net, in already vulnerable communities. Currently however, it seems unlikely that informal channels will disappear in Uganda in the near future, given the limited range of crops the formal sector can offer.

Informal channels remain the dominant pathway of choice for communities to access useful varieties for the entire range of household needs. The emerging system of Quality Declared Seed seems to complement both formal and informal systems, while providing an important pathway for modern varieties of less market-focused crops.

Overall, it seems that encouraging plurality in seed systems offers the best chance to leverage the strengths of formal and informal seed systems, while mitigating their respective weaknesses. The aim should be to strive for harmony between seed systems, And the ways they can complement one another. This suggests that Ugandan policymakers should encourage diversity in seed channels, protect local practices, and foster collaboration rather than competition. Such actions could be achieved through greater knowledge-sharing between seed custodians across seed channels. Policies could facilitate collaboration and partnerships to leverage the strengths of both systems. Some of this would include exploring new ways to recognise the value of informal seed systems within national policies, working to legitimise and protect them. This includes integrating local knowledge and traditional approaches into seed policies. Using this combined approach can guide efforts to enhance formal seed systems and strengthen agricultural policies. Doing so offers a more inclusive, diverse, and resilient seed sector to support the success of Ugandan smallholders.

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Chapter 9

Appendix

9.1 Varieties, breeding programmes and institutions

What do we actually mean when we group crops by varieties? For as long as we have cultivated crops, we have been shaping their genetics (Warwick and Stewart 2005). Before our involvement, evolutionary forces selected plants that survived long enough to pass on their genetics to the next generation (Fuller 2007; Purugganan and Fuller 2009; Hallauer 2011). This selection is competitive. It is not that all individuals adapted and improved, but that those without this advantage were lost to history. The living organisms we see around us today is the surviving remainder. Those individuals with the combination of genetics[1] to out-compete others for resources, raised their chances to proliferate in the population. Some beneficial traits might include: greater resilience to adverse conditions, more efficient resource use or greater fertility to produce more offspring.

Human cultivation forces a different process to natural selection. Traits that make plants successful in the wild, do not necessarily make them useful for our cropping needs. While a plant might be more efficient if it produces small fruits and many seeds, humans might select for the opposite. For instance, we might choose larger fruits for better harvests. Alternatively, we might alter the structure of the plant for more efficient yields, or ease of harvesting.

These effect of crop selection choices will generally be minor between generations, but the

[1]Different combinations of genes, and different alleles (versions) of genes, inherited or generated through sexual reproduction.

cumulative difference over the last 10,000 years is significant (Warwick and Stewart 2005). For this reason, the crops we grow today are almost unrecognisable from their wild relatives. But these same modern crops only continue to exist because of our ongoing selection. If we grew them over generations without selection, they would become more genetically diverse, and less uniform to our preferences. There might be some potential merit in this. For example, if doing so allows subsequent generations to become more adapted to local conditions (Westengen et al. 2014; Kilian et al. 2020). Similarly, having greater genetic diversity might offer some innate resilience to pests and diseases Mulumba et al. (2012).

The important point here is that crops do not naturally improve towards our needs without our selection. If entirely left without our manipulation, crops will diversify, and maybe even revert back over generations to a similar form as their wild relatives - or be out-competed by those relatives.

Figure 41: How our crops used to appear before genetic manipulation by humans. Originally shared by https://geneticliteracyproject.org/.

So our crops today exist and develop as a result of our ongoing selection. This process has caused many crop species to disappear from fields as they are replaced by newer varieties and monocultures become more prevalent. Genebanks offer a way to preserve older varieties, to save the potential value in these populations for ongoing improvement of our current crops (Kilian et al. 2020).

So human influenced cultivation *and preservation* are both genetic selection forces for variety persistence despite natural forces. We group the products of crop species selection through the language of *varieties* and *cultivars*. This language is important because, as we will later explore, it is used to define utility, advocacy and control (Tansey 2011; Ulmer et al. 2014).

9.1.1 What is a variety?

We use the language of 'varieties' when we differentiate crops within the same species. A variety is a group of plants that share the same physical characteristics, as a result of their genetics interacting with the environment (box 3 below).

Box 3: Genetics, genes and gene expression

All the genetic information of an organism is contained the 'genome'; DNA, organised into clusters, called chromosomes. DNA is a long chain protein structure, organised into four different base pairs (adenine, thyonine, cytocyene, guyaine). The order of these bases denotes the genetic code. Sections of these base combinations denotes a gene, like how letters combine to make words. Genes can come in different types, called alleles, which can be thought of like synonyms. A genes contains the information for a cell to code protein structures, which are the building blocks for life. They are basis for our form and how we operate. Proteins are created when genes are activated by the cell. We call this process, gene expression. We can use a recipe book as an analogy for this process: the base pairs are the alphabetic letters, the genes are words, these words make up recipes and the resulting protein structure is the cake. Similarly to a recipe book, the dish is only made when those instructions are selected and followed, as happens with gene expression. Otherwise, these 'recipes' remain dormant until needed.

The physical properties of a plant are termed 'phenotypes' and the genetic composition termed 'genotypes'. 'Cultivars' refer to varieties that have been selected by human intervention.[2] The point of these varieties or cultivars is to structure crop populations by gene combinations within the species.

[2]Quite literally, the shortened version of __culti__vated __var__ities.

For the majority of global farmers, varieties might be defined by the phenotypic properties of, for instance, shape, colour, taste, texture, tolerance and resistance (B. T. Asfaw, Worojie, and Mengesha 2021; Loko et al. 2018; Mekbib 2007; G. A. Otieno et al. 2017). These properties could be the desired trait, or an indicator of a desired trait. For example, farmers might choose shorter wheat plants with stronger stems as indicators for lodging resistance. Another example is how farmers might use different colours of maize kernels to select for particular desirable traits, whereby white kernels might be used as a marker for softer texture for grinding (Sibiya et al. 2013; Saenz et al. 2020). These kinds of 'folk taxonomy' marks a difference between how most farmers and modern crop breeding define cultivars and conduct selection (Mekbib 2007; Otieno et al. 2015; Loko et al. 2018; B. T. Asfaw, Worojie, and Mengesha 2021). Where farmers might use phenotypes, crop breeders define and select cultivars based on the genotype of the plant.

Structuring crop populations by cultivars has brought consistency in what is grown and harvested. Knowing which cultivar one is planting reduces uncertainty during the growing season and helps users group useful genetics for the context and their needs. For instance, growing a single variety might mean that all plants in a field will: yield at a similar time; grow in a similar way; require similar levels of inputs;[3] be resistant to a certain diseases; require similar processing or cooking methods. These kinds of uniformity help farmers choose varieties to complement their cropping strategies and harvesting. It means farmers know what inputs to use, how long it will take, when they will harvest, how they will harvest and the approximate yield to base their initial investments upon. Cultivar predictability also helps consumers choose the best product for their needs. To take an example from the fieldwork for this thesis, rural Ugandans might choose a local maize variety, *katamani*, for roasting, but Longe-5 for milling due to their different processing properties.

It is because of the utility of predictability that monocultures, fields of genetically identical lines, have become commonplace in much industrial agriculture (Altieri 2007; Coromaldi, Pallante, and Savastano 2015; Ekroth, Rafaluk-Mohr, and King 2019). Monocultures tend to be genetically near identical fields of 'elite cultivars', bred to contain a suite of the most useful genes for the environment, for the best yield. This 'genetic purity' across the field comes with three costs:

1. **Resilience.** Because of their genetic similarity, an entire field might be susceptible to a new pest or disease that genetic variation might provide tolerance or resilience against

[3]For instance how much fertiliser, pesticides of water is used. Having plants mature and grow similarly can also be used to reduce the overall resource use.

(Mulumba et al. 2012).[4]

2. **Adaptation and plasticity.** Elite cultivars contain genes that have been developed for relatively specific environmental contexts. Consequently, they might be poorly adapted to conditions dissimilar to the ones they were bred for, or across heterogeneous environments; such as with many smallholder plots. This specificity could also become a limiting factor where climate changes alter local conditions.
3. **Biodiversity and conservation.** The prevalence of monocultures comes at the cost of diversity in the field, where large land areas are covered with genetically near identical lines (Wouw et al. 2010; Khoury et al. 2022). Monocultures such as these come at a risk to crop biodiversity, with the potential for older varieties to be lost unless actively conserved (Dempewolf, Krishnan, and Guarino 2023). This conservation is important as older varieties still offer tremendous potential for future breeding improvement.

9.1.2 A shift to modern varieties

Monocultures of 'modern varieties' have proliferated across agriculture. Farmers choose modern varieties for improved total factor productivity, pest and disease resistance and climate resilience; often as a result of significant bioscience investment (Juma 2011; Steensland and Zeigler 2020; Toenniessen, Adesina, and DeVries 2008; International Food Policy Research Institute (Ifpri) 2011).

This term of *modern* marks another grouping in varietal structuring. The varietal outputs of farmer or bioscience crop breeding selection are labelled differently. Crop breeding programmes output *modern* or *improved* varieties. Both terms are misleading. 'Improved' is problematic on grounds of distinction because, as stated earlier, all domesticated crops are improved to some degree (Bagamba et al. 2023). 'Modern' is also problematic as farmers continue to use and improve varieties outside of this grouping. As such, these 'non-modern' varieties are still in contemporary use and should not be mistaken as antiquated relics of the past.

Farmer-improved varieties on the other hand are termed *traditional*, *local* or *landrace* varieties. Crops that have not been improved through crop breeding programmes are referred to as *underutilised*, *orphan* or *neglected crops*. Underutilised crops tend to be important indigenous crops, and rarely the cash commodities that breeding improvement centres focus on. These

[4] Disease tolerance is where the individual contacts the disease but does not succumb to it. Disease resilience is where the plant cannot be infected by the pathogen.

groupings of crops circulate between farmers as locally saved seed from previous harvests (Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019; Sperling et al. 2020). As such, they are bred and maintained by farmer selection and exchanged between farmers or sold on unregulated informal markets (Sperling et al. 2020; Mastenbroek, Otim, and Ntare 2021a).

As we can therefore see, there are a number of terms that group crop varieties. To summarise, these varietal groupings are listed below:

- *Underutilised crop*: A regionally important crop but one that has received less research and breeding improvement than the major global crops. May also be termed a neglected or orphan crop.
- *Traditional variety*: A variety that has been used by local communities over generations through saved seed. May be used interchangeably with 'local varieties'. Can be major or more indigenous crops.
- *Local variety*: A variety that is well adapted to local conditions, often derived from transgenerational selection by farmers. May be used interchangeably with 'traditional varieties'. Can be major or indigenous crops.
- *Landrace*: A variety that has developed naturally through adaptation to the local environment and traditional farming practices. Landraces tend to be genetically diverse.
- *Modern variety*: A variety that has been improved using bioscience and advanced breeding techniques to contain specific traits. Selection is often at the genetic level. Genetic variation is very low between individuals of the same variety. May be used interchangeably with 'improved varieties'.
- *Improved variety*: A variety that has received targeted breeding efforts to introduce or enhance specific traits. This improvement is the result of advanced breeding techniques, with selection at the genetic level. May be used interchangeably with 'modern varieties'.
- *Elite cultivar*: A carefully selected bred crop line that contains the best traits offered by breeders. Elite cultivars are the end products offered to farmers from breeding platforms. They are continually improved through the introgression of new or enhanced alleles.

The challenge of these terms is that their uncritical use brings value assumptions and perceived hierarchies of utility (Coomes et al. 2015; Mayet 2016). It implies that farmer-bred varieties are somehow antiquated, obsolete and low value. Such assumptions are incorrect. Traditional varieties are often well adapted to local growing conditions, as a result of generations of selection in the local area (Westengen et al. 2014). They may also be more tolerant or resistant to local pest and disease pressures than exotic varieties (Mulumba et al. 2012). Finally, even the most advanced elite cultivars are regularly improved through introgressing genetic traits from older varieties. Whole seed bank collections exist of historic crops for the potential genetic value they offer to ongoing improvement efforts (Kilian et al. 2020).

For the sake of consistency with other literature, this thesis will continue to use the terms of modern/improved or traditional/local, but this is not to disregard the value of farmer-selected varieties. Still, these terms are useful in that they point to a schism in crop breeding perception and practice. Behind the more subtle differences between what separates local and modern varieties, are clear differences in the actors, institutions and drivers of how crop breeding takes place today.

9.1.3 Difference in crop breeding approach

The previous section hints at some some differences between farmer and modern crop breeding pathways (Bentley, Mele, and Reece 2011). We can loosely separate these differences up into the following themes;

1. The precision and modes of selection
2. The place of selection
3. The organisation of crop breeding
4. How process influences decision making
5. Plant breeder and farmer rights

9.1.3.1 Precision on selection

Farmers generally select crops for breeding on physical traits, keeping the seed of individual plants that exemplify or improve upon the variety they have chosen. Put simply, farmers use plant phenotypes for selection. Conversely, modern breeding conducts selection at the precise genetic level. This difference marks a fundamental separation in breeding conceptualisation, operation and inclusion. This is not to say that farmers cannot have a degree of precision in the phenotypes they select for, but that it would be impossible for farmers to achieve the same genetic precision as that obtained through molecular breeding approaches. Much of crop breeding recent developments have focused on improving this degree of genetic breeding precision.

A major focus of modern plant research has been to understand what genotypes lead to phenotypic traits. Plant phenotypes can be dependent on single or multiple gene combinations, in response to the environment. For example, resistance to a disease might come down to the presence of a single gene while drought tolerance however might be the result of many genes (Cohen, Hanan, and Paris 2003; Eybishtz et al. 2009; Hu and Xiong 2014; Luo, Xia, and Lu 2019). Understanding these genetic drivers means we can make more informed breeding choices. It gives greater control to create crops with beneficial traits as selection can take place at a more detailed level. Continuing the single gene disease resistance example, selecting at the genetic level means we can choose plant individuals that we know to contain the gene, and therefore be resistant prior to encountering the pathogen.

Selecting on this genetic level therefore enables more precise identification and introgression of traits. The outputted cultivars contain known productivity and resilience genes that offer the genetic potential for a profitable mechanism to escape poverty, provided farmers can access and grow them in the required conditions (Wambugu 1999; Toenniessen, Adesina, and DeVries 2008; Juma 2011).

The previous examples show how different breeding methods bring useful genetics into crop technologies, but not how those genetics became to be understood in the first place. There are two general ways bioscientists find the function of a gene; forward and reverse genetics (Jankowicz-Cieslak and Till 2015).

Forward genetics starts by finding a phenotype of interest and trying to understand the genes that cause it. This might include developing more genetic variations of the individual, identifying which progeny have the desired phenotype and comparing their genetics with the individuals that do not. For instance, if there was one maize plant in a field that was resistant to a disease all others are susceptible to, forward genetics could be used to understand which genes cause this resistance.

Discoveries in forward genetics approaches have been complemented by new phenotyping technologies (Watt et al. 2020). These technologies can detect phenotypes at more precise level, and over much larger scales, than the human eye. For example machines can spot disease susceptibility earlier than humans, catalogue thousands of plant structures in minutes or monitor light wavelengths beyond the human visual spectrum (Tattaris, Reynolds, and Chapman 2016; Eshed and Lippman 2019). These advances can feed into forward genetics research.

Reverse genetics takes the opposite approach. In reverse genetics, researchers start with a gene of interest and work to understand its effect on the phenotype of the plant. In reverse genetics, microbiology techniques are used to change or remove the gene of interest, and study the resulting phenotype. For example, we know the genes controlling iron uptake in wheat and editing that gene results in iron-enriched wheat plants (Connorton et al. 2017). Such a phenotype could be of value for areas where wheat is commonly eaten and iron-deficiency prevalent in local populations (Balk et al. 2019).

Both forward and reverse genetics are now used in combination with recent leaps in sequencing technology over the last two decades (see box four below for reference). Technology advancements also mean that researchers have much greater control to directly edit the genome of a plant, rather than previously relying on sexual introgression of traits (Caccamo 2023; Chaudhry et al. 2023). Such 'precision breeding' technologies allow genes outside of the species to be incorporated into the plant. Doing so offers greater genetic manipulation for crop improvement, but is prohibited in most global legislation (Ewa et al. 2022; Caccamo 2023).

Box 4: Genetic tools and techniques

Many terms are used in crop breeding today and some of these denote which genetic tools were used in their creation. Some definitions for these terms are provided below:

Hybrid varieties: The result of cross-pollinating two different parent lines, with the intention of getting traits from both parents into the progeny. The parent lines are carefully bred to maintain genetic uniformity, which might include careful inbreeding. The crossed combination of beneficial traits often leads to improved performance in the hybrid progeny phenomenon called 'hybrid vigour' or 'heterosis'. This phenomenon is however reduced as subsequent generations have more mixed genetics

Genetically modified: Often shortened to GM or GMO (organism). A genetically modified organism is one which contains a *transgene* (see below).

Transgene: A gene that comes from outside the species that an organism could sexually reproduce with. Transgenes must therefore be introduced into the genome using genetic modification methods. The most common way is through use of *Agrobacterium tumefaciens*, which introduces genetic material into a host organism under certain conditions.

Transgenic: A transgenic organism or tissue is one that contains a transgene.

Cisgenic: Cisgenics is the genetic modification of an organism with a gene that could be sexually crossed in. Subsequently, cisgenics often viewed as an extension to traditional breeding methods.

Genetically edited (GE): Genetic editing is a form of genetic modification. It uses technology to precisely edit, delete or insert sections of the genome. CRISPR technology is the most common way to achieve this (Sedeek, Mahas, and Mahfouz 2019; Chaudhry et al. 2023). At present, there are three different types of gene edits: SDN1, SDN2 and SDN3 (Ahmad, Jamil, and Munawar 2023). SDN1 type changes have received particular attention recently as they can have edits made that are indistinguishable from natural mutations in the organism. GE organisms without transgenes are becoming more widely approved in global policy.

Precision breeding: The name given to GE breeding of organisms, based on the genetic precision on which selection is made (Caccamo 2023).

So the precision in genetic trait selection has become essential in how modern crop breeders develop elite cultivars. The challenge for farmers is that the process of gene discovery and breeding requires specific knowledge and certain infrastructure that is often absent from the field.

Most genetic breeding knowledge is taught at tertiary education levels, and even then only to specific disciplines. It is abundant with jargon, conceptually complex and difficult to visually observe (Ewa et al. 2022; Zakaria et al. 2022). This leads to disconnects in understanding and communication, and particularly so with impoverished smallholders. Farmer usually know what they want, but knowledge gaps distance them from genetic breeding discourses (Lewis et al. 2010). This situation creates the potential for farmers voices to be left out of breeding decisions: not necessarily included unless actively part of the breeding strategy, such as with participatory breeding approaches.[5] Another quirk of this disconnect is that bioscientists sometime struggle to know what traits farmers actually want developed, or how these preferences align with modern breeding targets (McGuire 2005). As a result, an increasing number of studies seek to find ways to quickly understand farmer crop preferences, to feed this information back into modern breeding (Kidane et al. 2017; Arora, Bansal, and Ward 2019; D. Arora and García 2019; Schaafsma, Ferrini, and Turner 2019).

[5] Described in more detail below.

Modern breeding has raised total factor productivity at an impressive rate for the world's major crops (Ann Steensland and Zeigler 2018). This return has brought further investment in modern breeding facilities. More generally, the call for genetic selection also depends upon, and legitimises, the further expansion of a specific style of bioscience infrastructure. Understanding how to use this infrastructure not only brings another knowledge barrier, it influences *where* modern breeding platforms manifest.

9.1.3.2 Place of selection

A consequence of the modern breeding approach is the separation of crop improvement from the field. Contrary to most agricultural history, crops today are increasingly developed away from the field, and by agents who are seldom farmers (D. Cleveland and Soleri 2002; McCann 2011; Scoones and Thompson 2011; Tansey 2011). Such separation makes sense given the specialist infrastructure and resources required for lab-based breeding selection. For instance this approach requires: constant electricity; specialist machinery and associated regents; lab facilities with infrastructure for sterile practice. These requirements make it difficult to conduct these same techniques at most field sites. Instead, modern crop breeding tends to be centred around highly resourced locations, with dedicated field trial areas (Morris, Edmeades, and Pehu 2006; Tansey 2011).

The separation of field and breeding sites brings knock-on effects which can be grouped by physical and social dimensions. The most obvious physical consequence is the potential difference in growing conditions between breeder and smallholder fields (McGuire 2005). Ideally, improved crops should be adapted to the field conditions. A crop's suitability to local growing conditions becomes less assured when selection takes place remotely from the field. For example, there could be differences in weather, soil type and pests. Conversely, the products of farmer selection are innately adapted to local conditions, by nature of their creation within the context. Modern breeding approaches do however try to select varieties under conditions designed to emulate farmers' fields. This emulation could be a similar agro-ecology to the target habitat, or it could be an artificial representation of the desired end habitat. For example, the International Center for Agricultural Research in the Dry Areas (ICARDA) now uses a robotised system to artificially create drought conditions that occur naturally in their end users' fields (ICARDA Communication Team 2023). Such artificial systems can also be used inform selection for future climate conditions (Hammer et al. 2020; Tian et al. 2021). The challenge with such approaches is how accurately these emulations proxy for a range of farmers' field conditions, or how tolerant the resulting cultivars are of other agro-ecological factors beyond the control of the emulation. Ideally, cultivars should perform similarly in farmers' fields as they do in breeders' fields. A concern for many farmers however is when they invest in a cultivar and find that it struggles in their farming conditions.[6] Whereas a farmer-bred cultivar is inherently suitable for local conditions, breeder-derived cultivars might not be so (D. Cleveland and Soleri 2002; McGuire 2005).

The physical separation of breeding sites from the field also influences *who* is involved in the breeding process. In farmer selection, the end user is part of the process. Their preferences for the crop and knowledge of the context are imparted in the cultivars they select (Mendes-Moreira et al. 2017; Weltzien and Christinck 2017; Singh, Gaurav, and Singh 2020). It is also worth noting that farmer and consumer preferences for cultivars may not always align; and may also vary by other factors, such as gender, age, etc. (Weltzien and Christinck 2017; McEwan et al. 2021). For example, a lower yielding but a more nutritious cultivar might be valued differently by farmers and consumers, where utility of the cultivar varies across actors (Isaacs et al. 2016; Schnurr, Addison, and Mujabi-Mujuzi 2020).

Even modern breeding centres that are based in rural areas may also be physically separated from farmers. For instance, their physical locations might have barriers to entry, such as gates, guards and key card access. Such obstruction measures make sense on security grounds but mean, consequently, that farmers are often a rare sight at many bioscience-based crop breeding centres.

9.1.3.3 The organisation of crop breeding

As is becoming apparent, there are clear differences between how farmers and crop breeding institutes operate around the process of crop improvement.

Farmer breeding is practised by individuals or localised groups of farmers (Singh, Gaurav, and Singh 2020). Productivity improvements are part of selection but culture and tradition are often drivers for continuing the cultivation of ancestrally grown varieties (McGuire 2005; Sibiya et al. 2013; Mendes-Moreira et al. 2017). The varietal products persist *in situ* in the fields and are taken up by the same end users who comprise the breeding process (McGuire and Sperling 2016). These users might practice crop selection individually or as part of local farmer cooperatives.

[6] As we will explore in later sections, these fears were regularly mentioned throughout the fieldwork of this project and are a major disincentive to adoption of new varieties to an area.

Farmer-based breeding selection is likely to have limited hierarchy levels, and limited division of actors by specialist tasks. These systems are supported by the ongoing nutritional, cultural and financial benefits they bring to the livelihoods of those involved.

Breeding platforms on the other hand tend to be large, complex, structured systems (Glover 2007; S. Arora and Glover 2017). This is especially so for multi-national breeding groups[7] but is still often the case for national breeding centres.[8] Breeding platforms can be contained within a single institution, or be comprised of collaborating distinct groups.[9] The scale of investment in these platforms alone can raise their political power to influence government action.

Contrary to farmer-based breeders, actors in breeding platforms are highly diverse and specialised in complementary roles, structured over numerous management levels. The process operates across actors who understand composite parts of the pipeline, with very few understanding the whole system (Glover 2022). Lab researchers perform distinct functions to those in the field, management, marketing, etc. (Glover 2007). This structuring, on top of the aforementioned bioscience resource requirements, mean breeding facilities require significant investments to continue operations (Renkow and Byerlee 2010; J. Alston, Pardey, and Rao 2022; Thornton et al. 2022). This infrastructure and roles are necessary for the multiple stages modern breeding platforms require to bring new varieties to market (Shimelis and Laing 2012; Joughin 2014; McEwan et al. 2021). The process can be outlined as the following:

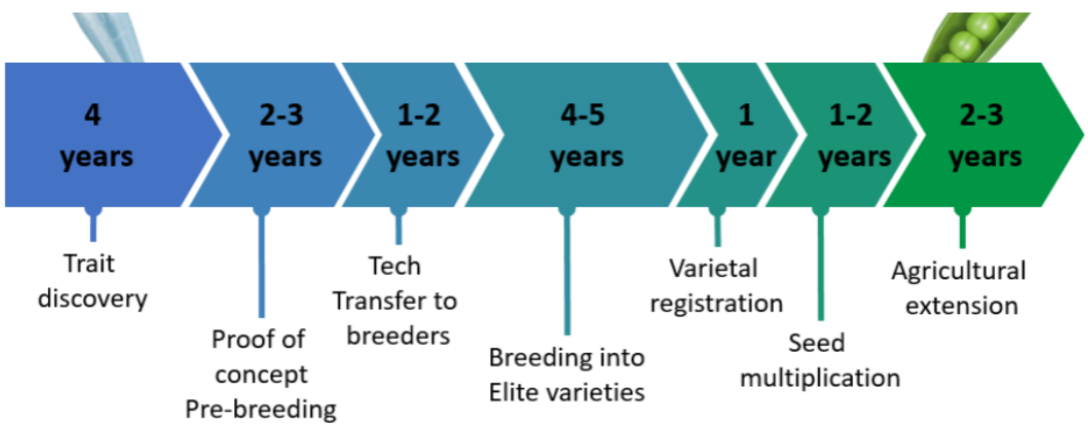

Figure 42: An estimated timeline for a breeding pipeline.

[7]Such as CIMMYT, BAYER or Sygenta.

[8]Such as the National Agricultural Research Systems (NARS).

[9]For example, international breeding initiatives such as Borlaug Global Rust Initiative (BGRI) or Cowpea breeding Initiative.

1. **Trait discovery and target setting:** Researchers identify specific traits of interest, such as disease resistance or yield increases. These traits might be discovered in crop breeding research plots, or as part of basic research into gene function. Useful traits are then targeted which offer value to farmers, processors or consumers.
2. **Germplasm collection and characterisation:** Plant breeders select accessions from a germplasm pool of genetic material for the target species. These accessions might come from diverse sources, such as wild relatives, landraces, and existing varieties. The germplasm is characterised to identify the genetic variety across the pool. This pool might be sourced from a breeders own varieties and other seed banks.
3. **Trait mapping and marker development:** Molecular techniques are used to identify the genetics associated with the traits. These markers track the genetic presence of traits. They can be used to guide selection.
4. **Parental line selection:** Breeders select parental lines with complementary traits. The chosen individuals will be used for crossing together.
5. **Crossing and hybridisation:** The breeder makes crosses and collects the resulting progeny. The cross usually occurs by manually taking the pollen from one accession and combining it with the female organs of the other. Visual or molecular markers might be used to confirm the presence of key genes in the resulting progeny.
6. **Selection and Evaluation:** The progeny are tested in targeted environments to evaluate how the key traits perform in the field. Selection is based on the performance of individual plants or lines. Field plots have many accessions growing in groups across a field, with ongoing phenotypic and environmental data capture taking place throughout the growing season. Previously this selection was done by eye but increasingly machines are used to record phenotypic data. Many of these machines are now able to observe features and visual elements beyond those of the human eye (Watt et al. 2020).
7. **Advanced generation selection:** Phenotypic data from the previous step is analysed to confirm how the progeny is performing in the environment. These phenotypic records can be associated with new genes of interest. The best-performing individuals then grown over several generations of selection to select accessions with stable levels of the desired traits. This process involves repeating the previous cycles of crossing, selection, and evaluation.
8. **Further trials and multi-location testing:** Promising lines are tested in a range of environments to assess their performance in different growing conditions. Lines that continue to perform well will be crossed together and back-crossed with elite cultivars.

This process will happen multiple times, taking between five to twelve years to advance the highest performing progeny for commercialisation. Much of this time demand is due to the repeated back-crossing that takes place to introgress key traits into elite cultivars. Each back-cross requires a generation cycle of the plant, adding time depending on how long this takes for the chosen species, and the frequency of the growing season. Norman Borlaug famously halved this time by flying wheat seeds across Mexico to achieve two growing seasons in one year in a process called "shuttle breeding" (Reynolds and Borlaug 2006). More recently, speed breeding facilities have dramatically increased the number of generation cycles a crop can complete in a year, thereby accelerating the breeding process (Watson et al. 2018).

9. **Deployment, commercialisation and seed multiplication:** New elite cultivars will be prepared for release. Depending on the type of breeding platform, these will either be marketed directly, or the seed sold/shared with seed companies for multiplication and sale. Governments or NGOs may purchase seed for deployment to farmers.
10. **Farmer adoption:** New modern varieties are presented to farmers through marketing, demonstrations, extension agents and seed aid. The producers of most modern varieties then reply upon repeated farmer purchase from specialist agro-dealer stores. Re-investment in the breeding process might also come from government funding or successful grant applications.
11. **Ongoing improvement:** Field performance, sales and farmer feedback are used to monitor variety performance. This feedback should inform the selection in subsequent breeding cycles.

Box 5: Linkage drag

Linkage drag occurs when unintended genes are inherited by the offspring due to how close they are to the genes of interest on the chromosome (Huang et al. 2023). For example, these could be traits that negatively affect crop qualities. Breeders use a process known as back-crossing to remove these unwanted genes from the resulting progeny. Back-crossing involves repeatedly mating promising individuals in the offspring with each other, or another line, until only the target traits remain. At each stage, individuals with the unwanted genes are removed from the selection process. The end result is near genetically identical lines with the new targeted genes incorporated. This process can take many generations to achieve.

The overall process of trait discovery, introgression, marketing and sales make modern variety generation a time-demanding process (Covarrubias-Pazaran et al. 2022; Swami et al. 2023). It requires a complex arrangement of actors across a pipeline of operations, each working on supporting parts of the process. This process continues across the breeding pipeline and into the seed production stages for markets. Where actors exist in the process, influences who has decision-making power and what outputs are prioritised (S. Arora and Glover 2017; Glover 2022). Such features are important as they influence the end products that breeders prioritise.

9.1.3.4 How the breeding process influences what is improved

The actors, knowledge and requirements of a breeding system influence the decision of *what* and *how* a product is improved. Farmers tend to selectively breed crops in ways that maintain the cultural identity of a traditional variety, or in ways that meet their livelihood needs (McGuire 2005; D. Cleveland and Soleri 2002). Many farmers practice ongoing crop selection through the selection of their own saved seed.

Conversely, crop breeding platforms are complex structures with large investment demands (Covarrubias-Pazaran et al. 2022). Meeting these requirements tends to be achieved in one of three ways. The first is through improving commercial crops and relying on sales to cover these costs. The second is through state investments that either profit national sales or reduce state spending elsewhere (J. Alston, Pardey, and Rao 2022; Thornton et al. 2022).[10] A final investment source is philanthropic groups, often seeking food security or agricultural development goals (Toenniessen, Adesina, and DeVries 2008).

The type of project and required investment influences which crops are targeted by breeding platforms. Private projects focus on crops which offer the greatest financial returns (Joughin 2014; Mastenbroek, Otim, and Ntare 2021a). Popular choices are high-value hybrid cereals that justify high sale prices due to the potentially high yields they offer.

Hybrid varieties are produced by deliberately crossing two distinct parent lines with known desired traits. The result is a combination of both parents' beneficial traits, within the same plant. A quirk of this genetic diversity in the same plant however is that hybrid varieties offer the

[10] Such as biofortifed crops that reduce spending on healthcare (de Valença et al. 2017; Siwela et al. 2020).

best returns for the first generation, with decreasing yield uniformity in subsequent generations. This variation is because the mix of genetics in the first generation becomes less uniform and predictable with subsequent reproduction. Commercial companies have drawn on this effect to incentivises return sales as farmers seek to maintain the high yields of the first generation (Rutsaert, Donovan, and Kimenju 2021a).

An alternative to this hybrid approach would be to offer open-pollinated varieties (OPVs), which produce seed true to their parent type, if they breed with others of the same accession (Nkuba et al. 2021). The degree of this 'trueness' to the parent type in the field is however dependent on a number of factors, including the varietal diversity locally that will influence out-crossing with other local lines.[11] Still, OPVs are generally more stable in phenotype than hybrids when resown over subsequent generations. While this stability benefits the farmer with reliability, it reduces the incentive for repeat sales from the company, undermining the potential investment returns for company breeders.

Companies are drawn to hybrid varieties as their sales model makes them more likely cover the high breeding investment costs. Agricultural companies also seek to profit by selling the agricultural inputs required for hybrids to achieve their potential productivity. This combined marketing strategy has proven to be lucrative for many of the largest agricultural companies today (Rutsaert, Donovan, and Kimenju 2021b). It has also made hybrid maize farming ubiquitous across Uganda. Of the 22,000 megatons of maize produced by in the country in 2017, 80% was hybrid (Longley et al. 2021).

The same financial pressures on agricultural companies that encourage the hybrid model, also disincentivise improvement of less commercial crops. For instance, a private breeding company in Uganda is unlikely to recuperate the costs involved in improving and marketing a less market-oriented crop, like sweet potato or cassava (Mastenbroek, Otim, and Ntare 2021a). This is because farmers are less likely to invest in more expensive seed and inputs for crops that offer limited financial returns.

Even within the category of cash-crops, the private model across agriculture disincentives non-commercial improvements. For example, improving the nutritional content of maize might be beneficial on food security grounds, but does not necessarily lead to a commercial return for

[11] A determining factor here is the type of pollination method the plant relies upon. For example, maize relies upon wind pollination and so subsequent generations will be influenced by the diversity of maize lines within the local area (Aylor, Schultes, and Shields 2003).

yield-orientated farmers (Snapp and Silim 2002; Owere et al. 2014; Ajambo et al. 2017; Namugga et al. 2017).[12] Instead, state or philanthropic funded projects tend to lead improvement of non-commercial crops, or non-commercial improvements. Even then however, such philanthropy-funded projects often favour crops or improvements that encourage commercial gains, on account of the agency such economic returns might offer farmers (Toenniessen, Adesina, and DeVries 2008; Agra 2017). Put simply, the hegemonic commercial system driving much of contemporary crop improvement offers productivity increases, but struggles with crops or traits that do not have an immediate market. This is particularly relevant for the improvement space for low market-value crops, despite their potential role in household nutritional security (Paliwal et al. 2021; Zafar et al. 2023).

Another consideration for breeding platforms is how compatible the crop is with modern breeding methods. Modern breeding works best with well-studied crops and especially those with shorter generation cycles (Dempewolf et al. 2017; Shah et al. 2020; Wanga et al. 2021). Gene discovery is resource demanding, making it less demanding to work with a well-studied species (such as wheat or maize). Resource costs might be felt in the time taken to uncover useful traits in these less documented species, as well as the time to breed new traits into elite cultivars. For example, crops with longer generation times cause cascading time demands for the repeated generation cycles required in the breeding process (Shimelis and Laing 2012; Ribaut and Ragot 2019). Most well-studied species are high market-value crops, and often associated with the agriculture of high income countries. Conversely, many low-market-value crops from poorer countries have received comparatively little research (Ribaut and Ragot 2019; Zafar et al. 2023).

The incentive for breeding platforms to focus on previously studied plants marks a form of path dependency (McGuire 2008; Chhetri et al. 2010; Conti, Zanello, and Hall 2021). We can define the concept of path dependency as how historical decisions and events shape the ongoing processes and trajectory of a system. This trajectory influences the ongoing options and opportunities that become available to the system, and the ability of the system to change. Path dependency is also apparent where breeding companies restrict focus to cash-crops for the re-investment they offer. An even deeper form of path dependency can be found in the continued trait targeting traditions that were created in the Green Revolution (McGuire 2005). Such traditions can be problematic when they use differs from the needs of the context (see box below)

[12]Unless if consumers are willing to pay more for higher nutrient products.

Box 6: Imported traditions

Mcguire (2005) shares an example where imported breeding traditions can lead to ill-fitting products. Dwarf varieties were hailed as a success of the Green Revolution for the productivity efficiency gains they brought. Perhaps unsurprisingly then, Ethiopian breeders, trained in modern breeding methods sought to re-create this success by creating dwarf varieties of sorghum. The challenge came when smallholders avoided the dwarf varieties. Instead, farmers preferred taller varieties that provide grains but also stems that could be used in building materials, or harvested like sugar cane. The dwarf varieties were the manifest product of a different context, with different needs. Yet these products had been created without question, as they continued the traditions of the system.

To put it another way, there are inherited patterns of thought with breeding platforms that restrict future thinking and behaviours. Examples of this can be found in how varieties are bred for fertiliser use (McGuire 2005; McGuire 2008). A major component of the Green Revolution was the application of synthetic fertilisers. Since the aim was to increase productivity, breeders selected varieties that responded well to this raised availability of nitrogen. How a plant responds to nitrogen fertiliser can be thought of through different types of yield stability (Cleveland 2001). The figure below shows three types of yield stability.

Yield is a product of genetics combined with the environment. The yield stability of a crop is how consistent and reliable crop production is, and average yield reduction over low potential environments (Simmonds 1991). A type 1 response returns little variation in yield, while a type 2 expresses greater variability.

The challenge with type 2 responses is that they can be highly performing in some contexts while also under-performing in others. When breeders target the best possible yields, they are often selecting crops under the best growing conditions. This practice will uncover highly productive lines, but these same lines might not excel in sub-optimal conditions. For example, it might be that some lines are especially good at utilising large amounts of available nitrogen (such as from fertilisers), but perform poorly in lower availability of nitrogen (such as with degraded soils).

In the figure above, we see three varieties. An assumption with yield improvements is that the

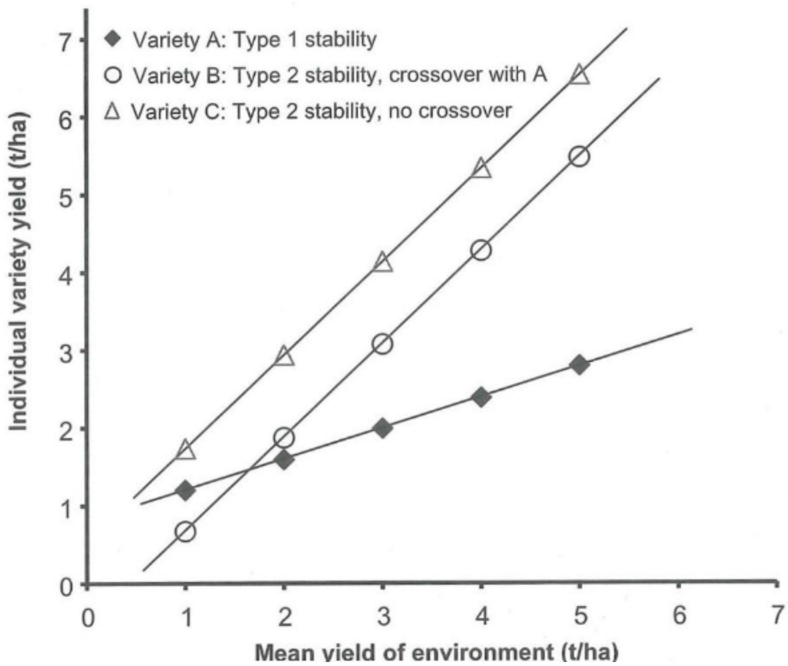

Figure 43: Type 1 and 2 yield stability. Adapted from McGuire 2005.

new variety will yield consistently higher than other varieties in difference contexts (line C). In practice, the picture is more likely to look like varieties A and B. Variety A shows a generally lower yield than varieties B and C. In less productive environments however, A out competes B.

This kind of yield stability become particularly important when selecting crops for smallholders where growing conditions and inputs might be more limiting (Jama et al. 2017; Madembo, Mhlanga, and Thierfelder 2020). It means that a variety can be considered high yielding when it leaves a breeder and yet offer lower performance in the field than less productive varieties. Ideally, breeders want to deliver variety C but the difference of A and B becomes more tricky. As discussed, many breeders rely on investment through product sales. As such, they're more likely targeting farmers on the right side of the graph, who tend to be more resourced and more commercially focused. These farmers are more likely to purchase higher-priced seed, provided it delivers a high yield. On the left side of the graph, we can imagine a situation closer to low-income subsistence farmers. From a breeders perspective, it is better to choose B as it performs better than A in the majority of cases. This same decision however makes it risky for subsistence farmers to invest in high-yielding varieties.

9.1.3.5 Plant breeders and farmers rights

A final difference to discuss regarding breeding approaches is about ownership and rights. In addition to the inherited behaviours of how crops are improved, are the behaviours of how crops technologies are controlled.

A strength of farmer seed systems is the open nature through which useful varieties can be shared and adapted (Coomes et al. 2015; Sperling et al. 2020). This feature makes useful varieties more accessible to farmers, and able to spread quickly across large areas (McGuire and Sperling 2013). This same open access nature is however a challenge to formal seed systems who rely on repeat sales to recuperate and fund ongoing research. This threat to plant breeding institutions has led to the development of plant breeders rights which grant exclusive rights to varieties to institutions (Tansey 2011).

Policies and intellectual property rights define the laws on what a variety is, ownership rights and rights to commercial exploitation. These patents grant exclusive rights to holders on how the technology is made, used and sold (Tansey 2011). Failure to comply to these policies is illegal and brings legitimised punishment in the form of fines to the patent holder (Jonge 2014; Ulmer et al. 2014; Wattnem 2016). Such policies can be inherited through the state association with international groups.

When Uganda joined the World Trade Organisation (WTO), it adhered to the International Union for the Protection of New Varieties of Plants (UPOV) (Tansey 2011; Jonge 2014). UPOV governs what a variety is and how it can be used. These rules dictate that new varieties should be ‘distinct, uniform and stable’, under the 1991 New Distinct Uniform and Stable (NDUS) criteria. These characteristics are increasingly regulated at the genetic level, further shifting control from farmers and placing it in the domain of breeding platforms (McCann 2011; Ulmer et al. 2014). Farmers reusing varieties without paying the owner are technically in breach of IP ruling and liable for fines (Louwaars, Tripp, and Eaton 2006; Wattnem 2016). Monitoring is not only limited to plant materials. Under the 2013 updates to the Plant Reproductive Materials policy, all individuals producing and trading seed are required to register their involvement and activities (European Commission 2013; Ulmer et al. 2014). Doing so requires understanding of bureaucratic processes, and the means to access these systems; further distancing these systems from many of the world’s farmers.

The purpose of plant breeders’ rights is to provide greater incentive and security for breeders to develop new technologies. In the absence of these policies, breeding platforms risk investing large amounts in research for little assurance of control to market their creations. Rights of ownership or control are usually given for a set period of time, with additional renewal fees to continue the rights. These same policies however restrict the accessibility farmers to share new varieties (Louwaars, Tripp, and Eaton 2006). IP rights effectively provide a legal monopoly to a holder to control prices and where seed is sold. Companies can even patent genes, giving them legal ownership of varieties those genes are bred into (Tansey 2011).

While these requirements seek to protect the property of plant breeder, they also place barriers to actors, such as farmers, who might lack the knowledge or infrastructure to interact with these systems (Ulmer et al. 2014). These same rights also restrict how seed is saved or passed on. Uganda's commitment to UPOV technically means that the majority of smallholders in Uganda are acting illegally by selling privately-bred varieties on local market channels (van der Borght and Ghimire 2022). While Uganda has not followed this up with punitive action, variety legislation currently works against the main methods by which smallholders access and share useful varieties (Wattnem 2016; McGuire and Sperling 2016). Instead, the power of the law sits with a smaller number of commercial enterprises. Clearly, there is a political power imbalance in this ruling. Farmers are in breach of these policies but they tend to lack the legal and bureaucratic capacity to engage or contest them. Despite this, some farmers groups are pushing back against the current restrictions to push for alternative models (Aistara 2012; Kloppenburg 2017).

The relevance of patent laws applies particularly to the modern variety products of breeding platforms. Thus the prevalence of legislative control power stands to grow with the transition to modern varieties and commercialisation (Thompson 2012). If one aim of a transformation to modern varieties is to reduce the risks farmers face, one has to question the logic of illegitimising the ways in which the majority of farmers operate. Clearly, breeders rights play an important role in incentivising crop innovations but caution must be taken to also protect the resilience of vulnerable farmers.

9.1.4 Participatory breeding

The previous sections have focused on opposite ends of crop breeding. Doing so demonstrates the differences between these approaches, but it would be misleading to omit efforts that build collaboration between breeding systems.

A more recent middle-ground to bridge lab and field separation is participatory breeding (Ceccarelli et al. 2000; Rattunde et al. 2016; Alves et al. 2017; Weltzien and Christinck 2017; Singh, Gaurav, and Singh 2020). Participatory breeding takes many forms but a major theme is the inclusion of farmers and local communities in the breeding process. It seeks to include farmers' voices in breeding platforms to influence products that are well-suited to local needs and preferences.

Contrary to many breeding platforms that develop varieties upstream from farmers, participatory breeding engages with end-users from the start (Almekinders and Hardon 2006; Weltzien and Christinck 2017). These engagements also seek to understand cultural preferences and socio-economic factors that determine local use. Doing so intends to help breeders understand farmers' traditional knowledge of what traits works well in their environment. Breeding platforms then use these phenotypic traits to guide genetic understanding and selection.

Contrary to many breeding platforms, participatory breeding trials might take place on farmers' fields (Rattunde et al. 2016). Farmers might actively be a part of the selection process, sharing with breeders how they evaluate crops in the local context (Weltzien and Christinck 2017). Placing end-users as central in the technology creation also aims to make the breeding process more equitable. Farmer selection can be empowered with the potential modern breeding offers (Mendes-Moreira et al. 2017). Their involvement also seeks to raise feelings of ownership. The combination of all these elements is designed to make more bespoke products and encourage adoption.

But participatory breeding projects are still comparatively uncommon with larger breeding platforms, although many have started to incorporate aspects of participatory breeding. There are a few reasons for this. Firstly the entire process can be resource demanding. Travelling to farmers, building relationships, working together over successive rounds of the breeding cycle all present resource demands for both partners. Participatory breeding can also make the process more complex. Working with diverse groups brings a range of breeding needs and preferences (Weltzien and Christinck 2017). Mcguire (2005) gives an example of how a group of local farmers in Ethiopia shared very little similarity in local selection. As such, it can be challenging to balance these multiple preferences in precise breeding objectives. This last component touches upon another challenge; participatory breeding requires a diverse skillset across crop science, local knowledge and interpersonal skills (Sperling et al. 2001). This presents a difficulty in creating the right teams to achieve the process. Recalling the earlier section on intellectual property, there are also concerns about how incorporation of local knowledge into new varieties affects ownership (Winge 2019). Finally, as a result of all these issues, participatory breeding is difficult to replicate and scale up (Sperling et al. 2001; Weltzien and Christinck 2017). The process depends on close working and embracing of local needs. These same values make it logistically difficult to scale up projects over diverse agro-ecological zones. Despite these challenges, participatory breeding appears to be growing in prevalence on account of the potential benefits it offers.

9.1.5 Summarising varieties

We would not feed the world of today without the varietal innovations from breeding platforms (Eshed and Lippman 2019). Such platforms supported a step change in productivity and the model for plant breeding that has been recreated internationally across countries. The previous section explored how this model changed the way breeding takes place, and how this influences the resulting technologies. A result of this change is that farmers used to be crop technology drivers, now they are the recipients. The previous section also demonstrates that the current system proliferates and increases dependency on modern varieties, while diminishing the rights of farmer crop exchange. The ambitions of the Ugandan 2040 vision are to protect farmers, but they also empower the interests of a smaller richer group. But the utility of any crop variety is questionable if farmers are unable to access it.