Seed Quality Study [1]

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Abstract

Improving agricultural output and food security is a major concern in sub-Saharan Africa, but many efforts to help farmers improve yields have failed. Recent research has shown that agriculture inputs are often of very low quality, which may explain suboptimal yields and low adoption of inputs. Researchers and policy makers have focused on two main explanations for this low quality: sellers purposefully faking or adulterating inputs, and poor storage processes along the supply chain. We present the results of testing seeds along the maize supply chain in Uganda for purity, germination and genetic similarity. We obtain two main results. First, we find no evidence that quality of seeds deteriorates along the supply chain. As soon as the seeds leave the breeders, the quality drops significantly and is the same across all geographic areas and types of suppliers, including wholesalers, retailers and major company outlets. Second, we do not find evidence of serious seed faking or adulteration. In fact, we find high levels of seed purity across all levels of the supply chain. Quality appears to be the main issue, not whether the seeds are pure. The results are consistent with mishandling and poor storage of seeds, possibly related to temperature control once the seeds leave the breeders. These results have potentially significant implications on agriculture policy and programming in sub-Saharan Africa, which has tended to focus on certification to reduce the possibility of adulteration rather than improve handling of inputs.

Keywords: Seed purity; fake inputs; maize; agricultural supply chains

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Introduction

Agriculture is a critical industry in Africa. In Uganda it contributed to 26 percent of GDP in 2016 (Ugandan Investment Authority). Maize is one of the largest crops grown in the region, after banana and cassava[3]. It is mainly grown by smallholder farmers on a subsistence level, and so has large implications for food security. For example, 55% of households reported that food self-sufficiency was the prime reason for maize production (Kiiza et al., 2011). Since 1990, the maize industry has also represented significant opportunities for export, with 14 percent to 20 percent from total production going to Kenya, Southern Sudan, and Rwanda (FEWSNET 2011).

Despite the importance of maize in Uganda, adoption of improved inputs is low. This has been attributed to several factors, such as a lack of economic incentives, weak institutions, poor infrastructure, limited information of the market, lack of insurance against drought risk, credit constraints, low social capital, lack of awareness by the farmers to value the new varieties, and low experimentation with newer technologies (Shiferaw et al., 2015; Langyintuo et al., 2010; Ilukor et al., 2017; Shiferaw et al., 2008). However, Sheahan and Barrett (2017) use a cross-country data set, the Living Standard Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA), to show that modern input use may be relatively low on average but not uniformly low across regions. Uganda is considered a relatively lower input country with sub-national variation. There are patches of high use of inputs but also of low uptake, especially of agro-chemicals. For seeds, the percentage of land under improved maize varieties in Uganda is 54 percent, compared to 95 percent in Nigeria. Nevertheless, the percentage of households purchasing commercial seeds is similar across the region, at 36.6 percent in Uganda, reaching a maximum of 41 percent in Ethiopia.

[3] Maize is grown in almost all the districts in Uganda due to its adaptability to different types of soil, ease of management and resistance to water stress (Ugandan Ministry of Agriculture and Fisheries, 2010).

On top of the reasons for low uptake mentioned, seed quality is a well-known issue in Uganda (Jack, 2011; IFDC, 2015; Langyintuo et al., 2010; Bold et al., 2017; Ashour et al., 2017; de Boef et al., 2014). Even in the case where NGOs have distributed improved seeds for free, as they have done in the Northern region following the 20-year civil war, evidence suggests that farmers prefer to go back to their saved seed, indicating that they didn't perceive the benefits of improved seed to be worth the cost (Tripp and Rohrbach, 2001; Remington et al., 2002; Sperling et al., 2008). This could be the result of behavioral reasons, where farmers are conditioned to not pay for inputs that they previously received for free, or of the lack of awareness of the new varieties' economic benefits. Informal markets are a big part of farming activities: they guide production, dissemination, and procurement of seed. Farmers tend to share seeds with neighbors, relatives, and friends, or trade with other farmers (Sperling et al., 2008).

The possibility that farmers, government and NGOs are sourcing adulterated seeds, or that seed quality deteriorates within the supply chain[4] before it reaches the farmer, is also a potential explanation for why adoption rates of improved seeds are low.

In this paper, we build off of the work of recent researchers that have looked at the quality of agricultural inputs in developing countries. Our goal is to measure the quality of the private sector supply chain and determine where the challenges of quality occur and where they are most pronounced.

The research team hired enumerators to pose as buyers to collect samples of seeds in three districts in northern Uganda and the capital, where most of the seeds originate. We are able to explore the entire value chain for several varieties of maize seeds, including hybrid and open

[4] Seed deterioration can be attributed to several factors that come from the seed's genetics or from external factors, such as the field or improper storage conditions at any level of the supply chain, bringing stresses to the seed: e.g. abiotic (high moisture, oxygen, and carbon dioxide) and biotic (pathogens or insects), resulting in lower quality.

pollinated variety (OPV), from three different producers and a census of distributors of improved maize seeds. The national supply chain for seed is very complex, involving multiple stakeholders before the seed gets planted by the farmer (Figure 1).

We then sent the seeds to a laboratory in Uganda to test for purity and germination rates. We also sent samples to a laboratory in Australia to test for genetic similarity. The results of the tests suggest that many indicators of quality are good, but there is significant variation, especially for moisture content, vigor tests, and germination rates. Genetic similarity and seed purity[5] are generally high, with purity rates above 98% in all samples.

We then test for the difference in seed quality, germination rates and genetic similarity across the supply chain and geographic areas. We find no statistically significant difference across any of the sales points for moisture content, vigor tests, seed purity, rate of dead seeds or genetic distance (See Table 1. with the details on the definitions of the tests conducted). We do though find a significant effect on germination rates, but only when compared to breeders. There is no difference in germination between wholesalers, retailers or company outlets.

The results of the tests point to potentially important issues for the quality of seeds. The variation in germination suggests that which bag of seeds a farmer purchases can matter a lot for production. The high rate of seed purity suggests that the main concern among policy makers and researchers, that sellers add inert or low-quality material to the seeds, is not the case, at least for the maize sector in the districts we study. However, given the remoteness of these districts and

[5] We define genetic purity, or DNA distance, as how similar are sample observations across each other, and purity as the percent of the sample that is actually seeds and not grain, rocks, etc (Table 4). Obviously, this allows for other seed varieties to be mixed into the samples. However, recent work by Ilukor et al., (2017) shows that seed quality in Uganda is actually better than what farmers expect, when they do purchase seeds. The study found that 100 percent of the maize seed samples tested in the lab actually corresponded to improved and hybrid varieties. Yet the average purity levels from the samples were only 63 percent and very heterogeneous with respect to the acceptable high-quality thresholds. The authors provide some reasons for these low levels, including violation of the minimum isolation distance during seed multiplication, mixing seeds purposely or unintentionally during multiplication or packaging, and possible counterfeiting.

the lack of any oversight in these areas, we believe the results are likely a lower bound for the country as a whole.

The results from the supply chain analysis suggests that the quality of seed does not deteriorate along the supply chain. As soon as the seeds leave the breeders, the quality drops significantly, but is the same across all geographic areas and types of suppliers. We believe these results are more consistent with issues of mishandling and poor storage of seeds, possibly related to temperature control once the seeds leave the breeders, rather than sellers purposefully adulterating seeds.

These results have potentially significant implications for agriculture policy and programming in Uganda and sub-Saharan Africa in general. Recent efforts by governments and donors to address the problem of seed quality has tended to focus on certification and labeling so as to reduce the possibility of adulteration by downstream sellers (Pologruto, 2017; Mabaya et al., 2016; Louwaars and de Boef, 2012). Very little effort has been placed by the international community to improve the handling of inputs.

We present several contributions to the literature on input quality and supply chains. First, we expand on recent work by Bold et al. (2017), who found that fertilizer and seeds in Uganda are of significantly lower quality than many had believed, by exploring the quality of seeds in three areas they did not test in. Assuming a (relatively) high value of time for farmers, they find that, because of lower than appropriate nitrogen content, the expected returns from using a random bag of fertilizer in Uganda is negative. Even without assuming a value of time, the returns to farmers is much lower than would be expected. They also looked at the quality of one variety of improved maize seeds and found a similar issue. However, they were unable to identify individual sellers of the seeds along the supply chain. They thus cannot discuss where the problems arise.

Second, we contribute to a growing literature on the quality issues in the seed sectors by providing evidence of where and how the issues are occurring. Recent studies suggest that several market failures have given rise to bottlenecks in the seed sector after market liberalization, affecting the entire maize seed value chain. These issues may come both from the demand and supply side, including lack of credit to obtain seeds, high investment costs, lack of extension services, lack of infrastructure, and a highly variable quality. The precise causes for the latter are not yet identified, but it is typically attributed to the absence of supervision. Recommendations from researchers has thus emphasize the need of exploring in depth the supply chain (Langyintuo et al., 2010; Joughin, 2014; Poulton and Macartney, 2012; Louwaars and de Boef, 2012; Kassie et al., 2013).

Third, we are able to contribute to the question of what is causing the issue with low quality seeds. This has potentially significant implications for policy makers, who have tended to focus on the issues of fake or highly adulterated seeds. For instance, a recent policy study by Ashour et al. (2017) looks at herbicide in Uganda. They tested samples and found that one in three bottles of the sample contains less than 75 percent of the labeled concentration of the active ingredient. However, as with many studies on this topic, the authors could not distinguish if the low-quality observed was caused by mishandling, but instead interpret low concentrations as misrepresenting the product, or counterfeiting.

Many policy makers assume that low quality is due to adulteration of products. However, there are many reasons why product quality could be low, some of which could be due to actions by sellers and some could be unknown to sellers. Both seeds and fertilizer require specific handling to ensure quality is maintained. Yet storage and transportation networks in Uganda, and sub-Saharan Africa in general, are known to be of low quality. Suboptimal storage[6] practices in maize seed reduces quality and may increase the probability of seeds developing pests (Govender et al., 2008). For example, moistures of 14% or higher will activate fungi in the seed. Also, fluctuations in temperature or humidity, or prolonged storage, will result in nutrient losses (Shah et al., 2002).[7] The results we present here are suggestive that adulteration is not a large part of the problem of low quality seed inputs, but poor quality of storage and transport could explain our results.

The present document proceeds as follows. In section 2 we discuss the context of the study and the districts that we worked in. In section 3 we present the methodology used for this study, for both genetic testing and sample collection. Section 4 is the results of looking at the relationship between the test results and the supply chain. Section 5 concludes and provides recommendations.

2. Context

In Uganda, the National Crop Resources Research Institute (NaCRRI) is the main supplier of breeder seeds to seed companies. The seed companies then multiply the seed at foundation seed farms, or using contract growers. Company-produced seed (labeled seed) is then packed and sold

[6] Proper storage is key for food supply and to keep seed quality. Suitable conditions are directly linked to maintain quality without loss of the seed vigor for three years. Many African countries still rely in traditional storage for seed. Storage structures include traditional silo made with mud and twigs, it is relative inexpensive but exposes seed to harsh environmental conditions. Other storage facilities include the use of iron tanks, re-used maize-meal sacks (Olakojo and Akinlosotu, 2004; Thamaga-Chitja et al., 2004)

[7] While stored, maize can also be contaminated by fungi. In some cases, it can develop mycotoxins that can be harmful to human and animal health. If developed from the fungus Aspergiullus flavus, maize can be contaminated by aflatoxin (Okello 2010; Jelliffe and Bravo-Ureta 2015; Hell et al., 2000).

to farmers through a distribution network consisting of company outlets, wholesalers, and retailers (Figure 1).

The breeder is a person authorized with variety development, release and variety maintenance and producing foundation seeds. This is usually a person from National Agricultural Research Organization, as well as Universities and Research institutes. Seed companies may also have Breeders to supervise bulking of Breeder seed and overseeing quality of seed production. Seed companies in Uganda are not licensed as breeders but can obtain Breeder seed or foundation seeds from the research station, the National Agricultural Research Organization, or import them from the Center for Crop Resource Genetic and plant for bulk production or multiplication without altering the variety characteristics. A breeder is only licensed for one seed class. Thus, a breeder cannot produce more than one seed class, such as both maize and legumes, but rather only one of the classes.

The wholesaler is trained and licensed to bulk and sell commercial seed classes from seed growers or that which it produces. They are categorized as a seed grower and/or seed vendor. They are not allowed to re-bag any seed consignment or else it is labeled as counterfeiting. Wholesalers consist of seed companies and are usually registered or licensed under the Uganda National Agro-Input Dealers Association.

Retailers are authorized and licensed to distribute or sell seeds of different classes. They are categorized as seed merchants and are usually agro dealers. They consist of seed companies and are licensed under the Uganda National Agro-Input Dealers Association. No unauthorized persons or general merchandise shop should deal/sell any seed class in seed handling.

The company retail outlet is the seed company shops. They are categorized as seed venders or seed growers. They are authorized to sell seed classes from the branded company and can also sell seed classes from other seed companies but without rebranding. A seed company can have several seed company outlets distributed across the various regions. The company factory gate sells seeds at production site or company warehouse at the production site.

Breeder maize seed supplied to seed companies by NaCRRI is specifically bred to have genetic attributes for stress tolerance (drought, low soil fertility, stress resistance, disease resistance, mycotoxin resistance, pre-and-post harvest pest resistance, improved storage), or specialized nutritional provision (quality protein and micronutrient enriched) (NaCRRI). Maize seed genetic purity is maintained during the production process through the highest levels of field execution. For example: using properly isolated plots, rigorous elimination of off-types, care in pollination procedures, and using accurate pedigree records, and labels (Vasal and Gonzalez, 1999b). In fact, the main sources of contamination of a seed crop include the previous crop grown in the field, pollen transfer from a nearby field, and mixtures during harvesting and handling (Bradford, 2006). As such, during the production and distribution chain from breeder to farmer, maize seed may become contaminated at every stage: on foundation seed farms, contract grower farms, or through adulteration with other maize varieties during seed handling, transportation, and distribution. Such contamination (and loss of genetic purity) may thus be determined by testing the genetic purity of the different seed classes: company-labelled seed (representing the final output from the seed company), seed from distributors or wholesalers and retailers.

The traditional method used to evaluate the genetic purity of maize seeds is morphological comparisons of different seed lots, which is a time consuming, expensive, and unreliable process (Smith and Register III, 1998). For example, the method cannot provide information on grain quality or the purity of specific genetic attributes bred into the varieties such as pest and herbicide resistance (Smith and Register III, 1998). It relies on seeds or plants possessing different phenotypic traits to identify the individual. Some reproductive traits must be observed within a specific period in order to detect phenotypic differences, and some traits are environmentally labile thus making it difficult to differentiate observations that have a close genetic relationship (Zhang et al. 2014). Instead, more efficient methods include marker assisted selection (MAS) techniques to analyze genetic diversity (Naghavi et al., 2009) and to test hybrid purity (Zhang et al., 2014). These techniques include isoelectric focusing of seed isozymes (SINUS Biochemistry & Electrophoresis GmbH n.d.), DNA-based technologies such as single or low copy probes, multi locus probes and repetitive DNA markers, arbitrary sequence markers (Kaufman, 2011), and methods that employ the polymerase chain reaction (PCR) (Hipi et al. 2013). As we did not have access to the original, pure samples, we are unable to test for genetic purity. Instead, we use genetic distance, which measures similarity in the samples.

Government certification of seeds is known to not be an adequate safeguard in the process of determining whether seed is likely to be of quality or not (Langyintuo et al., 2010). Rectifying these longer run issues within the regulatory processes have not been successful to date. With government liberalization in 1993, several issues arose including underfunding and understaffing of oversight agencies and created opportunities for seed companies to "facilitate" inspection which can undermine the expert independence of the certification agency. Indeed, with approximately 4 inspection agents, covering 25 national level companies, and over 900 seed growers, the capacity simply is not there to effectively certify crop-specific batches of seed from companies (Mabaya, 2016). Results from a study show that seed producers in Uganda rated their satisfaction with the availability of inspection services at only 43.5% (Mabaya, 2016). In addition, the number of active breeders is limited, making it very difficult to cope with seed growing demand (Joughin, 2014).

Farmers' complaints of low quality agricultural inputs have been frequently reported on the news, including complaints about very low germination rates and rotten seeds. The local media is inundated with cases of farmers narrating concerns about the seed market. This includes prices, poor storage facilities, pests and diseases in the seeds, as wells as experiences with fake seeds or highly variable quality, limited reliable information, difficulty to tell whether or not seeds are improved or fake, and which ones are indeed new varieties (Kolyangha, 2016; Joughin, 2014; Vernooy, 2017). However, rigorous quantitative studies are few, and there is virtually no data to prove a strong presence (or absence) of fake seeds.

Failures to ensure the quality of improved seed may have led farmers to distrust promises of enhanced productivity. This may provide additional explanation on why farmers in Uganda are not in the habit of purchasing seed and that country-wide adoption of agricultural inputs is yet low. A study conducted in Uganda reveals that farmers rely heavily on their own sources[8] and local markets rather than on agro dealers, social networks, or community-based systems (ISSD Uganda 2015a).

3. Methodology

We used the "mystery shopper" approach to collect samples. The research team targeted all of the seed companies that sell in three districts in the northern region of Uganda and sampled seeds at different levels of the value chain. We specifically focused on OPV / hybrid maize and

[8] Home-saved seeds coming from farmers are often referred as the "informal market", or "local market" although they are not purely locals as farmers exchange seeds through social networks, or "traditional market" even if it is constantly evolving (Sperling et al.,2008).

soybean seeds to increase comparability. The samples were then tested through genetic and germination tests to determine their true type and potential yield.

Given the wide range of seed companies operating in the regions chosen for the study, and the high variation in what is available, we collected samples from all seed companies that sell the targeted seed varieties. We are thus able to directly observe the choices that farmers can make in these areas.

The overall goal was to determine the genetic purity and performance of samples of hybrid maize seed sold in the Ugandan market along the supply chain, from company to farmer and to see where, if it does, degenerate. We examine samples of company-labelled seed to establish whether the seed companies produce genetically pure seed or whether contamination occurs during multiplication on foundation seed farms and contract outgrowing. We further examine samples of seeds sold by distributors and retailers to establish whether seed contamination (and loss of genetic purity) occurs along the supply chain before it is purchased by the farmer.

The samples came from seed sold at the main company outlets, the main wholesaler distributors for each company in selected districts, and at selected retail shops. Within the selected districts in Northern Uganda, seeds were purchased from the appropriate supplier. The seed purchased from retail shops was purchased in the smallest packaging available, e.g. 2 kg bags. For the main company outlets and wholesalers, this amount was substantially larger, e.g. up to 50 kg bags. Note that the standard sized bag in northern Uganda is 2 kg. However, some shops break these bags and sell them at 1 kg.

The sample of company outlets, wholesalers and retail shops was a census of all of these types of shops in the four districts. The districts were selected based on their size and oversight from government and NGOs. Lira district is one of the largest source of such supplies in northern Uganda. It also has a relatively large number of private sector retailers. The second district, Kitgum, was chosen in order to sample in an area where there have been a number of NGO interventions to improve the supply chain. The third district, Arua, is one that has a relatively low density of seed retailers and interventions. The last district is the capital, Kampala, which is where the main seed producers are located (Table 1).

The census of sales locations was conducted as follows. The survey team visited every company outlet, wholesaler and retail shop in the district headquarters. The exact locations can be found in Table 2. The survey team then traveled to each of the sub-county headquarters in the district and searched for sales shops. Not all of the sub-counties had sales shops.

Enumerators entered shops and identified themselves as a local farmer, asked for samples of all of the seeds that were being sold, bought those seeds and then labeled the seeds carefully to ensure the testing could be attributed to the right location. To ensure the team collected both 2 kg (the official and stamped size of seeds) and 1 kg samples (a "broken" bag that may be adulterated), the enumerator asked for 3 kg of seeds per seed type.

To obtain reliable data that could be reasonably compared across samples, this approach was developed and piloted carefully. Individuals were instructed on how to talk to the sellers, presented a back story for their purchase, and selected samples in the same way in every seller. Following the interaction with the seller, each of the enumerators filled out a survey to document their interaction, the condition of the shop where they purchased the seed and other important features. The exact steps the mystery shopper (MS) performed are the following:

1. The MS presented themselves to the agro dealers as ordinary farmers who belong to a farmer group that is interested in trying out different seed verities this season. If questioned about the timing of purchase, the MS said that the farmer group received their training late in the season and so were unable to identify and purchase seeds before that.
2. The MS carried along a hand-written list detailing the various seed varieties for purchase. However, the MS did not read off the seed list to the agro dealer but instead asked him / her for all available certified maize as well as soybeans seeds on the dealers shelve going from one company to another (as specified on the list). Upon confirmation of availability, the MS started by purchasing all the OPV and hybrid maize varieties on the shelf and use the hand-written farmer's list to update what is purchased as well as ensure that the dealer has given him all that he has in stock. The MS did the same for soybeans seeds.
3. Upon completion of purchase, the MS captured the GPS coordinates from outside the dealer shop before going back to the hotel where he/she completed the enumerator experience survey. After ensuring that the survey was complete and the GPS coordinates collected, the MS placed a sticker on each seed pack and handed over the purchased seeds to a record keeper for additional verification by a survey auditor. At this point, the MS went to the next shop per the day's plan and repeated the purchase process.

Enumerators were equipped with electronic data collection devices to record the samples, shop location and details, as well as a GPS point so the audit team can confirm they were in the location they were supposed to be in. Team leaders and auditors debriefed the enumerators every day to ensure there were no issues and that the team collected samples appropriately. In addition, audits of 10 randomly selected sample points were collected to test with the full sample.

Eight enumerators collected 112 seed samples from Arua, Kitgum, Lira and Kampala, as well as one sub-county in Masindi that borders Lira and was a common place for buyers in Lira to travel to. The samples were collected from several businesses, which included breeders, wholesalers, retailers, wholesalers/retailers, company retailer outlets, and factory gates. From all the businesses visited, besides selling maize or soybean seeds, half of them also sold fertilizers, 94 sold also chemicals, 76 sold also farm equipment, and 31 sold also grain produce.

The sample of seeds collected during the mystery shopper approach included 60 samples of hybrid maize and 52 samples of OPV maize[9]. The sample collected accounted for 21 varieties in total (Table 3), from 16 companies. Seeds came in packs of 0.25 kg, 0.5 kg, 1 kg, 2kg, 5kg, and 10 kg. After the sample collection stage, seeds were carefully packed and sent to a seed testing facility in Uganda and then ground up and exported to Australia for genetic testing.

3. Results

The results we present here include both a descriptive summary across the entire sample, and a correlation of quality across the different supply chains.

3.1 Descriptive results

In Table 4 we present the main indicators that we use to evaluate seed performance. At the testing facility in Uganda we tested for moisture content of the seeds, the rate of germination and vigor and purity tests. The genetic tests looked at the similarities across the different samples.

The results of the tests show that the indicators' performance was good at the average level across samples (Table 5). However, we found significant variation in several indicators,

[9] We also collected 10 samples of soybeans, but due to the limited sample size and lack of comparability to maize, we focus here on only the sample that we can make the best inferences on.

these are represented in the distribution graphs shown in the Appendix. Moisture content was good on average, at less than 13%, although there is high variation, meaning that for some samples moisture can get as high as16%. The germination of normal seeds was also good, above 86%, but again there was high variation in this indicator, with some samples only germinating 4% of normal seeds. Dead seed was another indicator that highly varied, going from 0 percent to 92 percent for some samples, even though the mean portion accounts for less than 10% per sample. The indicator for genetic purity represented by DNA distance performed on average good with most samples being very similar to seed varieties, although it was not exempted from some variation. We observed good performance and less variation for the percentage of pure seeds[10] and the vigor tests which were within the benchmark ranges, 71% and over 99% on average, respectively.

In addition to the indicators, we also constructed an index that includes whether the moisture content was below 13%, if germination rates were above 85%, the results of the vigor test, the percentage of seed that were pure, and the results of the DNA test. This index was used to improve the statistical power of the tests, as well as to present a unified measure.

3.2 Differences across the supply chain

We next present the results from comparing the results of testing across the different supply chains in Uganda. The results suggest little evidence of counterfeiting, but highly variable quality of seeds. We present a set of boxplots to better characterize the data spread, ranges, and extreme values by supply chain group. Figure 2 presents the indicators related to seed purity (DNA similarity, percentage of pure seeds, percentage of dead seeds, and percentage of inert

[10] Refers to seed that excludes inert matter and weed seed (dirt, stones, and stems)

matter). In general, observations here are more concentrated around the mean and the median, and vary in smaller ranges, except for at the retailer level. In Figure 3 we present plots for the results of performance (germination rates, vigor test, content of moisture, and rate of abnormal seedlings). Outliers are more common at retailer and wholesaler/retailer level than at any other levels. Overall, the breeder quality has better purity and performance than any other level, spreads by all other groups are larger and extreme values are frequent.

In Figure 4 we present our main outcomes, the rate of good germination and moisture content. For germination, good means a germination rate above 85%, while good moisture is moisture levels below 13%. These are considered the rates at which performance is acceptable. All of the three breeder samples we collected had a 100% germination rate. By comparison, wholesalers, retailers, company outlets and company gates all scored significantly below this. However, the standard deviation of these results is large.

We next conduct formal tests of a supply chain analysis are presented in Tables 6 and 7. We find that none of the different seller levels are significantly correlated with any of the outcomes measured, except for whether germination rates were deemed good, i.e. better than 85%. As already noted, the omitted category, breeders, have perfect rates of good germination. The normalized index of indicators is likewise very significant, showing a large decrease in quality for all supply chain levels compared to the breeders.

The story is similar for which district the seeds were sold from. The omitted category is Arua. Again, we do not find much that is statistically significant for most of the test indicators. However, we do find that seeds sold in Kampala have higher germination rates, are more likely to produce good germinations and have fewer abnormal seedlings and dead seeds.

Based on the descriptive results and the regression analysis, we find that the seed samples taken from the breeders and from Kampala are associated with better quality, while the rest are the same quality across suppliers and other districts. We tested the equality of samples between supply chain levels in Table 7 and reject the hypothesis that quality is the same in breeders relative to any other level. In contrast, larger p-values for the suppliers pairing of tests confirm quality being the same at the downstream levels of the chain.

4. Discussion

Our results do not fit with a story of sellers adulterating seeds as they go along the supply chain. Our prior belief was that seed quality would deteriorate as it is moves farther down the chain, but this has proven to not be the case. DNA tests suggest that samples of seeds were genetically similar across supply chain levels, and the percentage of pure seeds was higher than 99% in all of the samples which is inconsistent with findings anticipated in the presence of seed adulteration. While adulteration of seeds may be the result of the absence of regulation and policies in the sector, a limited number of agro dealers, and low incentives to assure quality standards, we do not find evidence of tampering. The results we present are in fact more consistent with reduced seed quality due to mishandling once it leaves the breeders, possibly due to the lack of infrastructure and skills within companies and transport networks.

In addition, we find that seed quality differs in Kampala with respect to the other districts. We hypothesize then that issues start after the seeds leaving the breeders, at the downstream levels of the supply chain (e.g. wholesalers and retailers) at areas outside Kampala. This conjecture coincides with evidence presented by Langyintuo (2010), where storage issues are the biggest issue in the more remote areas due to commercial companies' poor infrastructure having sales points within 20 km radius from the processing plants[11]. Companies consequently rely mainly on wholesalers, dealers, and government agents to reach the farmers that are located in rural areas. Non-company agents retailing seeds have resulted in limited knowledge to advising farmers, thus lack of credibility, and storing seeds in poor facilities. Also, bags of maize often go through several markets in large cities before reaching the more rural farmers. Bags are loaded and unloaded at intermediates stops (Ahmed and Ojangole, 2014), meaning that cracking of seeds is possible if mishandled.

Enhancement of the monitoring mechanisms and implementation of registered sellers who can guarantee quality and promote transparent information and trust may be key for the seed sector development, especially for the supply chain points and districts where we observed reduced quality. There is a lot of attention focused on seed certification, but very little going to quality control. Further studies to diagnose the causes that are driving the high dispersion of the seed performance are needed, in particular research on the management of seeds at each level of the supply chain to look closely at the conditions during storage and transportation (e.g. temperature exposure). Studies need to be conducted at different districts to screen whether or not performance is conditional to regions.

Satisfactory germination rates are susceptible to several factors, starting with the seed structure, and other variables given by good farming practices that maintain favorable conditions like moisture, temperature in the environment around the seed, and the supply of oxygen (Ferguson et al., 1991). The reasons for low quality seed may be various and may include lack of infrastructure and lack of agronomic expertise. For example, moisture is one of the variables with the largest impacts in seed performance, a slight change in moisture can have vast

[11] Commercial companies only retail 23 percent of hybrids and 28percent of OPVs in the region

implications in the storage life of the seeds. In the case of maize, foundation of the seeds requires special procedures, e.g. seeds should ideally be stored at a 12% moisture because low levels increase the viability and storability of the seed (Setimela and Kosina, 2006).

Evidence that suggests poor storage by agro dealers affecting seed quality supports our claim on storage affecting performance. Most agro dealers store seed, fertilizer, and other inputs side by side in the same store, and seeds are exposed to the sun or to humid conditions while displayed, negatively affecting quality (Langyintuo, 2010).

Dynamic relationships within stakeholders – suppliers, farmers, and public agencies – are likely key to improving commercial relationship between breeders, farmers, and distributors. For instance, seed companies could work on the mechanisms to inspect quality (e.g. moisture), and then public agencies can monitor and control that quality policies are met along the supply chain, and at any region, in the urban, peri-urban, and rural areas.

Collective action may also contribute to farmers' access to improved seeds through capital and information. In Shiferaw et al. (2008), collective action, defined as the membership in a crop production group, not only reduces significantly the likelihood of facing capital constraints in purchasing improved seeds, but also increases the probability of improved seed adoption to 53 percent and 70 percent for farms of 0.2 ha per person and 76 percent to 88 percent for 1 ha farms. For the issues concerning to this study, agencies may work with groups of farmers to promote simple and reliable information on the quality of seeds, the identification of the new varieties, and the economic benefits. Farmers networks are key for the dissemination of new and improved technologies (Conley and Udry, 2001). A recent study found that farmers can highly underestimate improved and hybrid varieties. Only 2 percent of the sampled farmers were able to correctly identify the name of a specific variety confirmed by DNA fingerprinting, and 55 percent couldn't state the name of the variety they were growing (Ilukor et al, 2017).

5. Conclusion

As low adoption rates and seed quality have been a well-known issue in Uganda and the rest of sub-Saharan Africa for decades, the challenges faced by the seed sector are not new, nor are some of the recommendations we provide[12]. Our study provides evidence of seed quality along the supply chain, a novel contribution that may help address existing issues of low uptake of seeds in Uganda.

Complex dynamics arise in the seed market, meaning more research on the policies and the causal mechanisms for adoption is crucial. Policy differences across countries may explain adoption rates more than biophysical market, farm, and even socioeconomic characteristics (Sheahan and Barrett, 2017).

Finally, three important caveats are needed when interpreting these results. First, the sample size is relatively small, and so caution must be made when interpreting the statistical tests as statistical power is limited. However, the mystery shopper approach allowed us to ensure that the sample of seeds collected was representative, as if an actual farmer would have purchased the seeds. Second, we focus only on a few, remote districts in Uganda, which may limit the external validity of the study. Given the remoteness of the districts, we believe this would place a lower

[12]Joughin (2014) provides an analysis on why the Ugandan seed market had failed to implement old recommendations to date. The author attributes the lack of interest to develop the industry to short-term political benefits overweighting the policy-making process, translated into long-term plans not being implemented with commitment, and public and private firms' economic interests from the status quo. The "relative stasis" he describes is difficult to break and may be explained by institutional dysfunction, failure of leadership, poor donor coordination, and risk of economic losses from larger farmers.

bound on quality. Finally, it is possible that seed quality can fluctuate from year-to-year. Early 2017 may have been an especially good (or bad) year. Future evidence is needed to determine conclusively what is leading to the low quality of seeds in Uganda. The replication of this work in different regions, seasons, years and countries in East Africa will allow for generalizing our findings and disentangling the broader seed market.

References

2015a, Integrated Seed Sector Development Uganda. 2015. "2015 seed event." *IISD Uganda Newsletter* (4).

A., Escasina. 1986. "A study of the causes of seed deterioration following processing in maize (Zea mays L.)." *Massey University, New Zealand* 114.

Ahdmed, M., Ojangole S., 2014. 2014. *Analysis of Price Incentives for Maize in Uganda. Technical Report.* Technical Notes Series, MAFAP, Rome FAO.

Ashour M, Billings L, Gilligan D. Hoel J., Karachiwalla N. 2017. "Do beliefs about agricultural inputs counterfeiting correspond with actual rates of counterfeiting? Evidence from Uganda." *In Press.*

Association, International Seed Testing. 2006. *ISTA Handbook on Seedling Evaluation.* second ed. Zurich, Switzerland: International Seed Testing Association.

Augustine S. Langyintuo, Wilfred Mwangi, Alpha O. Diallo, John Mac Robert, John Dixon, Marianne Bänziger. 2010. "Challenges of the maize seed industry in eastern and southern Africa: A compelling case for private–public intervention to promote growth." *Food Policy* 35 (4): 323-331. doi:10.1016/j.foodpol.2010.01.005.

Authority, Ugandan Investment. n.d. *Agricultural Sector.* http://www.ugandainvest.go.ug/priority-sectors/agriculture-agribusiness/.

B. Kiiza, G. Pederson, S. Lwasa. 2011. *The role of market information in adoption of agricultural seed technology in rural Uganda.* Edited by Int. J. ICT Res. Dev. Africa. Vol. 2 (1).

Boef, Niels P. Louwaars & Walter Simon de. 2012. "Integrated Seed Sector Development in Africa: A Conceptual Framework for Creating Coherence Between Practices, Programs, and Policies,." *Journal of Crop Improvement* 26:1: 39-59. doi:10.1080/15427528.2011.611277.

Bold, Tessa & Kaizzi, Kayuki & Svensson, Jakob & Yanagizawa-Drott, David. 2017. "Lemon Technologies and Adoption: Measurement, Theory and Evidence from Agricultural Markets in Uganda." *The Quarterly Journal of Economics* 132 (3): 1055-1100. doi:doi.org/10.1093/qje/qjx009.

Bradford, K. J. 2006. "Methods to maintain genetic purity of seed stocks." *Agricultural Biotechnology in California Series 8189, Division of Agriculture and Natural Resources, University of California, U.S.A.*

Conley, Timothy, and Christopher Udry. 2001. "ocial Learning through Networks: The Adoption of New Agricultural Technologies in Ghana." *American Journal of Agricultural Economics* 668–73.

Edward, Mabaya. September 23-26, 2016. "Performance of the formal seed sector in Africa: Findings from the African Seed Access Index." *Invited paper presented at the 5th International Conference of the African Association of Agricultural Economists.* Addis Ababa, Ethiopia.

FEWSNET. 2011. *Technical Report.* Uganda: FAO, Rome. http://www.fews.net/pages/marketflowmap.aspx?gb=ug&l=en.

Govender et al., 2008. V. Govender, T.A.S. Aveling, Q. Kritzinger. 2008. "The effect of traditional storage methods on germination and vigour of maize (Zea mays L.) from northern KwaZulu-Natal and Southern Mozambique." *S. Afr. J. Bot.* (74 (2008)): 190-196.

Hell K, Cardwell KF, Setamou M, Poehling HM. 2000. "The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa." *J Stored Prod Res* 36: 365–382.

Hipi A., Surahman M., Ilyas S., Giyanto. 2013. "Seed Genetic Purity Assessment of Maize Hybrid Using Microsatellite Markers (SSR)." *International Journal of Applied Science and Technology* 3 (5). http://www.ijastnet.com/journals/Vol_3_No_5_May_2013/7.pdf.

IFDC. 2015. "Developing Competitive Fertilizer Markets in Africa: Policy Lessons from FTF Country Assessments." *USAID and International Fertilizer Development Center.* Alabama.

Ilukor, J., Kilic, T., Stevenson, J., Gourlay, S., Kosmowski, F., Kilian, A., Sserumaga, J., and Asea, G. 2017. "Blowing in the Wind: The Quest for Accurate Crop Variety Identification in Field Research, with an Application to Maize in Uganda."

J. M. Ferguson J.M., Keys R.D., McLauglin F.W. and Warren J.M. 1991. "Seed and Seed quality." *NC State Extension Publications* AG-448. https://content.ces.ncsu.edu/seed-and-seed-quality .

J., Joughin. 2014. "The Political Economy of Seed Reform in Uganda: Promoting a Regional Seed Trade Market." *Africa Trade Practice Working Paper Series. World Bank* 3.

J.C., Smith J.S.C. and Register III. 1998. "Genetic purity and testing technologies for seed quality: a company perspective." *Seed Science Research* 8 (2): 285-294.

Jack, B. Kelsey. 2011. "Constraints on the Adoption of Agricultural Technologies in Developing Countries." *White paper, Agricultural Technology Adoption Initiative, J-PAL (MIT) and CEGA (UC Berkeley).*

Jelliffe J., Bravo-Ureta B., Deom C M. July 14-17, 2015. "An Assessment of Groundnut Aflatoxin Contamination, Awareness and Mitigation Practices in Rural Uganda.”." *APRES 47th Annual Meeting.* Charleston, South Carolina.

Kassie, M., M. Jaleta, B. Shiferaw, F. Mmbando, and M. Mekuria. 2013. "Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania." *Technological forecasting and social change* (80 (3)): 525-540.

Kaufman, B. June, 2011. "DNA markers in purity testing." *Nucleic Acid Analysis Laboratory, Pioneer, A DuPont Business, Presentation at the International Seed Testing Association (ISTA) Seminar.*

Kolyangha, Mudangha. 2016. "Farmers warned against fake seeds." *Daily Monitor*, March 23. http://www.monitor.co.ug/Magazines/Farming/Farmers-warned-against-fake-seeds/689860-3129084-ox7u5b/index.html.

Louise Sperling, H David Cooper and Tom Remington. 2008. "Moving Towards More Effective Seed Aid." *The Journal of Development Studies* 44:4: 586-612. doi:10.1080/00220380801980954.

M. Sheahan, C.B. Barrett. 2017. "Ten striking facts about agricultural input use in Sub-Saharan Africa." *Food Policy, Agriculture in Africa – Telling Myths from Facts* 67: 12-25.

Naghavi, M. R., Malaki, M., Alizadeh, H. 2009. "An Assessment of Genetic Diversity in Wild Diploid Wheat Triticum boeoticum from West of Iran Using RAPD, AFLP and SSR Markers." *J. Agr. Sci. Tech* 11: 585–598.

Okello, D. K., Kaaya, A. N., Bisikwa, J., Were, M., & Oloka, H. K. 2010. "Management of Aflatoxins in Groundnuts: A manual for Farmers, Processors, Traders and Consumers in Uganda." *National Agricultural Research Organisation.* Entebbe.

Olakojo S.A., Akinlosotu T.A. 2004. "Comparative study of storage methods of maize grains in South Western Nigeria." *African Journal of Biotechnology* 7(2004): 362-365.

Poulton, C., Macartney, J. 2012. "Can Public-Private Partnerships Leverage Private Investment in Agricultural Value Chains in Africa? A Preliminary Review." *World Development* (40 (1)): 96-109. doi:10.1016/j.worlddev.2011.05.017.

R. Tripp, D. Rohrbach. 2001. "Policies for African seed enterprise development." *Food Policy* 26(2001): 147:161.

Remington, T., Maroko, J., Walsh, S., Omanga, P. and Charles, E. 2002. "Getting off the seed and tools treadmill with CRS seed vouchers and fairs." *Disasters* 26(4): 302–315.

S., Pologruto. 2017. *Feed the future, Agrilinks.* July 17. https://www.agrilinks.org/blog/combating-counterfeit-agriculture-uganda-through-market-facilitation.

Setimela, P.S., and P. Kosina. 2006. *Strategies for Strengthening and Scaling up Community-based Seed Production.* Mexico, DF: CIMMYT.

Shah W.H., Rehman Z.U., Kausar T., Hussain A. 2002. "Storage of wheat with ears." *Pakistan Journal of Scientific and Industrial Research* 17 (2002): 206-209.

Shiferaw, B. , Kebede, T. , Kassie, M. and Fisher, M. 2015. *Market imperfections, access to information and technology adoption in Uganda: challenges of overcoming multiple constraints.* Vol. 46 . Agricultural Economics. doi:10.1111/agec.12175.

Shiferaw, B., Kebede, T.A., You, Z. 2008. "Technology adoption under seed access constraints and the economic impacts of improved pigeonpea varieties in Tanzania." *Agricultural Economics* 39: 1-15.

SINUS Biochemistry & Electrophoresis GmbH. n.d. "Genetic purity testing of F1 hybrid maize varieties by isoelectric focusing of seed isoenzymes." http://www.sinus-biochem.de/genetic_purity_maize.htm.

Smith, J.S.C., and J.C Register III. 1998. "Genetic purity and testing technologies for seed quality: a company perspective." *Seed Science Research* 8 (2): 285-293.

Thamaga-Chitja, J. M., Hendriks, S. L., Ortmana, G. F. and Green, M. 2004. "Impact of maize storage on rural household food security in Northern Kwazulu-Natal." *Journal of Family Ecology and Consumer Sciences* 32: 8–15.

Ugandan Ministry of Agriculture, A.I., Fisheries. 2010. *Agricultural Sector Development Strategy and Investment Plan: 2010/11-2014/15.* Entebbe, Uganda: Technical Report, Ugandan Ministry of Agriculture, Animal Industry and Fisheries.

Vasal, S.K. and F. Gonzalez. 2010. "Maintenance and breeder seed production of parental lines. Advanced Seed Production Course in Maize, ICAR-CIMMYT Collaborative Program, New Delhi, India. WEMA 2010." *Enhancing maize productivity in Uganda through the WEMA project.* http://www.aatf-africa.org/userfiles/WEMA-UG-policy-brief1.pdf .

Vernooy, R. 2016. "Options for national governments to support farmer seed systems. The cases of Kenya, Tanzania and Uganda." *Hivos and Bioversity International.*

Walter de Boef, Ben Pierson, Dan Kim, John Mennel, Carl Engle, Pradeep Prabhala, Joel Bryce, Nemo Nemeth, Alyssa Jethani, and Aliza Hoffman. 2014. *Counterfeiting in African Agriculture Inputs – Challenges & Solutions.* Feed the future/Agrilinks. https://www.agrilinks.org/library/counterfeiting-african-agriculture-inputs-challenges-and-solutions.

Zhang C B, Peng B, Zhang W L, Wang S M, Sun H, Dong Y S. 2014. "Application of SSR Markers for Purity Testing of Commercial Hybrid Soybean (Glycine max L.)." *JAST* 16 (6): 1389-1396.

Figure 1. Seed supply chain in Uganda

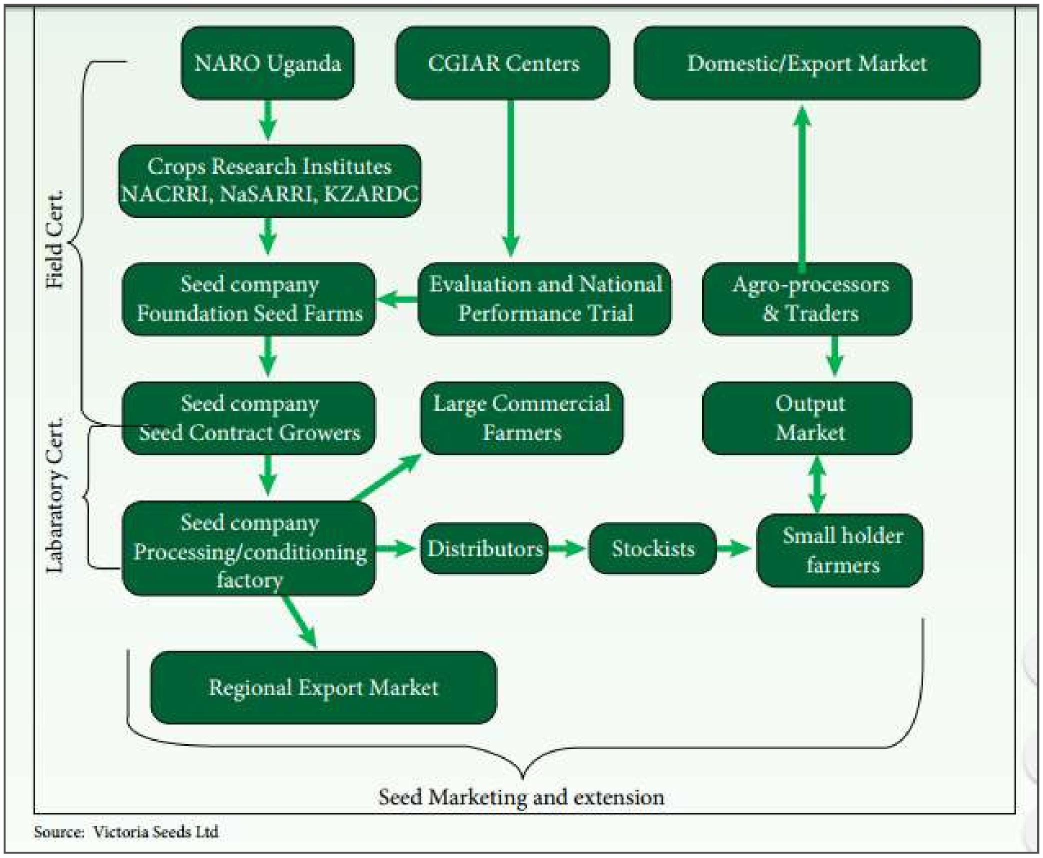


Figure 2: Results of seed purity

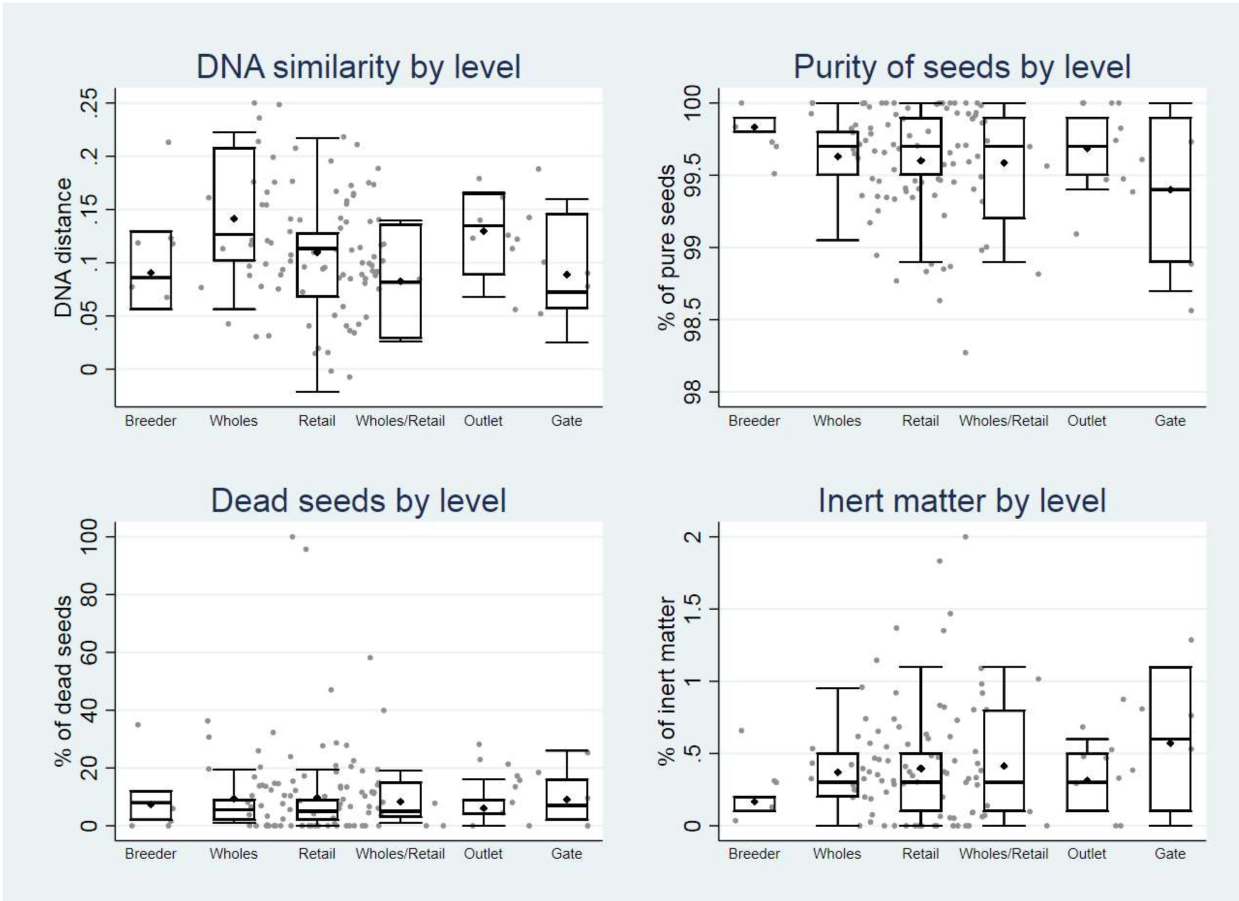


Figure 3: Results of seed performance

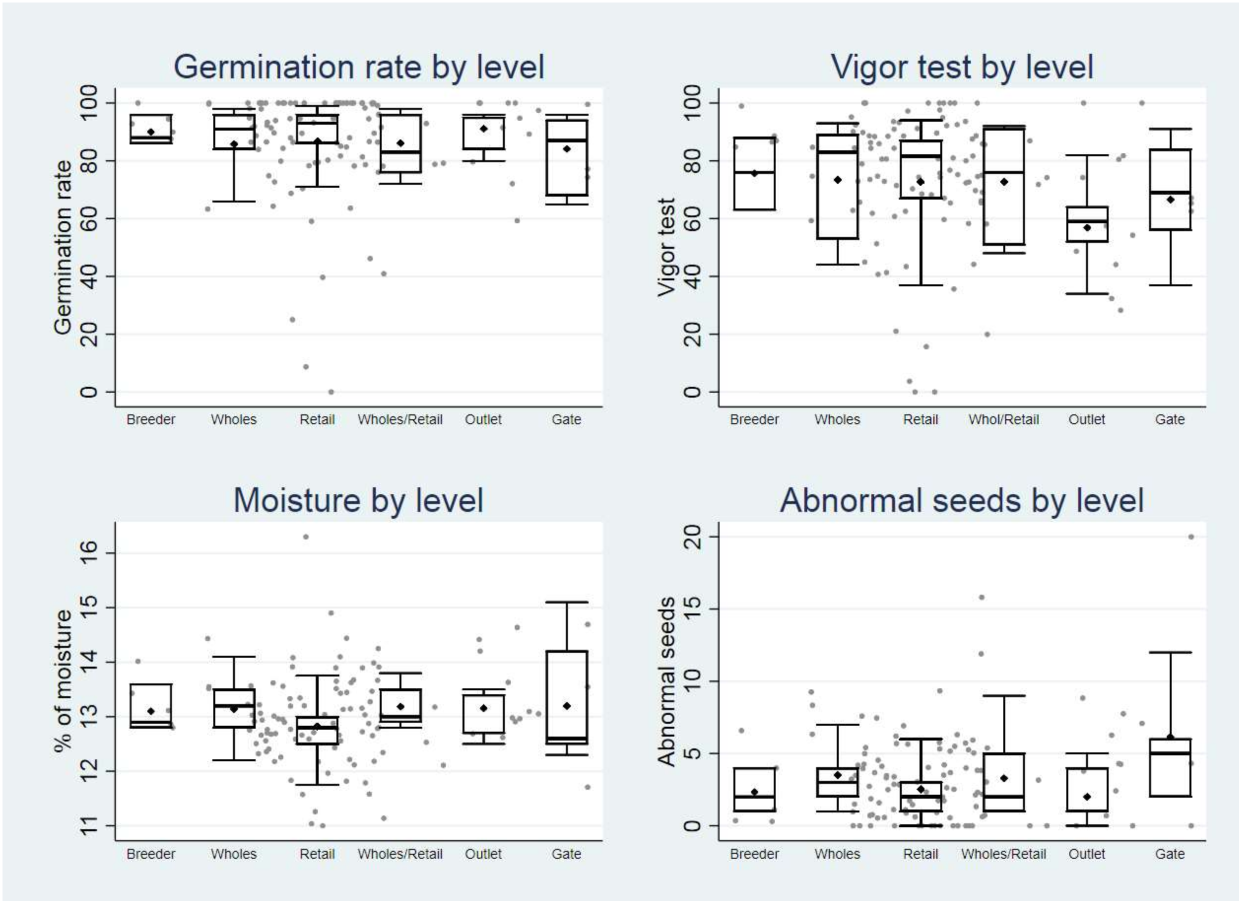


Figure 4: Results of seed germination

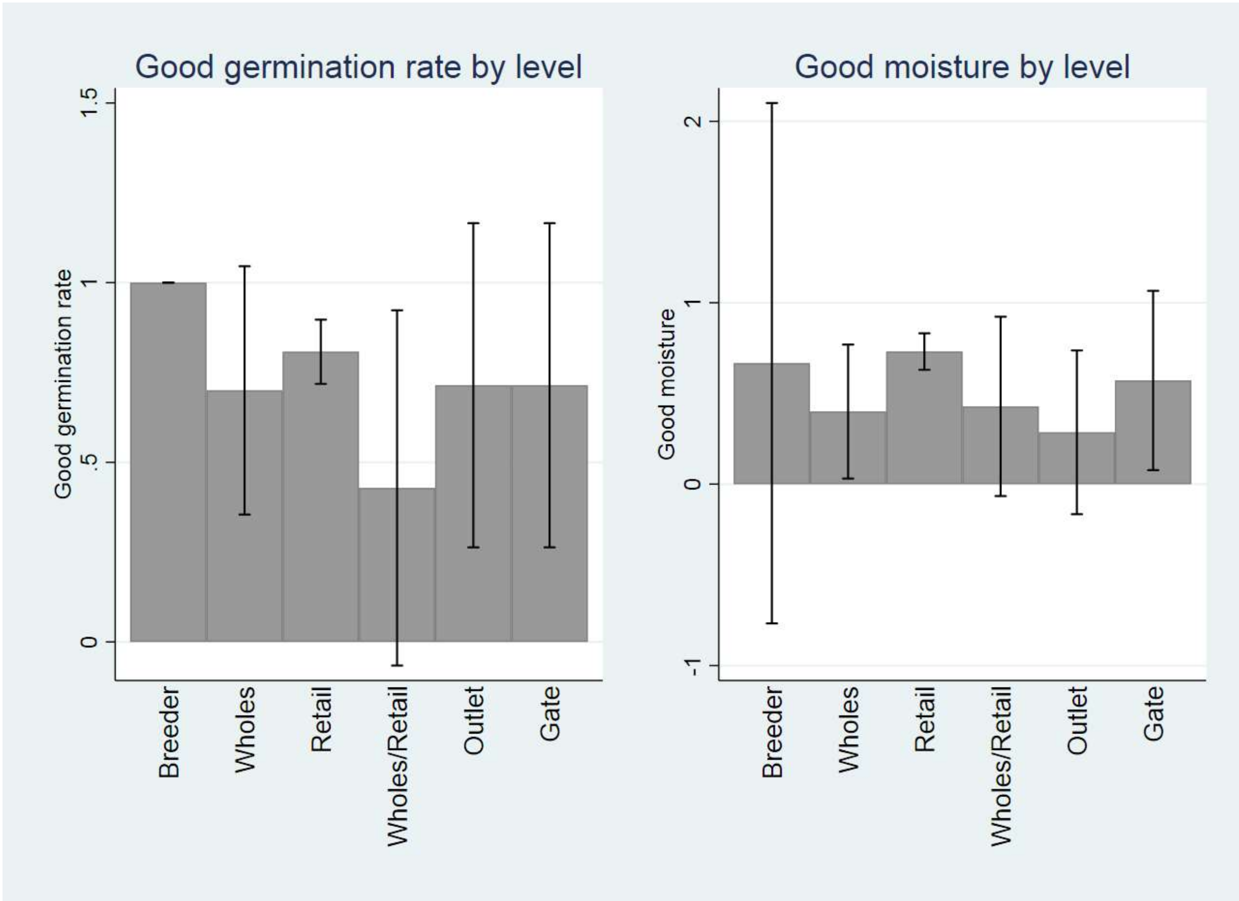


Table 1. Samples collected by district and sub-county

District	Samples collected by county									
Arua	Adumi	Arua Hill		River Oli		Vurra				
	4	15		2		2				
Kampala	Central	Kawempe		Nakawa		Nakivubo				
	3	4		1		10				
Kitgum	Kitgum	Kitgum TC		Kitgum		Omiya Anyima				
	12	3		1		2				
Lira	Adekokwok	Agweng	Central	Ojwina	Amach	Railways	Adyel	Agal	Agali	Aromo
	1	4	28	15	1	4	5	1	2	1
Masindi	Municipality									
	1									

Table 2. Supply chain levels by districts

Supply chain level	Districts					
	Arua	Kitgum	Lira	Kampala	Masindi	Total
Breeder			1	1	1	3
Wholesaler	1		9			10
Retailer	21	15	39	3		78
Wholesaler/Retailer			5	2		7
Company retail outlet				7		7
Company factory gate			3	4		7
Total	22	15	57	17	1	112

Table 3. Samples of Seed Varieties

Seed Varieties	Number of samples collected	Percent
AHADI (WE1101)	8	6.56
Aminika WH 505	2	1.64
Bazooka	5	4.1
DH 04	5	4.1
DK 8031	9	7.38
KH 500-43A	5	4.1
LONGE 10H	11	9.02
Longe 4	3	2.46
Longe 5	48	39.34
Longe 7N	3	2.46
Maksoy 1N	3	2.46
Maksoy 3N	6	4.92
PAN 4M-21	2	1.64
SC DUMA 43	2	1.64
SC SAGA	1	0.82
SC Sungura 301	2	1.64
UH5051	1	0.82
UH5053	2	1.64
VICTORIA 1	1	0.82
VP Max	1	0.82
WEMA 2115	2	1.64
Total	122	100

Table 4. Main indicators used in the seed testing analysis

Indicator	Description	Benchmark
Moisture[13]	The seed moisture content is the amount of water in the seed and it is expressed as the percentage on wet weight basis. This is a core parameter that influences the seed quality and storage life of the seed. Moisture is linked to seed maturity, mechanical damage, seed drying, and insect and pathogen infestation	12%-13.5%
Rate of germination	Refers to the rate of germination of normal seeds**.** This is an estimate of the viability of a population of seeds. The germination rate provides a measure of the time course of seed germination by calculating the germination percentage at different time intervals after planting.	85%
Vigor test	Gives performance of a seed lot in the field or in storage. The test simulates early ideal conditions by germinating seeds in wet soils and incubating at certain temperatures. Then the test is transferred to favorable temperatures for germination. It is expressed as the percentage of normal seedlings and indicates the seed vigor[14]	60%-80%
Purity test	Percentage of pure seeds and dead seeds, and inert matter. The portion of inert matter refers to dirt, sand, stones, sticks, glumes, stems, broken seed and other miscellaneous non-seed items that have made their way into the seed bag.	
Genetic purity or referred as DNA distance[15]	The DNA analysis focused on distance as there was not a pure comparison sample available. The test examines how closely related each sample is to each other. While not a perfect test of genetic purity, the average of all distance measures within a variety presents a close approximation of how genetically similar seed types are to each other.	

[13] The seed's storage life depends in large proportion on moisture and the temperature relative to humidity of the storage environment. The lower the moisture content, the longer the seed's storage life and the most resistant to fungi and mold. However, too low moisture (less than 2%) can also harm the seed, especially if the process of drying is done at very low moisture levels. Minimum damage occurs until 24% of moisture content (Escasina, 1986)

[14] The sum total of those properties of the seed that determine the level of activity and performance of the seed during germination and seedling emergence" (ISTA, 2006)

[15] Ground samples of seeds were shipped from Uganda to a laboratory test facility located in Australia, where scientists examined the seeds' genetic purity

Table 5. Data summary

	N	Mean	Std. Dev.	Min	Max
Moisture	112	12.92	0.71	11.3	16.3
Vigour test	112	71.47	21.80	0	97
% pure seeds	112	99.60	0.37	98.1	100
% inert	112	0.39	0.36	0	1.9
Germinate normal seeds	112	86.82	17.29	4	99
Germinate abnormal seedlings	112	2.85	2.70	0	19
% dead seeds	112	9.22	14.82	0	92
DNA distance	111	0.11	0.05	0.02	0.23

Table 6. Supply chain analysis

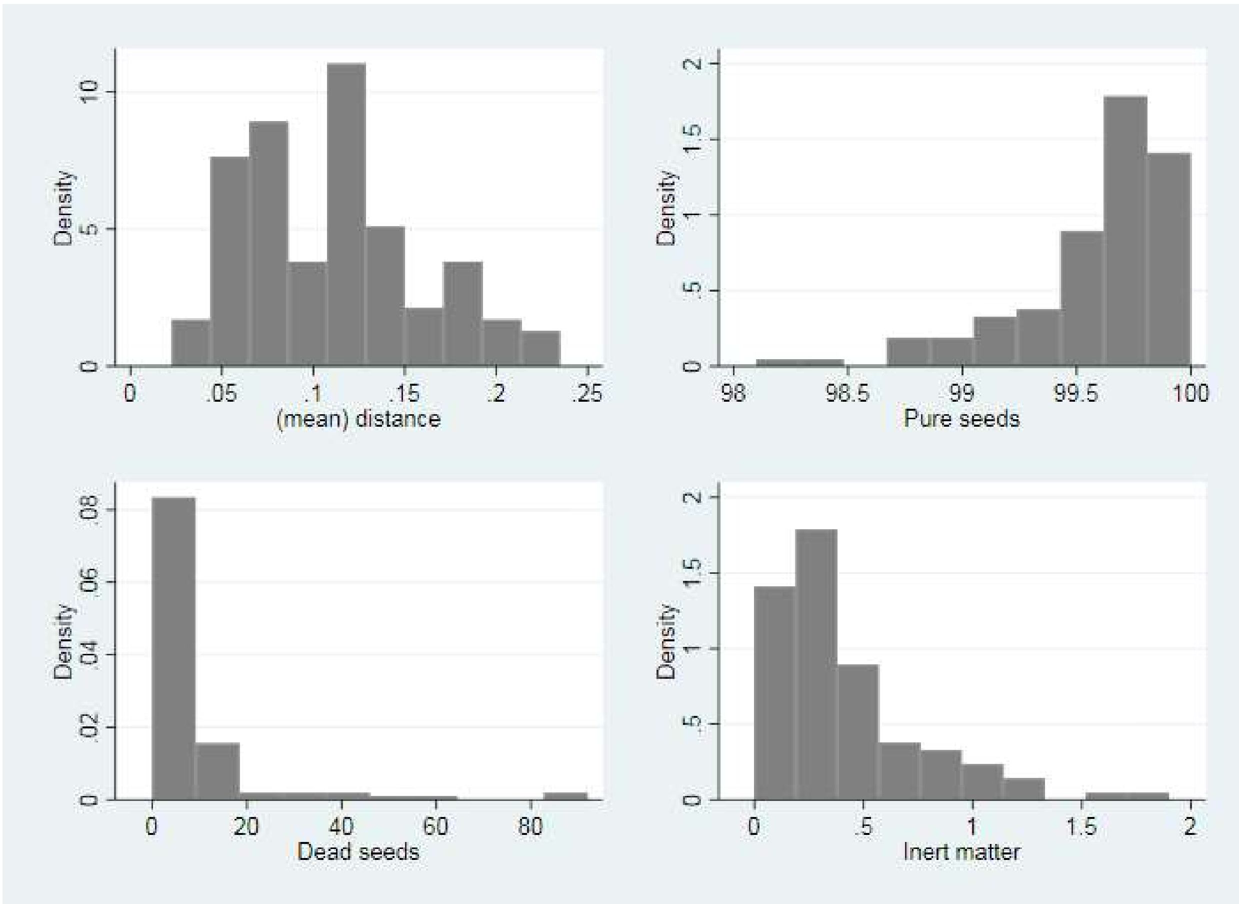
	(1) Moisture	(2) Good moisture	(3) Vigor test	(4) % pure seeds	(5) % inert	(6) Germinate normal seeds	(7) Good germination	(8) Germinate abnormal seedlings	(9) % dead seeds	(10) DNA distance	(11) Index
Wholesaler	0.404	-1.063	14.92	-0.574	0.583	-1.915	-1.323**	2.598	-2.063	0.0133	-2.257*
	(0.650)	(0.129)	(0.633)	(0.274)	(0.267)	(0.908)	(0.0148)	(0.487)	(0.889)	(0.543)	(0.0528)
Retailer	0.247	-0.775	12.52	-0.574	0.583	-5.022	-1.262**	1.652	2.251	0.00713	-1.989*
	(0.776)	(0.255)	(0.682)	(0.263)	(0.255)	(0.756)	(0.0172)	(0.650)	(0.876)	(0.738)	(0.0797)
Wholesaler/Retailer	0.171	-1.194	13.12	-0.657	0.659	-8.728	-1.530***	2.744	1.690	-0.000359	-2.529**
	(0.853)	(0.100)	(0.686)	(0.228)	(0.226)	(0.612)	(0.00684)	(0.479)	(0.912)	(0.987)	(0.0367)
Company retail outlet	0.500	-1.000*	-8.000	-0.100	0.100	-4.000	-1.000**	1.000	1.000	-0.00248	-1.741*
	(0.515)	(0.0988)	(0.767)	(0.825)	(0.825)	(0.780)	(0.0322)	(0.756)	(0.938)	(0.895)	(0.0828)
Company factory gate	0.344	-0.626	0.266	-0.484	0.473	-16.18	-1.381**	6.364*	7.251	0.0164	-2.142*
	(0.694)	(0.362)	(0.993)	(0.349)	(0.360)	(0.324)	(0.0101)	(0.0867)	(0.619)	(0.447)	(0.0620)
Kitgum district	0.234	-0.0445	5.994	0.173	-0.173	3.186	0.160	-1.116	-1.658	-0.00266	0.387
	(0.352)	(0.821)	(0.498)	(0.243)	(0.242)	(0.497)	(0.290)	(0.291)	(0.692)	(0.667)	(0.236)
Lira district	-0.154	0.168	7.042	-0.0331	0.0346	4.006	0.146	-0.189	-3.438	-0.00931*	0.399
	(0.427)	(0.269)	(0.301)	(0.771)	(0.760)	(0.268)	(0.208)	(0.816)	(0.286)	(0.0547)	(0.113)
Kampala district	-0.0151	-0.0534	14.44	-0.145	0.154	12.08**	0.295	-3.265**	-7.917	-0.00967	0.364
	(0.963)	(0.833)	(0.207)	(0.447)	(0.419)	(0.0482)	(0.131)	(0.0184)	(0.144)	(0.227)	(0.385)
Masindi disctrict	0.894	-1.607*	15.56	-0.507	0.517	-4.016	-1.115	1.464	0.814	-0.00642	-2.269
	(0.450)	(0.0849)	(0.708)	(0.466)	(0.457)	(0.855)	(0.118)	(0.768)	(0.967)	(0.825)	(0.141)
Observations	112	112	112	112	112	112	112	112	112	111	112
R-squared	0.638	0.514	0.520	0.521	0.505	0.785	0.633	0.553	0.768	0.953	0.707

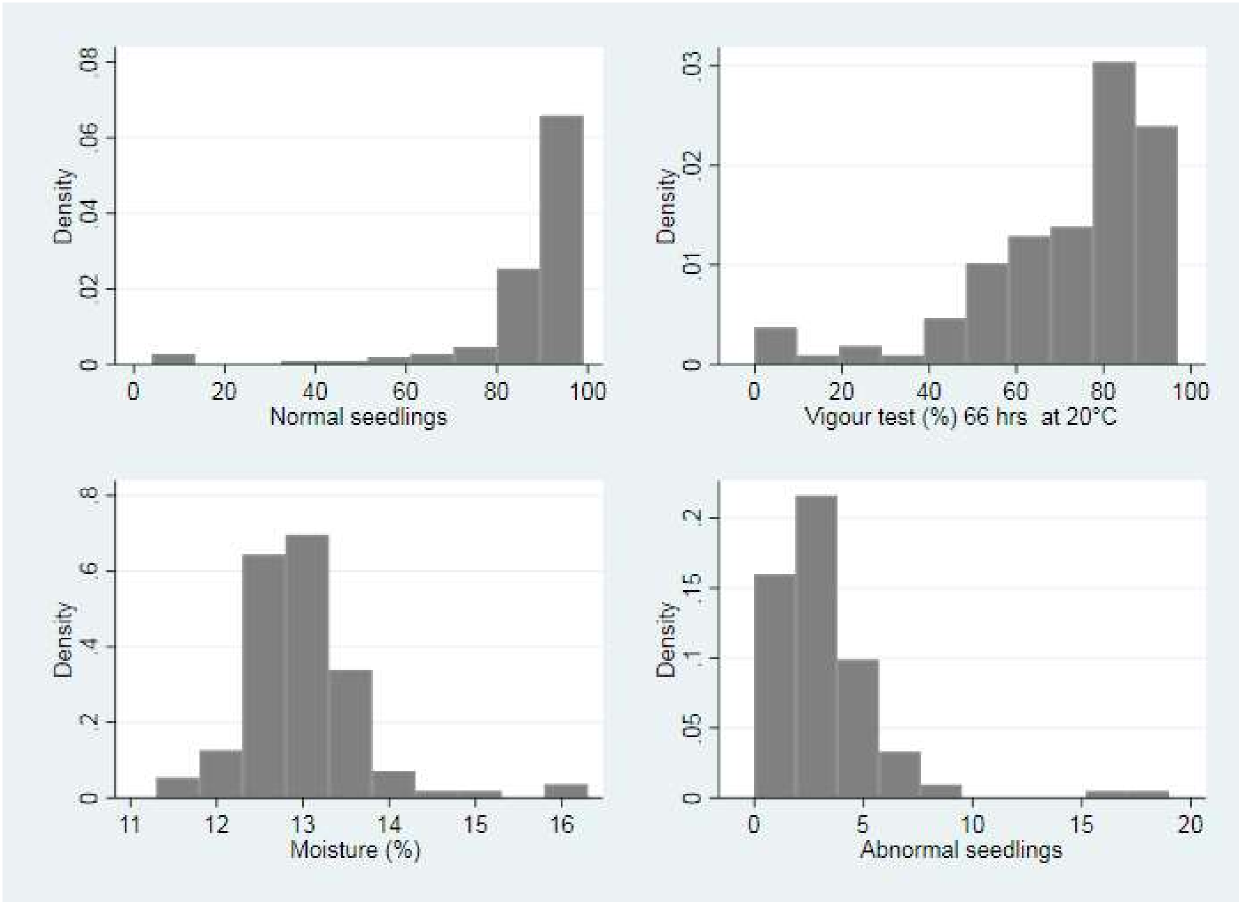
Notes: Analysis is for maize varieties only. Controls include seed variety, type and company. *** p< 0.01, ** p< 0.05, *p< 0.1.

Table 7. F-tests for equality of supply chain levels

Tests for equality of supply chain levels	
Breeder = Wholesaler	0.051
Breeder = Retailer	0.077
Breeder = Wholesaler/Retailer	0.035
Breeder = Company outlet	0.079
Breeder = Company gate	0.059
Wholesaler = Retailer	0.319
Wholesaler = Wholesaler/Retailer	0.599
Wholesaler = Company outlet	0.376
Wholesaler = Company gate	0.844
Retailer = Wholesaler/Retailer	0.256
Retailer = Company outlet	0.634
Retailer = Company gate	0.718
Wholesaler/Retailer = Company outlet	0.232
Wholesaler/Retailer = Company gate	0.488
Company outlet = Company gate	0.452

Appendix A: Densities of the data





Density
Normal seedlings
Density
Vigour test (%) 66 hrs at 20°C
Density
Moisture (%)
Density
Abnormal seedlings