Feasibility of Non-Shattering Sesame Production in Northern Uganda

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Contents

1. Introduction

Agriculture has been the key driver of economic growth in Uganda during the recent and greatest periods of economic growth, accounting for 24.5% of the country's GDP (LTS International Limited 2017). Agricultural growth has been seen to have a greater effect in overall poverty reduction than growth in any other sector, and it is easy to see why considering 71.9% of Ugandan employment is in the agricultural sector (Dorosh and Thurlow 2012), with 66% of households engaging directly in crop production for subsistence and sale (Kappel 2005). Development investment flows in the East Africa region have shifted to the urban-led economic growth model (Kappel et al. 2005), but more recent studies suggest regional development activities and investment in the agricultural sector as a more efficient focus for total-factor productivity and regional growth (Dorosh and Thurlow 2012). Economic investment models have shown that per $285 USD invested by the Ugandan government into the agricultural sector, 21.75 people had their levels of poverty reduced, which has a more efficient return on investment compared to investments in infrastructure, education, and healthcare combined (Fan and Zhang 2008).

While vegetables, banana, coffee, and cotton were historically the cash crops of the region, there has been significant diversification in the market for Ugandan agricultural products, with maize, rice, groundnut, sesame, sunflower, soybeans, and millet becoming potential cash crops for farmers (Laker-Ojok, 1994). These higher-value crops had good price points and experienced a boom in the mid-90's but export market opportunities have decreased significantly since 2000 (Kappel et al. 2005, Wacal et al. 2021). Most of these crops grown by smallholders are grown both for home consumption and for sale, with excesses of harvest being sold to local markets or to wholesalers (Dalipagic and Elepu 2014).

Sesame has emerged as a potentially profitable crop to produce for smallholder farm families (UKAID 2020). It is considered a drought-tolerant crop that performs well in semi-arid regions and can withstand high temperatures, making it a good candidate for production in the Northern and Eastern regions of

Uganda, which currently accounts for 93% of all sesame production in the country (Dalipagic and Elepu 2014). The USGS Climate Trend Analysis of Uganda shows expectations that the warmer regions will continue to expand, while rainfall is expected to decrease during both the wet and dry seasons, which may increase the ideal growing area for sesame in the near future (Funk et al. 2012). In Uganda, commercial uses for sesame include oil extraction, confectionery, and animal feeds. Sesame oil has a high concentration of antioxidants, giving it an exceptionally long shelf life, and can be used for cooking or in production of other manufactured goods such as margarine, and even has use in the pharmaceutical and cosmetic industries (Lin et al. 2017). The meal leftover from pressing sesame seeds is high in protein, and is often blended with flour for food uses, and can be used as a high-quality animal feed (LTS International 2017). Sesame is grown as a cash crop in Uganda, however its potential production is limited, and the value chain is considered inefficient, so the opportunities for farmers growing this crop have not been fully realized (UKAID 2017, Wacal et al. 2021). However, despite its popularity, sesame production and improvement are understudied in Uganda. In this paper, relevant information and recent communications with seed companies incorporating improved varieties of sesame into their portfolios are used to better understand Ugandan sesame production.

2. Purpose and Objectives

The purpose of this study is to outline the current issues surrounding sesame production throughout Uganda and articulate constraints to increasing production of sesame among smallholder family farmers and Small to Medium Sized Enterprises (SMEs). In this context, the limitations of the traditional sesame varieties that are grown in Uganda will be examined, as will the barriers to production and scaling of the production of these varieties, as well as the gender and social dynamics surrounding traditional sesame production in Uganda. Section 4 examines the economic benefits of a recently released improved variety of sesame with more uniform plant maturation coupled with a non-shattering trait that allows for combine harvesting. The economic viability and outputs from that variety by a smallholder farmer are evaluated utilizing the Land Use System Analysis methodology. Barriers to adoption and production of the improved sesame are outlined in section 5, with a focus on the infrastructure and mechanization constraints preventing the widespread adoption of the "Smarter Sesame" variety. The variety is then examined based on recent literature on gender dynamics, with an attempt to predict the changes in household interactions between men and women from non-shattering sesame adoption in rural households. Estimates and predications are made by cross-examining recent literature surrounding gender negotiations in rural Ugandan households and sesame production in Uganda in Section 6. Finally, recommendations for broader commercial adoption of the improved sesame variety by Ugandan farmers are made in Section 7, as are areas of future research surrounding sesame research and production in Uganda.

3. Background

3.1 Production constraints

Current production levels of sesame are extremely low - Uganda is ranked 39th in the world for productivity on a per-acre basis (FAOSTAT 2018). There are many challenges to crop production - lack of equipment for land preparation, disease and insect pressure, weed pressure and lack of labor for weeding, no access to quality fertilizer or other inputs, non-availability of quality seed varieties, and poor postharvest handling (UKAID 2020). Market access by growers for quality seed, fertilizer, and other inputs is a serious challenge that several interventions have tried to address over the years (Munyua 2013, UKAID 2020). Compounding these effects is a lack of credit extension to SMEs and smallholder farmers which prevents the purchase of these input. The lack of farmers being able to pay for inputs prior to planting helps explain why there are so few inputs available in the market (Wacal et al. 2021).

The national average yields for smallholder farmers are estimated at 500 kg per hectare (FAO 2018), with average plot sizes just under 0.4 hectares for small-holder farmers (SHFs) in the Northern Regions of Uganda (CASA 2020). Aggregate data for the region estimate the household consumption at 23%, leaving 77% available for sale (Munyua 2013). The sesame trading price is estimated at $1 USD/kg, for a total value of $500/hectare per season (UKAID 2020). Variable costs of production are around $128 USD, leaving a gross margin of $179 per hectare if all sesame was sold (LTS International 2017). Of the 77% sold, 42% (65,772 t) found its way to processors for export, 10% (15,860 t) was bought and resold to urban consumers, and 25% (39650 t) was sold by rural assemblers and retailers to rural consumers (Munyua 2013). The abundance of middlemen in the sesame value chain reduces the already limited supply of sesame that is available for the export market and decrease the overall value of the crop to the grower. A lack of knowledge of contract farming systems and poor linkages to wholesalers and export companies limits the economic potential of sesame as a cash crop in Uganda (Wacal et al. 2021).

The major insect pests of sesame in the Northern regions are reported to be sesame webworm (*Antigasta catalaunalis*) as well as sesame gall midge (*Asphondylia sesami*), which account for most of the insect damage on sesame in Northern Uganda (Egonyu et al 2005). The use of contact and systemic insecticides can mitigate the damage of these pests, however, access to these insecticides in a timely manner can be a significant challenge due to lack of well-stocked agro-input dealers in Northern Uganda (Zerihun 2013, Wacal et al. 2021). Disease pressure from *Cercospora spp.* leafspots have been reported to negatively affect sesame yields, and postharvest losses due to *Aspergillus flavus*, causal agent of Aflatoxin, have reduced available supply of sesame grains, especially to the high-value export market (Wacal et al. 2021).

High moisture content is an issue brought about by the current varieties commonly used Uganda. The current varieties, commonly referred to generically as “simsim”, have non-uniform ripening and are prone to pre-harvest shattering, and thus need to be harvested prematurely and placed on drying racks until appropriate moisture levels for efficient threshing are reached. This process can take up to three days and is vulnerable to errant rainfalls at the end of the season (Wacal et al. 2021). After the initial drying, the stalks are shaken and left to dry for an additional day, then manually beaten until all the grains have been separated from the pods and fallen onto tarps or the ground if no tarps are available (Kailashkumar 2019). The remaining pods attached to stalks that have not been opened in the threshing process are manually opened to extract the grains. The threshing process is time- and energy-consuming and results in the presence of broken grains, dirt, stones, and chaff mixed with the marketable grains. The costs associated with hand-harvesting and threshing due to shattering-prone varieties are estimated around 70% of total production costs (Islam et. al. 2016).

The systematic issues surrounding the sesame market are severely limiting the market potential of this crop. Lack of extension knowledge, coordination between smallholders, and a severely underdeveloped commercial seed market are key factors that could be improved to raise the production levels in Uganda (LTS International 2017). Experiments on improving extension practices in Uganda are ongoing and promising. Increased use of information and communication technology by extension agents is changing household crop selection (Pan et al. 2018), which could be a factor in adoption rates of improved varieties in the country moving forward. Having real-time information related to the markets, weather, fertilizer use, and pest management will be a key factor in bridging the yield gap between Uganda and other major sesame producing regions. Additionally, performance incentives have been found to be successful for increasing productivity for extension agents in the rural regions of Uganda (Amadu et al. 2018). Implementation of these programs combined with the availability of information to rural networks of extension agents could help to improve the impact of the public and private sector extension agents in rural Uganda. Additionally, a key issue among smallholders and SME's is the access to agricultural credit systems from financial institutions, which limits a grower's ability to purchase improved varieties and the fertilizers and pesticides required to maximize sesame yield potential on the acreage planted (Wacal et al. 2021).

3.2 Gender Impacts

Adoption rates of improved agricultural technologies has traditionally been lower for women than for men for a variety of reasons that are generally market related. Key factors to adoption rates include access to credit, extension support, and human capital (Hill and Vigneri 2014). The lack of access to capital is critical and self-perpetuating; by not being able to afford new varieties and fertilizers, yields and quality of crops grown decrease, and with that, lower incomes are brought home (Morrison et al. 2007). These interlocking challenges could hinder the adoption of improved varieties of sesame being introduced to the Ugandan market. This excerpt from the LTS International report in 2017 summarizes the roles of men and women with regard to sesame production:

> Historically, in Uganda, sesame was regarded as a woman's crop. It was grown on marginal lands or in kitchen gardens and grown for consumption at a local level. When commercialized sesame began to take off in Uganda, sesame became considered a cash crop. It is frequently noted in the literature that cash crops and export crops are male crops, while subsistence crops are female crops. Typically, evidence suggests, men may take over production and marketing, even of traditional women's crops, when it becomes financially lucrative to do so (LTS International 2017).

They go on to state:

> In Uganda, it is estimated that women do 85% of the planting, 85% of the weeding, 55% of land preparation and 98% of all food processing. When production of sesame is increased, especially at a smallholder level, it is estimated that women's workloads considerably exceed those of men (LTS international 2017).

With the increase of commercialization of sesame, the division of labor between men and women is expected to remain the same, while the control of the marketing and decision making will likely shift to the men of the household, as is the case in other cash crops (Hill and Vigneri 2014). Control of the allocation of income as well as knowledge of markets, contracts, inputs, and prices, has also been seen to shift to the men as well (LTS International 2017). To overcome these shifts in control and income while improving cash crop production for women will require some shifts in availability of capital and production at scale. Interventions that are focused on women's groups or marketing groups that allow for more female participation in cash crop markets can help increase the scale at which smallholder women farmers operate at and could help significantly with adoption of improved agricultural technologies.

3.3 New Variety Introduction

The introduction of shatter-resistant sesame varieties is ongoing through efforts by input supply companies based in Uganda (Ag-Ploutos 2021). These shatter-resistant varieties allow sesame in the field to dry down to proper pre-harvest moisture in the field, and do not require premature harvesting and drying, which could lead to significant savings in both labor and costs of production (Islam et. al 2016). These varieties enable the increased adoption of mechanical harvesters, either by larger individual growers or rented from cooperatives, which would eliminate many of the quality control issues with hand harvesting and allow for easier collection and transport, thus drastically improving the quality and quantity of the seeds (LTS International 2017).

These improved varieties are averaging yields closer to 450 kg/acre (TAMU 2007), versus the Ugandan national average of 200 kg/acre (FAOSTAT 2018). At a price of $1.00 /kg, this could represent an increase in household gross income of $154.30 USD per hectare per season, without accounting for the labor costs associated with the post-harvest drying and processing that is required currently. This increase in yield could raise Ugandan output on a per hectare basis to be 0.9 t/ha and would increase the national output from 124,000 MT to 189,000 MT (LTS International 2017). At a market rate of $2100/MT, this increase in output represents $78 million USD increase in output for the sesame supply chain (Tridge 2021). The reduction in costs of production combined with the increase in yield with minimal changes to production practices could potentially result in a significantly higher income for Ugandan farmers incorporating these varieties in their crop selections.

An improved sesame variety has been registered in Uganda by Equinom, an Israeli based seedtech company. This shatter-resistant variety is being released for commercial sale in Uganda in July. The variety and export market linkage are distributed by Ag-Ploutos Company, a Ugandan agro-input dealer operating nationally. Ag-Ploutos supplies this non-shattering 'Smarter Sesame' variety, as well as fertilizers, biostimulants, and crop protection inputs. They also facilitate the market linkage to large buyers or export groups based in Kampala, streamlining the offtaker market and providing better purchase pricing for farmers that are now growing export-quality sesame varieties. The Ag-Ploutos business model ideally supports an outgrower network of 144,000 smallholder farmers by utilizing the Village Agent model, where rural Village Agents facilitate the 'last mile' services for input supply and providing agronomic extension information to rural farmers. These Village Agents are intended to create a more formal market, help farmers to fulfill contracts, and facilitate access to credit (USAID FtF 2019). In the Ag-Ploutos business model, each Village Agent services roughly 200 growers, and the Village Agents receive agronomic information and trainings from 72 "Agripreneurs" that work directly with Ag-Ploutos staff. (Ag-Ploutos 2021). The outputs on table 3 below assume that this outreach model is successful, and that there are no issues in the last mile delivery service, and agronomic information is being disseminated to the farmer effectively to produce a quality crop.

To summarize, the low productivity of the traditional sesame varieties combined with the disorganized value chain surrounding current sesame production is leading to lower household earnings compared to the output potential of improved sesame varieties. These traditional varieties also require increased levels of household or hired labor, which is disproportionately allocated to the women of the household. The introduction of non-shattering varieties could help alleviate some of the labor burden of traditional varieties, as well as improve output potential of sesame grains. The full effects of the introduction of "Smarter Sesame" variety ES107 for smallholder farmers in the Northern Regions of Uganda are analyzed in the Land Use System (LUS) Analysis methodology outlined below.

4. Land-Use System (LUS) Analysis

The Land-Use System analysis is a tool utilized by economists to estimate the multi-year returns of different economic indicators on a particular geographic area. It can be used as means to measure the input prices and product revenues generated off a plot of land and can also help to calculate the economic returns to land and labor (Vosti et al. 2000). This Land Use System was used as a tool to determine the economic viability of improved sesame variety performance in comparison to the traditional hand-harvested varieties of sesame grown in the Northern region of Uganda. This LUS analysis examines a two-year crop rotation of maize, sesame, and wheat. The sesame crop planting typically starts in August and is harvested in December (UKAID 2020). The temporal time-step for this LUS begins in March of 2021 and continues for 10 years. This starting point is used for all input and output price parameters included in appendix 1, with figures cited from World Bank Commodity Reports (2021) as well as a recent report from UKAID's Commercial Agriculture for Smallholders and Agribusiness program analyzing pricing and infrastructure in the sesame sector (UKAID 2020). This LUS is meant to reflect a typical agricultural household with 6 members, 2 adults and 4 children, in the Northern regions of Uganda on the outskirts of the city of Gulu, in the Gulu district.

This region has an elevation between 1,020 – 1,272m and is considered semi-arid (<48 cm rainfall/year) (Kisembe et al 2018). The soil type surrounding Gulu is characterized as an Alisol, with a pH range of 5.54-5.72 and soil organic carbon levels between 0.98 - 2.11 % (Musinguzi et al. 2015, Ekesa et al. 2015). Full geospatial soil data are below on **figure 1** below.

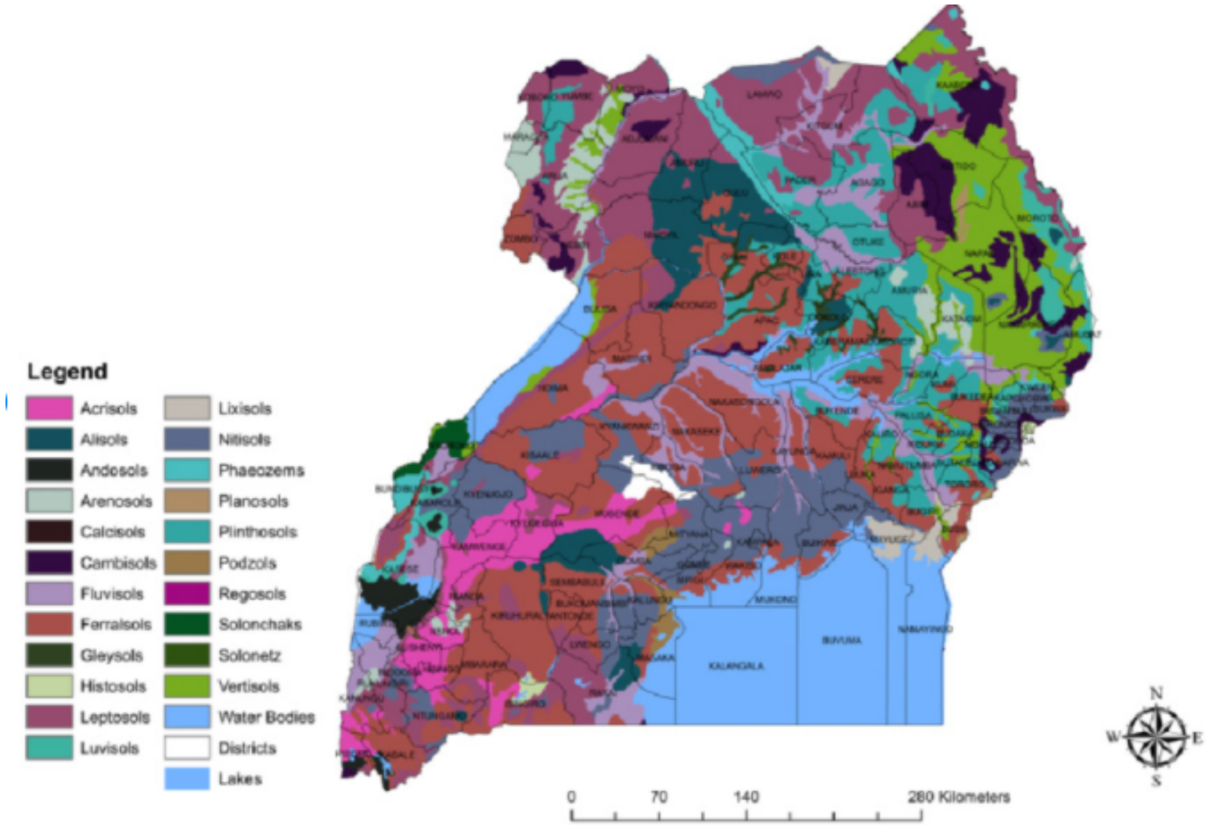

Figure 1: Geospatial soil types throughout Uganda (Ekesa 2015)

This region has a bimodal rainfall pattern, with the major rainfall season in March-May and a shorter rainfall period in September-November, with a total daily average shown throughout the country on **figure 2** (Kisembe et al 2018). The timing of this bimodal rainfall pattern allows for two seasons of annual crops to be grown in a year (Ekesa et al. 2015).

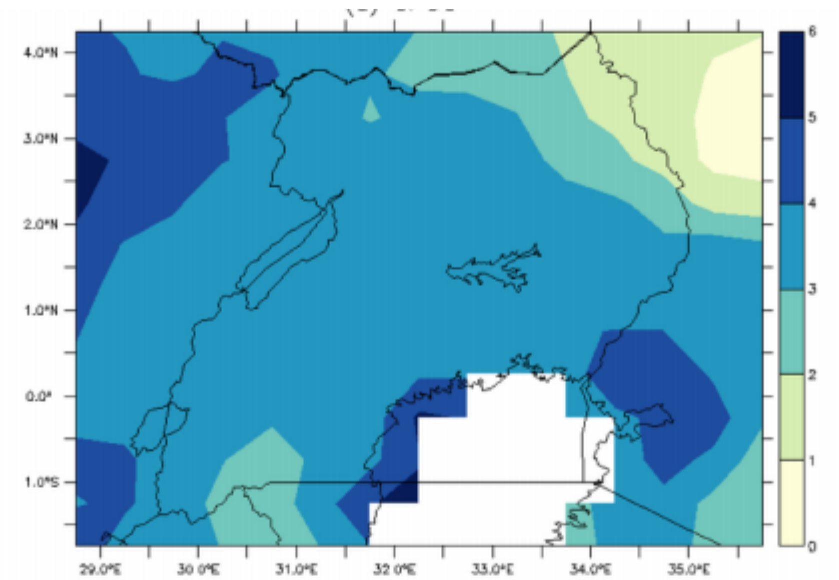

Figure 2: Annual rainfall data throughout Uganda (mm/day) (Kisembe et al 2018)

The economic performance of this crop rotation was determined through the LUS by analyzing the returns to family labor, returns to land, and net present value of the two-year crop rotation over the 10-year time period. Comparisons were made between traditional sesame varieties and shatter resistant varieties by completing two LUS analyses. No differences were made in the production systems for the first-season crops of maize and wheat. Maize is planted in rows, by hand, and is harvested by a rented combine harvester from a service supplier in Gulu. Wheat is also harvested by combine, but is broadcast planted. The traditional sesame is broadcasted and harvested by machete due to the uneven moisture content and will be hung upside down on wooden drying racks until moisture content for grains is at 6%. The sesame hulls are then split apart by hand onto tarps to be collected and bagged. Maize and wheat will be spread on tarps on the ground and raked until ideal moisture content is met for the offtaker. Inputs are listed in **table 3** in the appendix. Glyphosate and urea are used as herbicide and fertilizers, and sesame, wheat, and yellow maize seed are the key inputs in this system. When broadcast, sesame requires 4 kg/ha of seed, wheat at ~10 kg/ha, and maize at ~25 kg/ha. Approximately 1 MT of granular fertilizer may be used per hectare before planting during the sesame and wheat seasons, with the rate increasing to 2 MT/ha for maize. Glyphosate is applied via backpack sprayer as needed, with hand-weeding done as well to save costs. Yield estimates for this system were taken from FAO data on historical yields in the region and were calculated as follows: sesame ~350 kg/ha, wheat ~1.5 MT/ha, yellow maize ~2.5 Mt/ha. Using these yield estimates, outputs were calculated to be 7 50kg bags of sesame per year, 30 50kg bags of wheat in odd years, and 50 50kg bags of yellow maize in even years.

The improved, non-shattering sesame variety is planted in rows with 20cm spacing between rows and 40 seeds per linear meter with an estimated 50% germination rate, so 20 plants per linear meter germinated. Due to lateral branching and pod density, the yield estimates are calculated as follows: 60 pods per plant, each pod with an average of 30 seeds; 1800 seeds per plant with 1000 seeds weighing 3g, so 5.3 g seed yield per plant. With 600,000 plants per hectare, the yield potential for the crop is approximately 3,180 kg/ha. For this LUS, the assumption is that 60% of the genetic potential is reduced by unforeseen abiotic stress factors, so the yield per hectare is estimated at 1,000 kg. Some fluctuation in output is added to the LUS for each crop to reflect the variable nature of agricultural production. The genetic expression of the crop and the yield potential in Uganda's multiple agroecosystems is unknown and should be the subject of future research.

The temporal point of departure for this land use system was January 2020. This was used as a starting point to estimate price points for both the inputs and outputs. FAO and the World Bank had future price projections and were used for the estimates on maize, wheat, sesame, glyphosate, and urea. It is important to note that the wheat crop highlighted in the LUS may be replaced with other locally grown grains such as sorghum or millet. These crops are more difficult to find future price forecasting for the 10-year timespan of the LUS but for the sake of the LUS are loosely coupled with the price of wheat in Uganda. Labor price projections were made using the Ugandan minimum wage of $1.46 and were calculated to include inflation over the 10 years. The value for a rented tractor and the machine-hours required on a per-acre basis were calculated based on a report from the UKAID project for Commercial Agriculture for Smallholders and Agribusiness, with the rental rate found to be roughly $17 per machine-hour (UKAID 2020). Hand tools were estimated to last two years before needing replacement. On-farm processing was a fairly high cost, mostly due to the requirements for the sesame, namely the construction of the drying racks, and manual opening of the pods to harvest the grains. This whole process was estimated to be $40 per hectare per year. Full cost outline for this LUS is found in **appendix 1**. Data that could improve the LUS analysis would include household size and age data, crop rotations, labor estimates per activity, and agronomic performance data for the crops listed. These data were meant to be collected for the purpose of this feasibility study, but due to travel restrictions due to the COVID-19 pandemic, field studies and household surveys could not be conducted.

4.1 Agronomic and Economic Risk

In order to get a realistic evaluation of both land use systems, three sources of risk were introduced. The first is a learning curve for the adoption of the Smarter Sesame variety. This is introduced by reducing the output of Smarter Sesame to 500 kg/ha (10 bags of 50 kg) for the first year, 750 kg/ha (15 bags) for year 2, with the full output of 1000 kg/ha (20 bags) by year 3. This reduction and eventual gain in production represents the changes in production practices from the traditionally broadcasted sesame to the Smarter Sesame, which involves planting in rows. The improved sesame variety also has an earlier flowering period compared to traditional varieties in Uganda, flowering at roughly 30 days after planting compared to 50 days after planting traditionally. This represents a significant shift in cultural practices, as sesame farmers in the region are used to weeding at 40 days after planting, prior to the flowering period of the traditional variety. The flowers that form on sesame are delicate and are susceptible to falling off if physically disturbed, so any farmer that is weeding during the flowering period of the Smarter Sesame will see flowers dropping and a reduction in their overall yield. These two shifts in cultural practices will take time for farmers to adapt to, hence the learning curve in the first three years of the Smarter Sesame output.

The second risk factor is an abiotic stress event to the second season crop resulting in 100% yield loss on both the traditional and improved sesame varieties on year 5, with a 50% reduction of yield for the wheat crop of the same year. This could represent a period of heavy rainfall in which the yield for the wheat is reduced due to untimely rains prior to harvest, with heavy rains following the planting of the sesame crop. The cost of mechanized harvest has been reduced for the Smarter Sesame for this year, as there is no crop to harvest. Labor costs for harvest of the traditional sesame have also been reduced for this year.

The third is global price shock to the markets for sesame, wheat, and maize that results in a 60% price reduction to the farmgate price for all goods produced in year 8. The farmgate price for sesame in year 8 is set to \$0.51/kg, with maize set to \$0.09/kg. The price recovers 50% in year 9, with a sesame farmgate price at \$0.80/kg, and wheat at \$0.11/kg. In year 10, prices have stabilized to pre-crash levels, with sesame at \$1.09/kg and maize at \$0.19/kg.

Some of the outputs highlighting economic performance are found below on **table 2**. Interestingly, even with high costs of production for sesame, the overall LUS has a positive Net-Present Value (NPV), which is an economic indicator that translates the potential future returns of the system into today's dollars

(Gallo 2014). The bi-modal rainfed system allows for high outputs over the course of a year with no irrigation requirements, which means SHFs can grow two full crops per year with no need for irrigation. That combined with an extremely low cost of unskilled labor makes the overall system profitable over the 10-year period. Two key factors contributing to the lower net-present value are the discount rate, which was estimated at the Ugandan lending rate of 22%, and the high taxes of 30% for the Ugandan farmer. Even with high lending rates and high taxes, the returns to labor, or the family's potential wage rate while working on the farm are 1.5:1 compared to the Ugandan minimum wage of $1.46 USD (Mywage.ug 2021), which means that a family member can make more money working on the farm than they can with a minimum wage job. This helps to explain why 71.2% of Ugandans are involved with agriculture, and over 900,000 smallholder farmers are actively growing cereals and oil crops in this country (LTS International 2017). However, by looking at the years with introduced agronomic and economic shocks, it is apparent that abiotic stress factors and global commodity price are areas of significant risk for SHFs growing traditional varieties. Comparisons to the Smarter Sesame and risk analysis are conducted in section 4.3 below.

4.2 Outputs of Traditional Sesame Variety Rotation

Outputs		Year 1	Year 2	Year 3	Year 4	Year 5*	Year 6	Year 7	Year 8**	Year 9***	Year 10	Total
Total Simsim Produced	50 kg bags	**7**	**8**	**6**	**7**	**0**	**7**	**6**	**8**	**7**	**7**	**63**
Total Maize Produced	50 kg bags	**0**	**50**	**0**	**49**	**0**	**51**	**0**	**48**	**0**	**49**	**247**
Total Wheat Produced	50 kg bags	**30**	**0**	**28**	**0**	**15**	**0**	**29**	**0**	**27**	**0**	**129**
Total Simsim Value	**USD ($)**	$320.95	$373.60	$285.60	$339.50	$0.00	$352.45	$307.80	$205.20	$280.00	$380.10	$2,845.20
Total Maize Value	**USD ($)**	$0.00	$442.50	$0.00	$443.45	$0.00	$469.20	$0.00	$222.00	$0.00	$470.40	$2,047.55
Total Wheat Value	**USD ($)**	$304.50	$0.00	$289.80	$0.00	$157.50	$0.00	$310.30	$0.00	$147.15	$0.00	$1,209.25
Total Output Value	**USD ($)**	$625.45	$816.10	$575.40	$782.95	$157.50	$821.65	$618.10	$427.20	$427.15	$850.50	$6,102.00
Net Revenue	**USD ($)**	$147.46	$284.82	$188.99	$248.56	-$232.75	$284.01	$223.71	-$113.95	$28.30	$305.59	$1,364.74
Net Profits After Tax @30%	**USD ($)**	$113.43	$219.09	$145.38	$191.20	-$179.04	$218.47	$172.08	-$87.65	$21.77	$235.07	$1,049.80
NPV	**USD ($)**	$15.53	$29.99	$19.90	$26.18	-$24.51	$29.91	$23.56	-$12.00	$2.98	$32.18	$143.72
Average Annual Returns to Land	**USD ($)**	$1.55	$0.96	$0.64	$0.84	-$0.78	$0.96	$0.75	-$0.38	$0.10	$1.03	$7.19
Returns to Family Labor												1.5 : 1

Table 4: Outputs of Traditional Grain Cash Crop Rotation

*Year 5: 100% yield reduction for sesame due to abiotic stress factors, 50% reduced for wheat crop
**Year 8: Global commodity price shock, sesame sold for $0.51/kg, maize at $0.09/kg
***Year 9: Slight recover in pricing, sesame price of $0.80/kg, wheat price at $$0.11/kg

However, by looking at the years with introduced agronomic and economic shocks, it is apparent that abiotic stress factors and global commodity price are areas of significant risk for SHFs growing traditional varieties. Comparisons to the Smarter Sesame and risk analysis are conducted in section 4.3 below.

4.3 Outputs of Smarter Sesame Variety

Outputs		Year 1*	Year 2*	Year 3*	Year 4	Year 5 **	Year 6	Year 7	Year 8***	Year 9****	Year 10	Total
Total Simsim Produced	50 kg bags	**9**	**14**	**20**	**21**	**0**	**20**	**21**	**19**	**18**	**20**	**162**
Total Maize Produced	50 kg bags	**0**	**50**	**0**	**49**	**0**	**51**	**0**	**48**	**0**	**49**	**247**
Total Wheat Produced	50 kg bags	**30**	**0**	**28**	**0**	**15**	**0**	**29**	**0**	**27**	**0**	**129**
Total Simsim Value	**USD ($)**	$412.65	$653.80	$1,018.50	$970.00	$0.00	$1,007.00	$1,077.30	$487.35	$720.00	$1,086.00	$7,414.60
Total Maize Value	**USD ($)**	$0.00	$442.50	$443.45	$443.45	$0.00	$469.20	$0.00	$222.00	$0.00	$470.40	$2,047.55
Total Wheat Value	**USD ($)**	$304.50	$0.00	$0.00	$0.00	$157.50	$0.00	$310.30	$0.00	$147.15	$0.00	$1,209.25
Total Output Value	**USD ($)**	$717.15	$1,096.30	$1,461.95	$1,413.45	$157.50	$1,476.20	$1,387.60	$709.35	$867.15	$1,556.40	$10,671.40
Net Revenue	**USD ($)**	$104.52	$430.62	$794.28	$745.78	-$287.51	$806.36	$861.57	$37.12	$337.78	$881.57	$4,687.90
Net Profits After Tax @30%	**USD ($)**	$80.40	$331.25	$610.98	$573.68	-$221.16	$620.28	$662.75	$28.55	$259.83	$678.13	$3,606.08
NPV	**USD ($)**	$11.01	$45.35	$83.64	$78.54	-$30.28	$84.92	$90.73	$3.91	$35.57	$92.84	$493.67
Average Annual Returns to Land	**USD ($)**											$24.68
Returns to Family Labor	**USD ($)**											11:1

Table 5: Outputs of Smarter Sesame provided by Equinom and Ag-Ploutos.

*Year 1, 2, and 3: Adoption curve for sesame crop, 50%, 75%, 100% crop potential per year, respectively.
**Year 5: 100% yield reduction due to abiotic stress factors, 50% reduced for wheat crop
***Year 8: Global commodity price shock, sesame sold for $0.51/kg, maize at $0.09/kg
****Year 9: Slight recover in pricing, sesame price of $0.80/kg, wheat price at $$0.11/kg

Cost outlines for both varieties are found in **appendix 2 and 3**.

The costs of the Smarter Sesame variety are significantly higher compared to traditional sesame varieties that are either purchased for low cost or saved from previous seasons. Adding to the costs of production is the increased costs for mechanized harvesters, which are rented from local service providers or larger farms in the surrounding area. These harvesters take 4 machine hours per hectare per year for the harvesting of the sesame. This cost is slightly offset by the savings in hired labor for manual harvesting and drying rack construction, which takes 16 person-days per hectare. Family (predominantly women) labor is saved in the manual splitting of sesame hulls to extract seeds after drying, which is traditionally done for local varieties, as well as the rack construction and hanging of the sesame for drying. The combine harvesters used for small grains will do this automatically throughout the course of harvesting the fields and will save approximately 3 days of labor for the hull splitting and seed collection, and 8 days of labor on the rack construction and hanging of sesame. In total, the Smarter Sesame variety saves 11 days of family labor and 24 days of hired labor per hectare per year.

The risk factors added in the Smarter Sesame LUS highlight some interesting strengths and weaknesses of the new variety compared to the traditional sesame. First, the learning curve beginning in year 1 could present a challenge to traditional sesame farmers. The lower output due to the changes in cultural practices combined with the increased cost of seed and mechanical harvesters results in a slightly lower NPV compared to traditional sesame farmers. This could mean that farmers may be hesitant to change varieties until additional agronomic studies have been conducted on the variety performance and extension services have been developed based on lessons learned through these agronomic studies.

The crop failure introduced in year 5 represents another challenge that may hinder adoption of Smarter Sesame. The increased cost of seed and the lack of revenue generated leads to a significant loss in the event of a bad year. This loss of revenue is greater than the traditional varieties due to the up-front investment associated with the Smarter Sesame and highlights the importance of crop insurance systems to be put into place to commercialize sesame production with Smarter Sesame in Uganda. Risk-averse SHFs may be hesitant to incorporate the Smarter Sesame into their rotations without some form of insurance policy in place with the purchase of the seeds.

The economic risk implemented in years 8 and 9 in the form of a price shock show a potential resilience to price fluctuations from the Smarter Sesame. The traditional variety LUS shows profitability turning negative when the price for sesame drops significantly, while the Smarter Sesame maintains a positive albeit lower NPV for both years. There is a possibility that planting Smarter Sesame could reduce vulnerability to economic risk factors for growers that are planting traditional sesame currently. Farmers concerned with global economic risks may be more interested in the Smarter Sesame variety and may have a higher adoption rate compared to those who have limited exposure to global market forces and are selling their sesame to local retail markets. This could also mean a higher adoption rate for medium to large sized commercial farming operations for Smarter Sesame compared to the SHF adoption rate.

5 Barriers to Smarter Sesame Production

With the economic data and questions raised in Section 4, Section 5 hopes to analyze the limiting factors regarding the expansion of the Smarter Sesame variety and the barriers to adoption from the perspective of the SHF as well as the seed companies producing and distributing the variety in Uganda. The systematic barriers to increased sesame production in Uganda were well outlined by Wacal et al. and are highlighted below in **figure 1**:

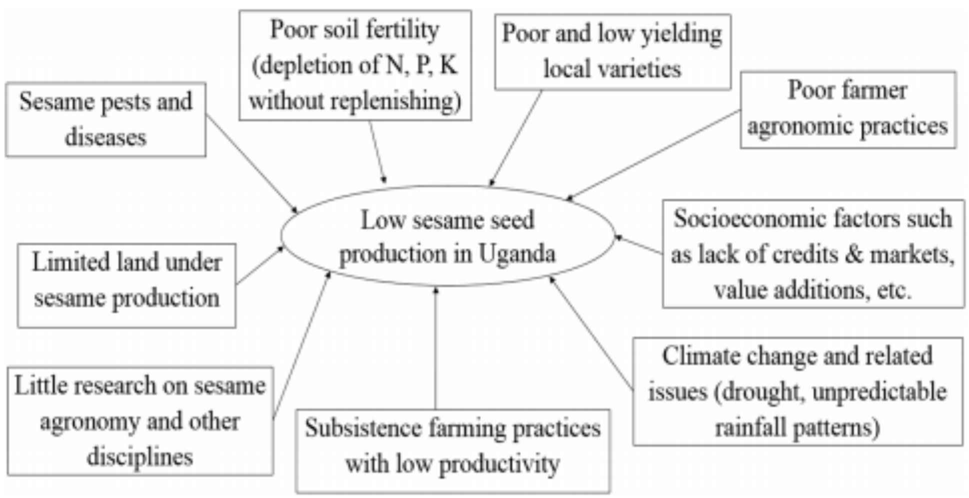

Figure 1: Wacal et al. Barriers to Sesame production

Many of these points have been touched on in the production constraints above, such as the lack of agronomic research, low fertility, low yielding varieties, and insect and disease pressure. However, these barriers should be addressed within the context of the Smarter Sesame variety.

To first address the lack of agronomic research surrounding this variety, and more generally for other newly introduced crop varieties, an adjustment of policy from the Ministry of Agriculture in Uganda regarding registration testing could be made. According to the Plant Breeders Protection Act (2014), testing of new varieties in Uganda requires at least two seasons of field tests with the National Agricultural Research Organization (NARO) to establish if the variety is properly expressing unique, identifiable traits. However, these two seasons of data are not released to the public nor to the company registering the variety, and it is unclear whether extension agents working for NARO are able to include these data in their educational modules. So, potentially reducing factors in the production of the new variety cannot be identified by the company responsible for the variety's registration and distribution, nor by extension agents educating growers on how to properly grow the variety. While these registration trials are ongoing with NARO, field trials of the variety cannot begin anywhere else in the country, which increases the amount of time a grower must wait to incorporate an improved variety into their crop rotation, as well as the time to identify production problems and develop solutions to overcome reducing and limiting factors with the production of a new crop variety. The release of this information by the Ministry of Agriculture would cut down the research and development time by at least one year and help get this information into the hands of growers and extension agents more quickly.

Nutrient loss and mineral offtake by sesame has been recently studied in order to better understand the nutritional requirements of higher-yielding sesame varieties (Langham et al. 2020). Langham reports that per sesame crop that yields 1000 kg/ha of grains, the nutrients lost from the field amount to: 99 kg N, 18 kg P, 98 kg K, and 9kg S. The leaf residues can be reincorporated into the field. The continuous removal of these nutrients and the lack of replacement of them by conventional fertilizers or organic sources will eventually lead to a decline in soil fertility that needs to be addressed (Wacal et al. 2019). Finger millet husks have been found to be an adequate source of N and P to improve sesame growth and could be readily available in the Ugandan countryside (Anguria et al. 2017). This combined with potential nutrient availability from poultry manures have been found to be effective in nutrient replenishment to maintain soil fertility through sesame crop rotations, but current use of improper fertilizers or no fertilizers will lead to an eventual decrease in soil fertility and subsequently the yield of sesame (Anguria et al. 2017, Wacal et al. 2021).

If the Smarter Sesame variety can raise output and tolerate local pests, then the key barriers to adoption of this technology would be the socioeconomic factors of the increased up-front cost of the variety and the market access to the export market for higher price points compared to the local simsim varieties traded through local aggregators. Robert Anyang, CEO of Ag Ploutos Co., had this to say regarding grower adoption rates of non-shattering sesame varieties in Uganda:

> The non-shattering variety is a game changer in the simsim production and marketing in Uganda. Farmers can't go wrong. There are double benefits to farmers in terms of reduction of the amount of labor in post -harvest handling and the increase in income as

> a result of reduction in postharvest loss and variety performance. We should not forget the reduction in environmental damage, as farmers do not have to cut trees anymore during postharvest [for drying rack construction], as the variety can be mechanical harvested or manually harvested on the fields. Some barriers to adoption we have encountered in last year include farmers understanding of the agronomy of the new variety and the access to finance and mechanization tools, such as planters and combines. These are issues we have to address to increase the adoption of the non-shattering sesame variety (Anyang 2021).

This aligns well with the identified constraints to sesame production outlined above. The lack of credit access to make a significant investment in the improved variety is a significant hurdle to overcome for smallholder growers in this region, as are the constraints surrounding mechanization access. Comparing the LUS systems, the growers that are utilizing the traditional varieties and farming methods will have a significant cash flow constraint if they try to switch to non-shattering sesame production. The combined cost for seed ($90/ha) and increased machinery rental for harvest ($68) would require 75-80% of the annual on-farm profits, leaving little income from farming activities. Without flexible payment terms or access to microfinance loans, the cost barrier of this improved technology and the required changes in agronomic practices may prevent the adoption of the Smarter Sesame variety.

One of the key assumptions with the LUS is the availability of mechanization services to access the land for sesame harvest. This is due to the location of the farm chosen for the LUS being near an infrastructure hub, namely the town of Gulu. This facilitates the logistics of the tractor delivery to the farm and allows the LUS to proceed under the assumption that the mechanization services will be on time, available, and functional. These assumptions may not hold true as the selected farm area increases in distance from the logistical hubs where tractor services are available, especially in historically poor agricultural regions such as Karamoja (UNPFA 2018, USAID 2017). The use of mobile threshing units has been considered to facilitate the post-harvest handling and collection of grains from sesame pods, but typically these large-capacity threshers are inappropriate for the SHF or SME level sesame producer (Kailashkumar 2019). Multi-purpose mobile threshers in the hands of trained service providers may provide one solution if these single axis threshers could easily be moved from farm to farm in sesame production zones. Thresher testing with cost-benefit studies would have merit in areas where grain combines are not established or available. The development of mobile threshers has been focused on more commonly grown crops such as maize, soybean, wheat, and rice (Patil et al. 2007), However, there has been a recent shift to include small grains in the focus for postharvest processing equipment development, but more work is needed to design implements specifically for SHF use for sesame production (Kumar et al. 2013, Singh et al. 2015). The lack of locally available threshers, tractors, and combine harvesters suitable for use by SHF and SME's severely limits the scalability of the non-shattering sesame variety across a large portion of the arable land in Uganda. However, if the sesame production and market value chain improve to the point where more widespread use of these technologies is needed, then entrepreneurial links can be made for importation or local production of mobile threshers or small-grain combines, as their use is more widespread in China, India, and Brazil (GAP OPENS 2019).

6 Gender Impacts

The impact of the Smarter Sesame variety with respect to gender equity and workload allocation is unknown but can be estimated based on current workload allocation of sesame and estimated labor savings. Using the above estimates generated by LTS International in 2017, women's workload with regard to sesame production can be broken down as follows:

Activity	Workload percentage
Land Preparation	55%
Planting	85%
Weeding	85%
Postharvest Processing	98%

Applying this percentage breakdown to the LUS with the non-shattering sesame variety yields the following potential labor savings:

Activity	Workload Percentage	Traditional Sesame (days/year)	Improved Variety (days/year)	Women's labor savings (days/year)
Land Preparation	55%	7	7	0
Planting	85%	3	3	0
Weeding	85%	3.5	3.5	0
Postharvest Processing	98%	18	7	10.8

The primary labor-saving activity provided by the new variety is the hanging of sesame on drying racks and the splitting of the sesame pods to extract the seeds after drying, both of which would fall under the "Postharvest Processing" category as outlined by the LTS International report. These are extremely tedious tasks that are eliminated by the sesame drying in the field and the use of a combine harvester.

These tasks are said by CASA to "Compromise women's economic productivity because [the tasks reduce] the time women have available to focus on income generating activities and to participate in social interactions, networking, and community activities, and in group and training opportunities" (CASA 2020). The full effect of the labor savings on household dynamics between the men and women of the household growing the improved variety is not yet clear. It is also unclear what a woman would be able to do with the saved time, and both points merit attention as scaling expands.

An additional area of interest regarding the gender dynamics surrounding this improved sesame is the increase in value of the sesame and how that changes the ownership of the crop. With improved output and quality of the sesame being grown, the crop has significantly higher value compared to the traditional counterpart. It has been well documented that as a crop value increases, the responsibility and 'ownership' of that crop and the profit from its sale begins to shift to the husband in these smallholder households (USAID 2017, Peterman 2015, UKAID 2020,). However, in a number of interviews conducted in Mukono, Uganda, it was revealed that women have a number of renegotiation strategies that they can implement to shift the bargaining power within their households (Sahlaney 2014). One of these strategies include leveraging their status as mothers and utilizing their children to help convince the husband to allocate the profits more equitably, or to place the investments in school fees or other expenditures that benefit the entire household. Another negotiation tactic is to remind the men of the women's knowledge of production, such as the identification of a pest problem that would have otherwise destroyed the crop, making the woman responsible for the profits the crop generated afterwards (Sahlaney 2014). These renegotiation tactics could help to shift the balance of power as the introduction of new sesame varieties is implemented and could also have influence on the inclusion of women in trainings and extension services around the crop. The crop production knowledge being in women's control could help to maintain or improve gender equity as the production value of the sesame crop increases.

7 Insights and Recommendations

Given the outputs of the non-shattering variety that is outlined in this paper, the potential economic benefits of the adoption of this technology are high. However, noted in their study on improved maize variety adoption in Ghana, a potential gain in increased household income by itself is not necessarily enough to overcome barriers to adoption of such technologies (Essilfie 2018). Policy measures that increase seed technology utilization should be implemented to compliment the introduction of these technologies, such as access to credit in order to access the technology or for insurance, in case of externalities like a drought or in case the variety does not perform to theoretical expectations. Formal agronomic studies of these improved varieties need to be conducted by the agricultural research stations of the countries releasing these varieties for commercial production to affirm the genetic expression of the desired traits from these varieties, as well as documenting any challenges or changes in cultural practices with the variety cultivation. Robert Anyang, Ag-Ploutos' CEO had this to say regarding the production challenges with the Smarter Sesame:

> Traditionally farmers planting the local varieties used 8kg -10kg/acre of seed during planting to suppress weed infestation, 8 times more than the seed rate recommended for Smarter sesame (0.75kg-1.2Kg), making Smarter seed susceptible to weed infestation. With no post-emergence herbicides available for sesame and the high cost of seed makes it difficult for adoption of such traditional practices with the non-shattering sesame seed.

The susceptibility of weed pressure was an unforeseen consequence of the switch to Smarter Sesame, as traditional sesame crops were broadcasted at higher rates and were able to sufficiently suppress weeds (Wacal et al. 2021). According to Robert Anyang in 2021, the initial planting of the Smarter Sesame into rows was new to the region, and the recommended row spacing had started at 30 cm, which unfortunately allowed for *Bidens Pilosa,* a weed commonly referred to as Blackjack, to grow easily in the wide rows. The row spacing was then closed to 15cm to help the sesame compete against this unforeseen weed pressure. Coordination with field stations of the Ministry of Agriculture may have been able to anticipate this consequence, however the current policy does not allow the disclosure of experimental data, however relevant it may be for field production of new crop varieties. Tweaking this policy to allow the disclosure of government field data or allowing certified third-party research organizations to conduct research in parallel to the experimental trials for registration of a new crop variety could be beneficial to the seed sector of Uganda and allow for more rapid introduction of improved crop varieties to the country. The agronomic data of the Smarter Sesame variety is also necessary to increase the likelihood of insurance companies approving sesame-producing households for crop insurance. Inclusion of crop insurance may be a necessary component to increase adoption among smallholder farm families as the risk-return of Smarter Sesame may not favor these risk-averse households.

The adoption of labor-saving technologies is a critical issue for farmers globally, especially in high- or rising-income countries with a diminishing labor pool. As the availability of rural labor decreases, and the rise of manufacturing jobs increases, traditional growing methods will no longer be cost-effective as rural wage rates will see an upward trend. The Lewis model of development states that eventually both factories and farms will have to pay higher wages to attract workers, leading to competition between the agricultural and manufacturing sectors (Lewis 1954). The intersection of the marginal value product of labor will dictate the higher wage once the labor abundance has been diminished. Labor intensive crops such as traditionally grown sesame will likely fall out of favor of smallholder farmers as crops with lower labor requirements begin to dominate the market. However, Lewis also noted that the traditional agronomy sector suffers from geographical polarization due to the development process, as the best pay and demand for skilled/educated labor is with the manufacturing/urban sector as it develops, leaving the rural sector in poverty even with wage rate hikes after the intersection point (Kirkpatrick et al. 2004). With Lewis' traditional economic development model, nations with transition from low-productivity agricultural to high-productivity manufacturing over time. The introduction of high-production varieties of crops and agricultural technologies and their effect labor flows have not been adequately studied in Uganda, but what has been noted by Baymul and Sen are complications with the Lewis model more generally: the shift of workers as a country develops generally goes to service jobs, not to manufacturing, and that some countries undergo a 'premature deindustrialization' of their manufacturing sector (Baymul and Sen 2017). Given the difficulties in export from Uganda due to infrastructure and geospatial challenges, an interesting question arises from the shift to high-value agricultural products and their effect on the labor flows in Uganda and other developing countries: Would agriculture become a more attractive business prospect and source of employment than the service or manufacturing sector? And should agricultural intensification take priority over industrialization with regard to policy and development projects for long-run growth? The top ten exports of Uganda in 2020 are all agricultural goods, so it is entirely possible that a competitive advantage exists for the agricultural sector in Uganda compared to the manufacturing sector, and that value addition for the agricultural goods could have a higher impact in total factor productivity compared to improvements in the manufacturing sector (World Top Exports 2020).

The numerous systematic changes involved with the adoption of non-shattering sesame represent challenges and opportunities for farmers. The challenges go beyond just the financial constraints that smallholder farmers may face and require an enabling environment from the public and private sector. Policies that allow for more rapid dissemination of information and easy access to financial lending services would be a crucial piece that would mitigate constraints for the entire agricultural sector of Uganda. Smallholders that could access loans could invest in improved seeds and inputs to increase their productivity and on-farm incomes, allowing for more time to be spent off-farm for those who would prefer to get out of agriculture, or perhaps lead to opportunities to acquire more land for those that want to scale up. The transformation out of subsistence agriculture is key to enhancing rural livelihoods and innovations like the Smarter Sesame variety can help make that prospect more attainable and attractive to the next generation of farmers. By decreasing labor load and increasing farm profitability, agribusiness can be presented as an attractive business opportunity rather than a drudgerous fallback plan for youth. The Smarter Sesame can be used as an attractive opportunity that can help to overcome the other barriers to adoption that this report has outlined and provide a reason to scale up the mechanization of the agricultural sector, increase the use of fertilizers and other inputs, increase use of and accessibility to extension services, distribute household workloads more equitably, and transform from subsistence agriculture to a productive commercial agricultural sector. Success with the introduction of Smarter Sesame is on the horizon and can open the door for the other improved technologies to be introduced to Uganda and more easily adopted with the changes in production practices. The adoption of non-shattering sesame in Uganda represents a significant opportunity for rural enterprises with social as well as economic capital gains, and the lessons learnt from the adoption of Smarter Sesame can pave the way for the next generation of farmers in Sub-Saharan Africa.

Appendix

Appendix 2: Traditional Sesame LUS Cost

Inputs	Units	Year One	Year Two	Year Three	Year Four	Year Five	Year Six	Year Seven	Year Eight	Year Nine	Year Ten	Totals
Land Preparation												
Land clearing	Person-days/ha	0.5	0	0	0	0	0	0	0	0	0	0.5
Axe	Quantity	1	0	1	0	1	0	1	0	1	0	5
Plowing (rented)	Machine-hours/ha	3	3	3	3	3	3	3	3	3	3	30
Fertilizer/lime spreading	Person-days/ha	4	3	4	3	4	3	4	3	4	3	35
Crop Management												
Maize Seed	Kilograms/ha	40	0	40	0	40	0	40	0	40	0	200
Sesame Seed	Kilograms/ha	4	4	4	4	4	4	4	4	4	4	40
Wheat Seed	Kilograms/ha	0	6.5	0	6.5	0	6.5	0	6.5	0	6.5	32.5
Planting	Person-days/ha	6	6	6	6	6	6	6	6	6	6	60
Herbicide	Liters/hectare	4	4	4	4	4	4	4	4	4	4	40
20 L Backpack sprayer	Quantity	1	0	1	0	1	0	1	0	1	0	5
Application Herbicide	Person-days/ha	4	4	4	4	4	4	4	4	4	4	40
Mineral Fertilizers	MT/ha	1	2.5	1	3	2	3	2	3	2	3	22.5
Application Fertilizer	Person-days/ha	2	1.5	2	2	2	2	2	2	2	2	19.5
Hoe or Shovel	Quantity	1	0	1	0	1	0	1	0	1	0	5
Manual Weeding	Person-days/ha	3.5	3.5	3.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	28
Harvest and Postharvest												
Harvesting (Hand)	Person-days/ha	16	16	16	16	16	16	16	16	16	16	160
Harvesting (Rented Combine)	Machine hours/ha	2	2	2	2	2	2	2	2	2	2	20
Drying	Person-days/ha	10	10	10	10	10	10	10	10	10	10	100
Rakes	Quantity	1	1	1	1	1	1	1	1	1	1	10
Tarps	Quantity	5	5	5	5	5	5	5	5	5	5	50
Bags	Quantity	37	57	37	57	37	57	37	57	37	57	470
Cleaning/Bagging	Person-days/ha	8	8	8	8	8	8	8	8	8	8	80
Storage	SQFT	556	556	556	556	556	556	556	556	556	556	556
Marketing	Person-days	2	2	2	2	2	2	2	2	2	2	20
Transport	Person-days	5	5	5	5	5	5	5	5	5	5	50

Total Hired Labor requirements	Person-days	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	265
Total Family labor requirements	Person-days	44.5	43	44.5	43	44.5	43	44.5	43	44.5	43	437.5
Total Labor requirements	Person-days	71	69.5	71	69.5	71	69.5	71	69.5	71	69.5	702.5
Simsim Seed Required	Kilograms/ha	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	40
Maize Seed Required	Kilograms/ha	**0**	40	0	40	0	40	0	40	0	40	20
Wheat Seed Required	Kilograms/ha	10	0	10	0	10	0	10	0	10	0	50
Total Fertilizer Requirements	MT/ha	**1**	2.5	1	2.5	1	2.5	1	2.5	1	2.5	17.5
Total Herbicide Requirements	Liters/hectare	4	4	4	4	4	4	4	4	4	4	40
Total Storage Requirements	SQFT	**556**	300	556	300	556	300	556	300	556	300	**556**
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Total**
Prices												
Land Costs	USD	$125.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$395.00
Total Tool Costs	USD	$23.00	$0.00	$23.00	$0.00	$23.00	$0.00	$23.00	$0.00	$23.00	$0.00	$110.50
Total Machine costs (rented)	USD	$85.00	$85.00	$85.00	$85.00	$85.00	$85.00	$85.00	$85.00	$85.00	$85.00	$850.00
Total Labor costs (hired)	USD	$32.85	$32.85	$32.85	$32.85	$0.00	$32.85	$32.85	$32.85	$32.85	$32.85	$386.90
Total Simsim Seed Costs	USD	$23.36	$23.60	$24.20	$24.72	$25.24	$25.80	$26.36	$26.92	$27.48	$28.08	$255.76
Total Maize Seed Costs	USD	$0.00	$13.96	$0.00	$15.56	$0.00	$17.32	$0.00	$19.28	$0.00	$21.44	$87.56
Total Wheat Seed Costs	USD	$21.60	$0.00	$23.80	$0.00	$26.20	$0.00	$28.80	$0.00	$31.70	$0.00	$132.10
Total Fertilizer Costs	USD	$119.00	$297.50	$119.00	$297.50	$119.00	$297.50	$119.00	$297.50	$119.00	$297.50	$2,082.50
Total Herbicide Costs	USD	$8.18	$8.37	$8.56	$8.76	$8.96	$9.17	$9.38	$9.60	$9.82	$10.04	$320.00
Total Storage Requirements	USD	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$400.00
Total Input costs	**USD**	$477.99	$531.28	$386.41	$534.39	$357.40	$537.64	$394.39	$541.15	$398.85	$544.91	$4,704.41

Appendix 3: Non-shattering Sesame Variety LUS Costs

Inputs	Units	Year One	Year Two	Year Three	Year Four	Year Five	Year Six	Year Seven	Year Eight	Year Nine	Year Ten	Totals
Land Preparation												
Land clearing	Person-days/ha	0.5	0	0	0	0	0	0	0	0	0	0.5
Axe	Quantity	1	0	1	0	1	0	1	0	1	0	5
Plowing (rented)	Machine-hours/ha	3	3	3	3	3	3	3	3	3	3	30
Fertilizer/lime spreading	Person-days/ha	4	3	4	3	4	3	4	3	4	3	35
Crop Management												
Maize Seed	Kilograms/ha	40	0	40	0	40	0	40	0	40	0	200
Sesame Seed	Kilograms/ha	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	25
Wheat Seed	Kilograms/ha	0	6.5	0	6.5	0	6.5	0	6.5	0	6.5	32.5
Planting	Person-days/ha	6	6	6	6	6	6	6	6	6	6	60
Herbicide	Liters/hectare	4	4	4	4	4	4	4	4	4	4	40
20 L Backpack sprayer	Quantity	1	0	1	0	1	0	1	0	1	0	5
Application Hebicide	Person-days/ha	4	4	4	4	4	4	4	4	4	4	40
Mineral Fertilizers	MT/ha	1	2.5	1	3	2	3	2	3	2	3	22.5
Application Fertilizer	Person-days/ha	2	1.5	2	2	2	2	2	2	2	2	19.5
Hoe or Shovel	Quantity	1	0	1	0	1	0	1	0	1	0	5
Manual Weeding	Person-days/ha	3.5	3.5	3.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	28
Harvest and Postharvest												
Harvesting (Hand)	Person-days/ha	0	0	0	0	0	0	0	0	0	0	0
Harvesting (Rented Combine)	Machine hours/ha	6	6	6	6	6	6	6	6	6	6	60
Drying	Person-days/ha	2	2	2	2	2	2	2	2	2	2	20
Rakes	Quantity	1	1	1	1	1	1	1	1	1	1	10
Tarps	Quantity	5	5	5	5	5	5	5	5	5	5	50
Bags	Quantity	50	70	50	70	50	70	50	70	50	70	600
Cleaning/Bagging	Person-days/ha	5	5	5	5	5	5	5	5	5	5	50
Storage	SQFT	556	556	556	556	556	556	556	556	556	556	556
Marketing	Person-days	2	2	2	2	2	2	2	2	2	2	20
Transport	Person-days	5	5	5	5	5	5	5	5	5	5	50
Total Hired Labor requirements	Person-days	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	25

Total Family labor requirements	Person-days	33.5	32	33.5	32	33.5	32	33.5	32	33.5	32	327.5
Total Labor requirements	Person-days	36	34.5	36	34.5	36	34.5	36	34.5	36	34.5	352.5
Simsim Seed Required	Kilograms/ha	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	25
Maize Seed Required	Kilograms/ha	**0**	4	0	4	0	4	0	4	0	4	20
Wheat Seed Required	Kilograms/ha	10	0	10	0	10	0	10	0	10	0	50
Total Fertilizer Requirements	MT/ha	**1**	2.5	1	2.5	1	2.5	1	2.5	1	2.5	17.5
Total Herbicide Requirements	Liters/hectare	4	4	4	4	4	4	4	4	4	4	40
Total Storage Requirements	SQFT	**556**	300	556	300	556	300	556	300	556	300	**556**
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Total**
Prices												
Land Costs	USD	$125.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$395.00
Total Tool Costs	USD	$23.00	$0.00	$23.00	$0.00	$23.00	$0.00	$23.00	$0.00	$23.00	$0.00	$130.00
Total Machine costs (rented)	USD	$153.00	$153.00	$153.00	$153.00	$75.00	$153.00	$153.00	$153.00	$153.00	$153.00	$1,530.00
Total Labor costs (hired)	USD	$32.85	$32.85	$32.85	$32.85	$32.85	$32.85	$32.85	$32.85	$32.85	$32.85	$36.50
Total Simsim Seed Costs	USD	$90.00	$90.00	$90.00	$90.00	$90.00	$90.00	$90.00	$90.00	$90.00	$90.00	$900.00
Total Maize Seed Costs	USD	$0.00	$13.96	$0.00	$15.56	$0.00	$17.32	$0.00	$19.28	$0.00	$21.44	$87.56
Total Wheat Seed Costs	USD	$21.60	$0.00	$23.80	$0.00	$26.20	$0.00	$28.80	$0.00	$31.70	$0.00	$132.10
Total Fertilizer Costs	USD	$119.00	$297.50	$119.00	$297.50	$119.00	$297.50	$119.00	$297.50	$119.00	$297.50	$2,082.50
Total Herbicide Costs	USD	$8.18	$8.37	$8.56	$8.76	$8.96	$9.17	$9.38	$9.60	$9.82	$10.04	$320.00
Total Storage Requirements	USD	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$400.00
Total Input costs	**USD**	$612.63	$665.68	$520.21	$667.67	$445.01	$669.84	$526.03	$672.23	$529.37	$674.83	$5,983.50

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