# Determinants of Postharvest Losses along Smallholder Producers Maize and Sweetpotato Value Chains: An Ordered Probit Analysis

Apurba Shee*(Natural Resources Institute, University of Greenwich, UK, a.shee@gre.ac.uk)

Sarah Mayanja (International Potato Center (CIP), Uganda, S.Mayanja@cgiar.org)

Eria Simba (National Agricultural Research Organisation (NARO), Uganda eriasimba@gmail.com)

Tanya Stathers (Natural Resources Institute, University of Greenwich, UK, T.E.Stathers@greenwich.ac.uk)

Aurelie Bechoff (Natural Resources Institute, University of Greenwich, UK, A.Bechoff@greenwich.ac.uk)

Ben Bennett (Natural Resources Institute, University of Greenwich, UK, Ben.Bennett@greenwich.ac.uk)

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***Contact Author:**

Apurba Shee
Business Development Economist, Natural Resources Institute, University of Greenwich, UK
a.shee@gre.ac.uk

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## 1. Introduction

Postharvest loss of food crops is a global challenge to attainment of the sustainable development goals such as zero hunger and responsible consumption and production. Reduction of postharvest food loss is important for sustainably improving food and nutrition security. In Sub-Saharan Africa (SSA), postharvest loss is particularly important because not only is agricultural productivity low, but about 374 million people experience severe food insecurity (FAO et al., 2018). There is a renewed international attention to reducing postharvest food losses following the African Union member states and United Nations pledging to halve food losses by 2025 and 2030, respectively. Overall, food losses can be measured in quantitative and qualitative terms although most of the research to date has focused on quantitative measure (Sheahan and Barrett, 2017). Quantitative losses occur when the actual physical amount of food reduces over time and space, while qualitative losses occur through the loss of nutrients, viability, visual aesthetic appeal or breakage or contamination of food amongst other factors (Sheahan and Barrett, 2017). Large amounts of foods are physically lost at different stages as food commodities move across their value chains. According to the Food and Agriculture Organization (FAO) of the United Nations, each year about one-third of all food produced for human consumption is lost world-wide[1]. In SSA, the physical loss of food has been approximately estimated as 37% or 120-170 kg per year per capita (FAO, 2011). The World Bank et al. (2011) estimate the value of postharvest loss per year in SSA for all grains to be about $4 billion, which is more than the value of food aid received in SSA over last decade. The volume and value of these postharvest loss estimates are alarming highlighting the urgency to better understand and reduce postharvest food losses.

[1] http://www.fao.org/platform-food-loss-waste/food-loss/definition/en/

The magnitude of farm-level postharvest quantitative losses reported in the literature vary widely. The African Postharvest Losses Information System (APHLIS) www.aphlis.net uses locally-contextualised science-based estimates of the losses occurring at each postharvest stage, estimating that maize postharvest dry weight losses in Uganda from 2008 - 2016 ranged from 17.2 to 23.8 %, equating to an annual national loss of between 320,000 and 465,000 tonnes of maize (APHLIS, 2018). By maize postharvest stage, APHLIS estimates harvesting losses of 6.4 - 16.4 % occurred in Uganda during this period, with a further 4.0 % during further drying, 1.3 % during shelling, 2.4 % during transport to farm, and 1.2 – 5.9 % during five to eight months of farm-level storage (APHLIS, 2018). A recent study of maize postharvest losses in Apac and Lira districts of northern Uganda, reported estimates (based on a combination of measurements and farmers' perceptions) of quantitative losses of 1.9-4.7% at harvesting due to spillage, 3% at drying, 4% during threshing, 10% during on-farm storage (plus up to 50% qualitative loss due to the presence of aflatoxin levels >10ppb), 5% at milling (FAO, IFAD, WFP, forthcoming 2019). While a postharvest loss perceptions survey with focus groups of farmers in Uganda in 2013, did not report perceived levels of loss by postharvest activity stage, but identified the perceived major loss-causing factors for maize as spillage, pests (weevils, moulds and rodents), theft, high moisture content (inherent or wetting), poor quality (discolouration, broken grains); and for sweetpotato and cassava as bruises, breakages, theft, vermin and rodents (AGRA, 2014). The FAO (2011) Global Food Loss and Food Waste study similarly estimates cereal losses across SSA of about 6 % during harvesting and 8 % during the other postharvest handling and storage stages. In a comprehensive review Affognon et al. (2015) estimate the magnitude of postharvest loss in six SSA countries and report maize loss levels from 5.6 to 25.5%. Using Living Standard Measurement Survey (LSMS) data in Ethiopia, Hengsdijk and de Boer (2017) report average self-reported postharvest cereal loss to be about 24 % amongst the 10 % of households that reported any postharvest loss. In the LSMS survey, an average maize postharvest loss of between 21 and 27 % of total maize production, was reported by smallholder farmers, but it is notable that few farmers responded stating they had any postharvest loss (i.e. just 7% in Malawi, 22 % in Uganda, and <20% in Tanzania) (Hengsdjik and de Boer, 2017). However, there were a very high number of records (>88 %) with 'missing data' on self-reported postharvest cereal losses in the LSMS Malawi and Tanzania (2008/09 to 2012/13) datasets, the reason for such a high-incidence of missing data is unknown but would preclude most further analysis of the postharvest loss figures (Hengsdijk and de Boer, 2017).

Sweetpotato roots, on the other hand, are more perishable than maize, and are reported to suffer significantly higher postharvest losses than maize in SSA. The meta-analysis by Affognon et al. (2015) reports the magnitude of quantitative losses as high as 45-69% for sweetpotato. More recently, Parmar et al. (2017) report farm-level harvesting losses of 5 to 20% for the sweetpotato value chain in Ethiopia.

There have been significant efforts in developing countries to reduce postharvest food loss, however with limited success (Sheahan and Barrett, 2017). Storage loss interventions have dominated, including in recent years the development and promotion of hermetic storage technologies (bags and silos). Numerous recent studies (such as Tefera et al. 2012; Bokusheva et al., 2012; Gitonga et al. 2013; Baoua et al., 2014; Ng'ang'a et al., 2016; Ndegwa et al., 2016; Mlambo et al., 2017; Abass et al., 2018) have shown that hermetic technologies can reduce postharvest losses and have a positive impact on households' food and income security. Omotilewa et al. (2018) implemented improved postharvest storage technology in Uganda and showed that improved storage not only increases food security, but also promotes the use of hybrid maize varieties. Although such studies indicate positive impacts of improved postharvest storage in reducing food losses and in improving food security the adoption and use of these technologies is currently still low in SSA (Gitonga et al., 2013, Tesfaye and Tirivayi, 2018).

Postharvest losses occur along the entire value chain of a commodity and the value chain stages vary significantly by crop and regional environment. One of the main challenges to postharvest loss reduction is the lack of empirical information on losses and their determinants along the crop value chains (Hodges et al., 2011; Prusky, 2011; Affognon et al., 2015). Recent literature reviews such as Affognon et al. (2015) highlight the importance of understanding at which nodes in the value chains losses occur, at what levels and what socio-economic factors influence such losses. Hodges et al. (2011) assert the main postharvest issue in developing countries as inefficient postharvest agricultural systems. The positioning of loss within the postharvest value chain is important because it can impact the value of the commodity. For example, a 5% quantity loss at marketing stage can be valued differently from a similar scale of loss at the harvest level. This is because prices usually increase as commodities move from one node of the value chain to another further downstream. So, the cost of losses increases at the later stages in the value chain. Hence, preventing losses at the later stage of value chain may have greater overall value compared to reducing losses at the earlier stages. To deliver effective postharvest loss reduction and to make a commodity value chain efficient it is important to investigate the extent of losses and the factors influencing them at each stage.

Physical postharvest losses at different stages of commodity value chains are influenced by socio-economic factors as well as the postharvest methods currently practiced (Harris and Lindblad, 1978). Recent reviews such as Affognon et al. (2015) and Sheahan and Barrett (2017) highlight that the imperfect human handling of crops along the value chain is widespread in African agriculture and often results in postharvest losses. Along with sub-optimal postharvest practices, poor road, transport and market infrastructure throughout SSA result in postharvest losses (Sheahan and Barrett, 2017). Food is lost throughout the supply chains; from production to processor to retailer to end consumer. In this study, we specifically focus on food crop value chains from the perspective of smallholder farmers rather than on the value chain stages managed by processors, retailers, and consumers. In SSA, the majority of the food lost or wasted at or after harvest occurs during farm-level (i.e., for cereal crops estimated/assumed losses at each of the following stages are: harvesting (6%); postharvest handling and storage (8%); processing and packaging (3.5%); distribution (2%); and consumption (1%); and for root and tuber crops the equivalent figures are 14%, 18%, 15%, 5% and 2% respectively) (FAO, 2011).

The main research questions this paper intends to address are: what are the determinants of postharvest losses at various stages of the value chains for smallholder producers of maize, and sweet potato (White Fleshed sweetpotato, WFSP), and Orange Fleshed sweetpotato, OFSP)? are the determinants different for different stages of a value chain? what are the extent of influence by the determining factors? To answer these questions, we set up an experimental framework to study each node of the maize, fresh WFSP and OFSP value chains, and traced the commodities from farm production to market. The study was conducted in Omoro and Mpigi districts in Uganda, where 215 farmers growing maize and sweetpotato were randomly selected and interviewed. We assess the determinants of postharvest losses in each stage of the maize, WFSP, and OFSP value chains for smallholder farmers using cross-sectional data. We estimate an ordered probit model (Davidson and MacKinnon, 2003; Wooldridge, 2010) at each stage to identify the determinants of losses along the value chains for the three crops, an experimental protocol that we have yet to find elsewhere in the literature.

The paper unfolds in the following way. We first present a postharvest value chain system and the activities for maize and sweetpotato. Research design and data description are presented in the following section, where we summarize farmers' socio-economic background information. This includes commodity value chain activities and self-reported postharvest losses farmers experienced at each node of the commodity value chain in the previous season. We then describe the econometric methodology to identify the determinants of postharvest losses along the value chains. Finally, we present and discuss the estimation results, followed by concluding comments.

## 2. Smallholders' postharvest value chain for maize and sweetpotato

A postharvest agricultural system for a smallholder producer is a chain of interconnected activities from the time of harvest to the delivery of foods to market. After harvesting, agricultural food crops go through several procedures such as drying, storing, processing, transporting, selling, consumption and disposal. This system of interconnected activities and procedures is called value chain where the stages may vary significantly by crop (Gibbon and Ponte 2005). Postharvest losses (both quantitative and qualitative) can occur in any postharvest stage of a commodity value chain. The level of loss can be influenced by numerous factors such as crop perishability, mechanical damage during a value chain activity, exposure to temperature, rain, and humidity, pest infestation, inappropriate processing and storage techniques, transport etc. (World Bank et al., 2011; Kaminski and Christiaensen, 2014; Affognon et al., 2015; Hengsdijk and de Boer, 2017; Sheahan and Barrett, 2017). Since the stages of the value chain and the losses associated with each stage vary by commodity, we examine separately the value chain stages and associated activities for maize, WFSP and OFSP. Maize, is typically dried after harvest to render it more durable which enables it to be stored for many months by smallholder farmers and other value chain actors. Fresh sweetpotato roots, on the other hand, have a higher water content and are more perishable, and cannot be stored for long durations at smallholder farmer level in SSA, although if the fresh roots are processed into dried chips or chunks they then can be stored for several months (Stathers et al., 2013).

The main maize postharvest value chain activity stages along with the timing of the activities in our study area are depicted in Figure 1. After maturity, maize cobs are harvested, then dehusked and transported, usually by headload or bicycle, to the homestead. Drying is done mostly on tarpaulin or on bare soil after which shelling is conducted either by placing the cobs in a sack and beating them with sticks, or by using bare hands to remove the grains, or by using manually-operated shelling machines. Although use of shelling machines or the process of beating cobs in sacks may be time-efficient compared to manually removing all the kernels from the cob, these methods can cause physical damage (breakage and cracking) to grains. Following shelling, most households winnow the grain to remove the chaff and other material. Then, the grains are typically stored in a living room in the house or in a brick and mortar store room. During storage, the moisture content of the grain is a key factor for deterioration, and heat can also damage the grain at this stage. Depending on the environmental conditions during storage and on the grain protection method used, insect pests can cause weight losses of up to 30 % (Mvumi et al., 1995; Stathers et al., 2013). Fungal growth can also cause losses in quality during storage, especially if the grain was not dried sufficiently or is wetted during storage (Stathers et al., 2013). Insufficient pre-storage drying can result in the accumulation of mycotoxins during storage (Hodges et al., 2011). Weather and climate variability may thus influence postharvest losses severely. Given that most farmers rely on sun-drying, unseasonal rains and unfavourable weather conditions can result in rewetting and insufficient drying, resulting in mould growth, discoloration, and insect pest damage (Hodges et al., 2011).

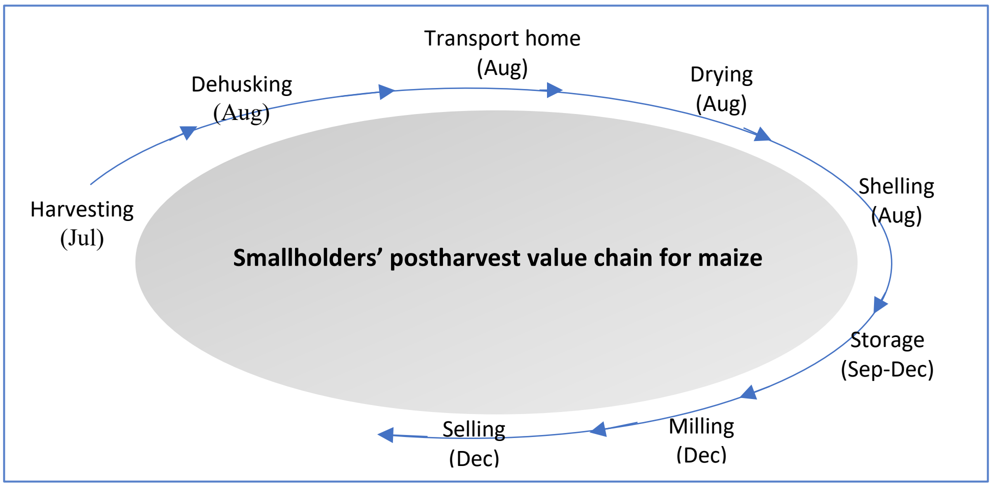

Figure 1 Postharvest stages for smallholders' maize value chain in Uganda

Sweetpotato is a nutritious staple food crop grown in all regions of Uganda (Bashaasha et al., 1995). Most Ugandan farmers grow WFSP and increasingly more are also growing OFSP for food and income generation through direct sale of fresh or dried sweetpotato chips (Mwanga and Ssemakula, 2011). Fresh sweetpotato roots are bulky and usually contain about 63-83% moisture (Osundahunsi et al., 2003; Aina et al., 2009) and have a short shelf-life. Typical sweetpotato postharvest value chain activities along with their timings are depicted in Figure 2. Smallholders generally harvest the crop in a piecemeal fashion for several weeks using sticks or hoes, sometimes finishing by complete harvesting of the whole field if the land is required for the next crop or all the remaining roots are to be sold. Sweetpotato roots are then transported usually by headload or bicycle to the homestead. Freshly harvested roots are then stored either in the living room or kitchen hut, usually loose and occasionally in woven polypropylene sacks. Roots to be used as food will be cooked that day or the following one, while those to be sold will be transported to the local market, or in some cases sweetpotato roots are sold at the farmgate. About 20 % of our sample WFSP farmers (35 out of 181) dry about 25 % of their sweetpotato while 40 % of the sample OFSP farmers (33 out of 86) dry about 25 % of their sweetpotato roots. Farmers involved in dry value chains chop their sweetpotato roots into small pieces and dry them for about 2-4 days before storing them for food or sending them to market or milling them. Losses can occur at each stage of the fresh and dry sweetpotato value chain due to pests, rotting, and physical damage during harvesting, handling or transport. Weevils (*Cylas* spp.) are the most prevalent pests reported by Sweetpotato farmers. Apart from physical losses, nutritional losses can occur rapidly in dried and stored OFSP chips, as described for vitamin A by Bechoff et al. (2010).

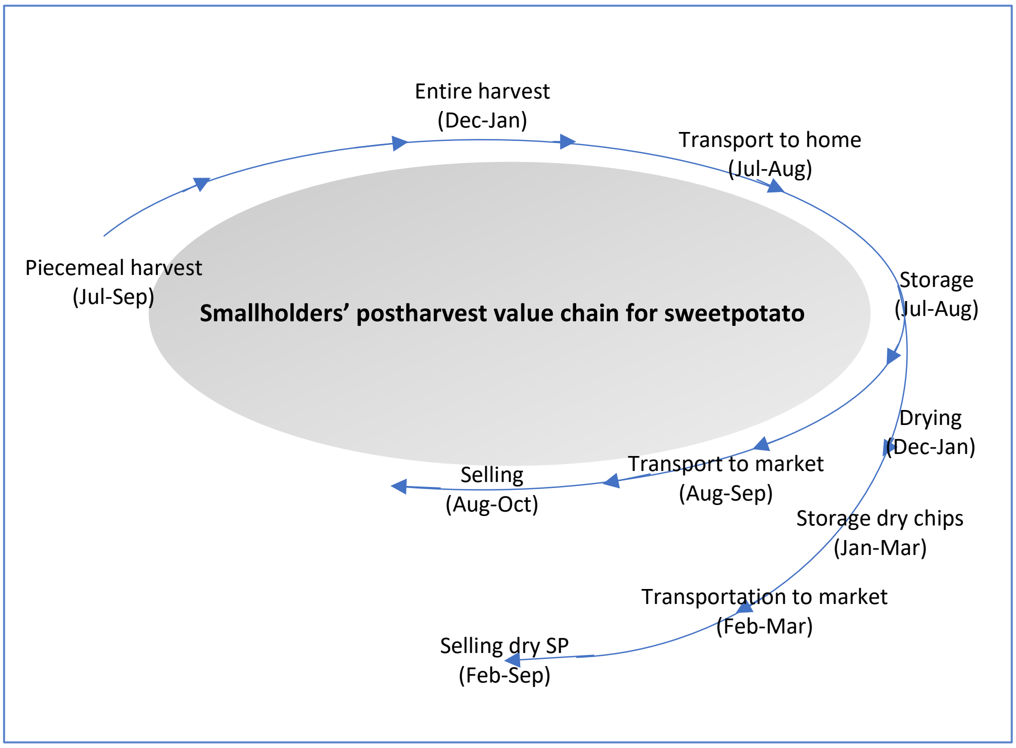


Figure 2 Postharvest stages for smallholders' sweetpotato value chain in Uganda

## 3. Data description

The study is based on a household survey on socioeconomic information and direct elicitation of farmers' self-reported perception of postharvest losses at various stages maize, WFSP, and OFSP value chains. A cross-sectional household survey approach was used to collect data from households that grow maize and sweetpotato (WFSP and OFSP) for food and income in Uganda. The Omoro district in Northern Uganda and the Mpigi district in Central Uganda were purposively selected because smallholder farmers cultivate both maize and sweetpotato in the area. Both the districts are significant producers of maize and sweetpotato in the country. About 29,160 (92%) and 45,644 (76%) households are dependent on crop growing for their livelihoods in Omoro and Mpigi, respectively (Uganda Bureau of Statistics, 2017). In Omoro, about 43% and 26% of the total households are engaged in maize and sweetpotato farming, respectively whereas in Mpigi, about 52% and 46% of the total households are engaged in maize and sweetpotato farming, respectively (Uganda Bureau of Statistics, 2017). NUTRI-P-LOSS project partners, the International Potato Center (CIP) and the National Agricultural Research Organization (NARO) prepared a sample frame of households in four villages in Omoro district and six villages in Mpigi district, from which equal number of respondents were randomly selected from each of the two districts. Figure 3 shows a map of the study sites and Table 1 presents the distribution of interviewed households.

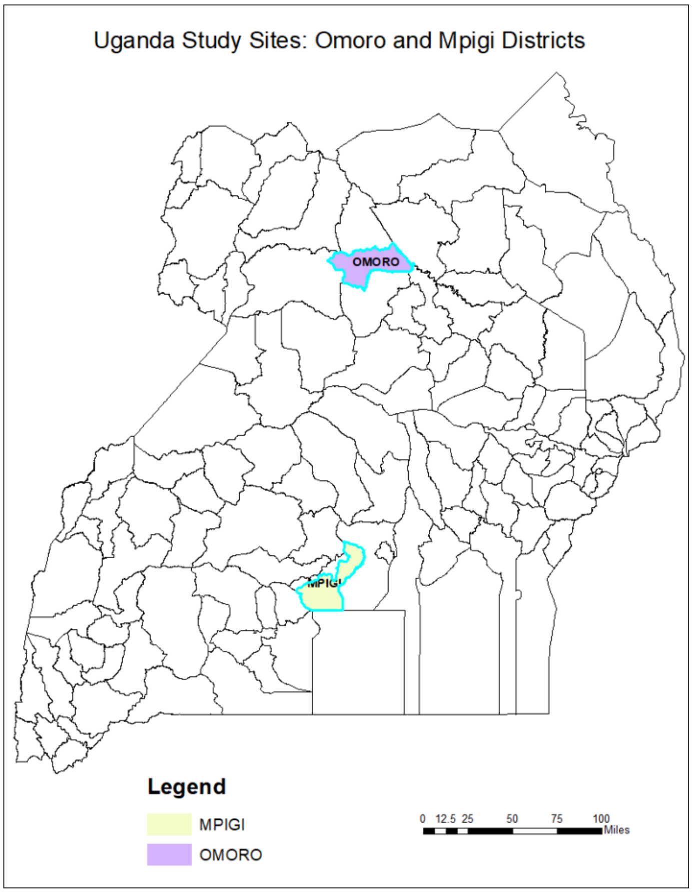


Figure 3 Map of the study sites

The data collection was implemented using Computer-Assisted Personal Interviewing (CAPI) by programming the questionnaire in CSPro for tablets. Survey data was collected for 199 maize farmers, 181 white-fleshed sweetpotato farmers and 86 orange-fleshed sweetpotato farmers. The data collected included information on socio-economic status, demographic, postharvest practices, and farmer's self-reported perception of their quantitative postharvest losses experienced in the previous season.

Table 1 Distribution of interviewed households

| District | Villages | No of HH growing maize | No of HH growing WFSP | No of HH growing OFSP | Total no of HH |
|---|---|---|---|---|---|
| Omoro | Acwera | 4 | 2 | 4 | 4 |
| Omoro | Aremo | 39 | 42 | 11 | 45 |
| Omoro | Idopo | 33 | 29 | 18 | 37 |
| Omoro | Lapainat West | 10 | 6 | 11 | 13 |
| Mpigi | Kikoota | 13 | 9 | 12 | 13 |
| Mpigi | Lubanda A | 39 | 37 | 4 | 40 |
| Mpigi | Lubanda B | 16 | 16 | 6 | 16 |
| Mpigi | Lubanda C | 18 | 19 | 8 | 20 |
| Mpigi | Kayunga | 25 | 20 | 10 | 25 |
| Mpigi | Nningye | 2 | 1 | 2 | 2 |
| Total | | 199 | 181 | 86 | 215 |

## 3.1 Socioeconomic background

An overview of the socio-economic background of households cultivating maize, WFSP and OFSP is provided in Table 2. The table presents the summary of means and significance tests of equality of means among two districts, Omoro and Mpigi for all the three crops. We describe the socioeconomic background of the households, first for maize and then for WFSP and OFSP. For households cultivating maize, about 53% of the respondents are females who usually work together with their spouses on their farms. About 76% of the respondents are either married (monogamous and polygamous) or living together. The average age of the respondents is 41 years, the mean age of respondents in Mpigi (42) being significantly higher than that in Omoro (38 years). The average number of years of education of the respondents is about 6 years. Average total land size is about 3.85 acres whereas average land size used for maize production in the previous year is 1.43 acres, implying that the farmers are mostly small to medium scale producers. The average land size and land size for maize are significantly higher in Omoro than in Mpigi. About 24 % of respondents reported having received trainings on postharvest loss (PHL) management, offered mostly by non-government organizations. A typical maize farmer harvested about 11 bags or 550 kg of maize grain in the previous season translating to an average yield of 384 kg/acre.

Table 2 Socioeconomic background of study households

| | **HHs cultivating maize** | | | **HHs cultivating WFSP** | | | **HHs cultivating OFSP** | | |
|---|---|---|---|---|---|---|---|---|---|
| | Omoro | Mpigi | Total | Omoro | Mpigi | Total | Omoro | Mpigi | Total |
| Female respondent | 0.54 | 0.51 | 0.53 | 0.57 | 0.56 | 0.56 | 0.65 | 0.5 | 0.58 |
| % of married respondent | 0.71 | 0.79 | 0.76 | 0.70* | 0.80* | 0.76 | 0.67 | 0.81 | 0.74 |
| Avg age of respondent | 38.27** | 42.41** | 40.7 | 38.23** | 42.75** | 40.77 | 39.12 | 42.55 | 40.8 |
| Avg years of education of respondent | 5.82 | 6.07 | 5.96 | 5.7 | 5.92 | 5.82 | 6.02 | 6.67 | 6.34 |
| Total land size (Acre) | 4.51** | 3.37** | 3.85 | 4.08* | 3.23* | 3.6 | 4.34 | 4.18 | 4.26 |
| Training received on PHL | 0.27 | 0.22 | 0.24 | 0.27 | 0.23 | 0.24 | 0.51 | 0.36 | 0.44 |
| Land size for maize (Acre) | 1.60* | 1.30* | 1.43 | | | | | | |
| Land size for sweetpotato (Acre) | | | | 0.84 | 0.89 | 0.87 | | | |
| Land size for sweetpotato (Acre) | | | | | | | 0.80* | 1.25* | 1.02 |
| Avg maize harvest (in 50kg bag) | 12.05 | 9.77 | 10.7 | | | | | | |
| Avg fresh WFSP harvest (in 100kg bag) | | | | 9.74*** | 4.87*** | 6.92 | | | |
| Avg fresh OFSP harvest (in 100kg bag) | | | | | | | 8.31 | 10.16 | 9.22 |

Key: statistically significant differences between the two districts for each crop type and variable are marked: * significant at 10%; ** significant at 5%; *** significant at 1%; 1 hectare=2.47 acres

For the households cultivating WFSP, about 56% of the respondent are females. About 76% of the respondents are either married (monogamous and polygamous) or living together, with the distribution of married or cohabiting respondents significantly higher in Mpigi (80%) than in Omoro (70%). Average age of the respondents is 41 years with this statistic being significantly higher in Mpigi (43 years) compared to Omoro (38 years). Average number of years of education of the respondents is about 6 years. Average total land size is 3.6 acres whereas land size for sweetpotato (all varieties included) cultivated in the previous season is about 0.87 acres. Compared to Mpigi (3.2 acres), average sweetpotato households in Omoro (4 acres) have significantly higher total land size. About 24% of the respondents reported that they received trainings on postharvest loss management, offered mostly by non-government organizations. A typical WFSP farmer harvested about 7 bags or 700 kg of fresh WFSP roots in the previous season, and the average harvest amount is significantly higher in Omoro (974 kg) than in Mpigi (487 kg). The average yield for WFSP reported is about 800 kg/acre.

Similarly, OFSP production in the sample is found to be dominated by females with about 58% of the respondent being females who usually work together with their spouses on their farms. About 74% of the respondents are either married (monogamous and polygamous) or living together. Average age is about 41 years and average number of years of education of the respondents in the sample is about 6 years. Average total land size is about 4.3 acres whereas average land size for OFSP is 1 acre. Average land size for OFSP is significantly higher in Mpigi (1.25 acres) than in Omoro (0.8 acre). About 44% of the respondents received trainings on postharvest loss management, offered mostly by non-government organizations. A typical OFSP farmer harvested about 11 bags or 922 kg of fresh orange fleshed sweetpotato roots in the previous season. The average yield for OFSP reported is about 900 kg/acre.

### 3.2 Estimated quantity losses reported along the value chains

Special attention was given to eliciting perceived crop losses at each postharvest stage of the three value chains. Estimations of perceived quantitative postharvest losses were elicited through a participatory 'bean exercise' where 100 beans represented their total production, and the farmers who were responsible for postharvest activities were asked to select how many they lost in each stage of a value chain. The elicited losses were therefore not measured but were rather represented by farmers' self-reported perception of the losses experienced in the previous season, either as physical weight of edible mass lost, or the food quantity discarded due to apparent damage or spoilage. The loss estimates were recorded as an ordered range of percentage of quantity losses and were stored as a categorical variable. Farmers loss estimates were then grouped into four ordered ranges; minimal loss (quantitative loss between 0 and 1%), low loss (between 1 and 3%), moderate loss (between 3 to 7%), and high loss (higher than 7%). The percentage of respondents reporting losses at each postharvest stage of the maize value chain are presented in Table 3. For the drying and shelling stages more than 50% of the respondents reported quantitative losses to be higher than 1 %. At the drying, shelling, and storage stages, more than 25 % of respondents reported losses to be in the 'low' range. At the milling stage, about 13 % of respondents reported losses to be 'moderate' and another 13% respondents reported their losses to in the 'high' range. Ten percent or more of the respondents perceived their losses at harvest, shelling, storage or milling to be 'high'.

Table 3 Percent of respondents indicating Maize loss category

| Maize Loss category | Harvesting | Dehusking | Transport to home | Drying | Shelling | Storage | Milling | Selling |
|---|---|---|---|---|---|---|---|---|
| Minimal loss (0-1 percent) | 58.4 | 57.7 | 67.0 | 43.8 | 49.7 | 50.9 | 54.3 | 65.3 |
| Low loss (1-3 percent) | 22.2 | 23.8 | 19.7 | 30.5 | 26.0 | 26.7 | 19.2 | 22.7 |
| Moderate loss (3-7 percent) | 8.1 | 12.2 | 10.6 | 17.7 | 14.1 | 12.4 | 13.3 | 7.3 |
| High loss (>7 percent) | 11.4 | 6.4 | 2.7 | 8.0 | 10.3 | 10.0 | 13.3 | 4.7 |
| Number of observations | 149 | 189 | 188 | 187 | 185 | 161 | 151 | 150 |

Table 4 presents the percentage of respondents reporting four loss categories in WFSP value chain that shows that in entire harvest and storage stages, more than 50% of the respondents reported losses to be higher than the 'minimal loss' category. Entire harvest is the stage where the highest proportion (20%) of the respondents reported their losses to be in the 'high loss' category. Overall, more than 10% of the respondents reported 'moderate losses' in both harvest (both piece-meal and entire) and storage stages.

Table 4 Percent of respondents indicating WFSP loss category

| WFSP Loss category | Piece-meal harvest | Entire harvest | Transport to home | Storage | Transport to market | Selling |
|---|---|---|---|---|---|---|
| Minimal loss (0-1 percent) | 57.7 | 38.4 | 73.4 | 46.6 | 63.9 | 66.9 |
| Low loss (1-3 percent) | 17.8 | 24.1 | 15.4 | 29.3 | 23.6 | 18.5 |
| Moderate loss (3-7 percent) | 11.0 | 17.0 | 7.1 | 20.7 | 8.3 | 9.2 |
| High loss (>7 percent) | 13.5 | 20.5 | 4.1 | 3.5 | 4.2 | 5.4 |
| Number of observations | 163 | 112 | 169 | 58 | 72 | 130 |

Table 5 presents the percentage of respondents reporting losses in the OFSP value chain. This table shows that in the entire harvest and storage stages, 50 % of the respondents reported their losses to be higher than 'minimal loss' category. Storage is the stage where the highest proportion (24%) of the respondents reported their losses to be in the 'high loss' category. Apart from storage stage, more than 10% of the respondents reported 'high losses' in piece-meal and entire harvest stages.

Table 5 Percent of respondents indicating OFSP loss category

| OFSP Loss category | Piece-meal harvest | Entire harvest | Transport to home | Storage | Transport to market | Selling |
|---|---|---|---|---|---|---|
| Minimal loss (0-1 percent) | 70.7 | 50 | 76.7 | 45.5 | 68.3 | 63.5 |
| Low loss (1-3 percent) | 12 | 24.2 | 12.3 | 24.2 | 14.6 | 20.6 |
| Moderate loss (3-7 percent) | 6.7 | 10.3 | 8.2 | 6.1 | 7.3 | 11.1 |
| High loss (>7 percent) | 10.7 | 15.5 | 2.7 | 24.2 | 9.8 | 4.8 |
| Number of observations | 75 | 58 | 73 | 33 | 41 | 63 |

It is important to recognise that this study, as in many others (e.g., FAO, 2011; Kaminski and Christiaensen, 2014; Hengsdijk and de Boer, 2017) is based on respondents' self-reported perceptions of the postharvest losses occurring at each postharvest stage. The loss figures presented are thus 'perceptions' or 'guestimates' and thus highly subjective and not to be confused with 'measured assessments of postharvest loss'. Whilst these 'guestimates' are relatively easy to obtain in comparison to 'objectively measuring losses', their accuracy is not well-understood and may vary by study (Harris and Lindblad, 1978;

Hodges, 2013; Hodges et al., 2014; Stathers et al., 2018). One recent postharvest loss assessment study in Ghana (GSARS, 2017) compared 'perceptions of loss' and 'measurements of loss' from 200 farms, and found a weak apparent correlation between them, with measured losses being higher than farmers self-reported perceptions of loss. However, measuring losses is a complex and costly undertaking and requires the use of skilled and experienced data collection teams, repeated visits at different activity stages, significant measurement equipment and well-defined questionnaires customised to the local context and postharvest farming practices. Given the pros and cons of the loss measurement versus perceptions of loss approaches, the Ghana study team conclude that a combination of the two approaches would be practical but notes that further work is necessary to understand how measured and perceived losses can be combined into a sound modelling framework (GSARS, 2017).

## 4. Empirical methodology

Given that our postharvest loss measures are categorical and ordinal, ordered probit or logit models are the most appropriate for analysis (McKelvey and Zavoina, 1975; Davidson and MacKinnon, 2003; Wooldridge, 2010). While the logit assumes a logistic distribution of the error term, the probit assumes a normal distribution. The logistic and normal distributions generally yield similar results in practice. Since the ordered probit model is widely used in empirical econometric application (Davidson and MacKinnon, 2003) we briefly describe the ordered probit model. Following Wooldridge (2010), let the ordinal dependent variable y takes the values $\{0,1,2,...,J\}$ for some known integer J. The variable y can be derived (conditional on explanatory variable x) from a latent continuous variable y* (unobservable) which can be determined as follows:

$$y_i^* = x_i^{'}\beta + u_i \quad (1)$$

where $u_i$ is normally distributed with mean zero and variance one, $\beta$ is a vector of unknown parameter to be estimated, and $x$ is a matrix of independent variables including households' socio-economic characteristics and existing postharvest handling practices used in each stage of the value chains. Following recent literature (Kaminski and Christiaensen, 2014; Hengsdijk and de Boer, 2017; Kikulwe et al., 2018) the socio-economic variables we explore include gender (female respondent), age, years of education, land size, harvest amount of the commodity, and postharvest training received. Following Wooldridge, let us assume $\alpha_1 < \alpha_2 < \ldots < \alpha_J$ to be unknown threshold points and define these thresholds such that

$$\begin{aligned} &y = 0 \text{ if } y^* \le \alpha_1 \\ &y = 1 \text{ if } \alpha_1 < y^* \le \alpha_2 \\ &\quad \vdots \\ &y = J \text{ if } y^* > \alpha_J \end{aligned} \tag{2}$$

In our case, y takes on four values 1 ('minimal loss'), 2 ('low loss'), 3 ('moderate loss'), and 4 ('high loss') and the three threshold points are 1%, 3%, and 7%. Since the error term is standard normally distributed, each response probability can be written as follows.

$$\begin{aligned} &P(y = 0 \mid x) = \Phi(\alpha_1 - x'\beta) \\ &P(y = 1 \mid x) = \Phi(\alpha_2 - x'\beta) - \Phi(\alpha_1 - x'\beta) \\ &\quad \vdots \\ &P(y = J \mid x) = 1 - \Phi(\alpha_J - x'\beta) \end{aligned} \tag{3}$$

where $\Phi(.)$ is the standard normal cumulative distribution. This is a generalized version of binary probit model in which parameters $\alpha$ and $\beta$ can be estimated by maximizing the following log-likelihood function:

$$\begin{aligned} &L_i(\alpha, \beta) = [y_i = 0]\log[\Phi(\alpha_1 - x'\beta)] \\ &+[y_i = 1]\log[\Phi(\alpha_2 - x'\beta) - \Phi(\alpha_1 - x'\beta)] + \ldots + [y_i = J]\log[1 - \Phi(\alpha_J - x'\beta)] \end{aligned} \tag{4}$$

The marginal effect of an increase in x on the probability of selecting alternative j can be written as

$$\partial P_{ij} / \partial x_i = [\phi(\alpha_{j-1} - x^{'}\beta) - \phi(\alpha_j - x^{'}\beta)]\beta \qquad (5)$$

where $\phi(.)$ is the standard normal density function.

## 5. Results and discussion

### 5.1 Determinants of postharvest physical losses along maize value chain

We assess maize quantity losses during harvesting, dehusking, transport to homestead, drying, shelling, storage, milling, and selling. Since the outcome dependent variable is ordered and categorical we cannot use ordinary least square and multinomial logit/ probit type models. We use ordered probit model, first developed by McKelvey and Zavoina (1975) and described in empirical methodology section. The results of the determinants of postharvest losses for each node of maize value chain are presented in Table 6 (A and B).

Results from panel 1 of Table 6 A show that female respondent and the dummy variable for district (1 for Omoro and 0 for Mpigi) have statistically significant coefficients. During the harvesting stage, female farmers are found to be less likely to perceive their losses to be in the higher loss categories than male farmers. This result is consistent with the finding of Kaminski and Christiaensen (2014) who report perceptions of postharvest losses for maize to be substantially lower for female-headed households compared to male headed households. This may be due to differential perceptions or expectations of harvesting losses between men and women. Although harvesting activity is shared by men and women, usually men are responsible for carrying maize cobs to the homestead, while women are responsible for drying, shelling and storing. Since losses are dependent on environmental conditions, we used a dummy variable for district to control for this condition in the ordered probit estimation. The estimation of this variable indicates that Omoro district is less likely to be in the higher category of losses compared to Mpigi district. The coefficient of hand plucking being negative and significant (-0.654), hand plucking is likely to result in lower losses compared to using machetes to harvest maize.

The coefficient estimates at other nodes of the maize value chain (Table 6 A&B), average years of education is significant and negative for transport (to homestead), drying, shelling, and selling, suggesting that at these stages, more educated farmers are less likely to report they experience higher losses. This result is in line with the findings from recent literature such as Mebratie et al. (2015) and Kikulwe et al. (2018) that farmers with more education have lower postharvest loss compared to their counterparts with less education. For the transport, drying and milling stages, the coefficients of the training received on PHL are negative and significant, which indicate that farmers who received training on PHL management are less likely to be related to high losses at transport, drying, and milling stages. About 24 % of our sample of maize farmers had received trainings on PHL management that mainly delivered by NGOs. This result is similar to Abass et al. (2014) who found farmers' lack of training and skills on postharvest management were largely responsible for postharvest food losses. The dummy variable for district is consistently negative for all stages, suggesting that compared to Mpigi district farmers in Omoro district are less likely to perceive that they incur higher losses. Female farmers are less likely to perceive that they incur high loss for harvest, transport and storage stages than male farmers. Apart from these socio-economic variables, the methods used in each stage of the value chain influence postharvest losses. At de-husking stage, use of sticks, knives etc. is more likely to lead to higher perceived loss compared to using bare hands. Transporting to homestead by truck is more likely to be related to higher loss compared to transporting by bicycle. At drying stage, use of plastic sheets is more likely to lead to higher loss compared to use of tarpaulin. For shelling, beating cobs in sack with sticks is more likely to lead to higher loss compared to shelling with bare hands. At storage stage, storing in brick and mortar store room and use of sacks/containers and are more likely to lead to lower loss compared to storing maize in living room in the house. Similarly, selling in local market is likely to result in higher loss compared to selling at the farmgate. On the other hand, at the milling stage, use of manual milling is perceived to be likely to lead to lower losses compared to the use of commercial hammer mills.

We also estimate marginal effects of ordered probit model described in Equation (5). Since the marginal effect estimations for all stages of the value chain are consistent with their main parameter estimates, we report the marginal effect estimation only for one stage (milling stage) as an example in Table 7. The four sets of marginal effects presented in the Table 7 show that farmers who received training on PHL management are 30 % more likely to perceive they experience 'minimal losses', 9 % less likely to perceive they experience 'low losses', 10.7 % less likely to perceive they experience 'moderate losses', and 9.5 % less likely to perceive they experience 'high postharvest losses'. Marginal effects of using a manual milling show that compared to using commercial hammer mills, the use of manual milling will increase the likelihood of the 'minimal loss' category by 45% and will decrease the likelihoods of the 'low loss', 'moderate loss', and 'high loss' categories by 21%, 14%, 10%, respectively. Note that these marginal effects sum up to zero for each variable, as the order probit model predicted.

Table 6 A Determinants of PHL along a maize value chain

| Variables | 1Harvesting | 2Dehusking | 3Transport | 4Drying |
|---|---|---|---|---|
| Female respondent | -0.352 | -0.291 | -0.347* | 0.194 |
| | (0.223) | (0.230) | (0.204) | (0.184) |
| % of married respondent | 0.251 | 0.318 | 0.0956 | 0.399* |
| | (0.263) | (0.267) | (0.232) | (0.217) |
| Age of respondent | 0.00558 | 0.000447 | -0.00360 | -9.07e-05 |
| | (0.00809) | (0.00831) | (0.00782) | (0.00690) |
| Avg years of education of respondent | 0.0126 | -0.0241 | -0.0684** | -0.0941*** |
| | (0.0314) | (0.0336) | (0.0313) | (0.0297) |
| Total land size (Acre) | -0.0347 | -0.0347 | 0.00355 | 0.0706** |
| | (0.0413) | (0.0413) | (0.0401) | (0.0349) |
| Training received on PHL | 0.00621 | -0.0712 | -0.406* | -0.164 |
| | (0.259) | (0.265) | (0.250) | (0.213) |
| Maize harvest (in 50kg bag) | -0.00615 | -0.00450 | -0.00935 | -0.00706 |
| | (0.00971) | (0.00986) | (0.0101) | (0.00769) |
| District | -0.809*** | -0.447** | 0.0116 | -0.878*** |
| | (0.233) | (0.220) | (0.204) | (0.195) |
| Intercept/cut1 | -0.437 | -0.0576 | -0.129 | -0.496 |
| | (0.553) | (0.549) | (0.520) | (0.474) |
| Intercept/cut2 | 0.301 | 0.687 | 0.614 | 0.468 |
| | (0.551) | (0.549) | (0.522) | (0.476) |
| Intercept/cut3 | 0.715* | 1.053* | 1.578*** | 1.307*** |
| | (0.556) | (0.553) | (0.548) | (0.484) |
| How[Machetes] | | | | |
| Hand Plucking | -0.654*** | | | |
| | (0.251) | | | |
| Other (Specify) | -0.778*** | | | |
| | (0.294) | | | |
| How[Bare hands] | | | | |
| Sticks | | 0.933* | | |
| | | (0.569) | | |
| Knives | | 0.0900 | | |
| | | (0.235) | | |
| Other (Specify) | | 0.763* | | |
| | | (0.417) | | |
| How[Bicycle] | | | | |
| Bare hands/ on head | | | 0.320 | |
| | | | (0.228) | |
| Motrocycle/Tricycle | | | 0.245 | |
| | | | (0.278) | |
| Trucks | | | 0.847** | |
| | | | (0.425) | |
| Other (Specify) | | | 0.0943 | |
| | | | (0.493) | |
| How[Tarpaulin] | | | | |
| On bare soil | | | | -0.315 |
| | | | | (0.234) |
| Polythene/ Plastic Sheets | | | | 1.091*** |
| | | | | (0.285) |
| Other (Specify) | | | | -0.325 |
| | | | | (0.410) |
| Observations | 149 | 189 | 188 | 187 |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 6 B Determinants of PHL along a maize value chain

| Variable | 5Shelling | 6Storage | 7Milling | 8Selling |
|---|---|---|---|---|
| Female respondent | 0.157 | -0.333* | -0.207 | -0.0990 |
| | (0.185) | -0.205 | (0.218) | (0.225) |
| % of married respondent | 0.156 | -0.237 | 0.0659 | -0.0116 |
| | (0.216) | (0.232) | (0.261) | (0.254) |
| Age of respondent | 0.00533 | 0.00909 | 0.0137 | -0.000275 |
| | (0.00697) | (0.00742) | (0.00878) | (0.00870) |
| Avg years of education of respondent | -0.0495* | -0.0368 | -0.0276 | -0.0779** |
| | (0.0283) | (0.0303) | (0.0351) | (0.0355) |
| Total land size (Acre) | 0.0222 | 0.0287 | -0.0151 | -0.0725 |
| | (0.0337) | (0.0364) | (0.0436) | (0.0514) |
| Training received on PHL | -0.00217 | -0.0964 | -0.772*** | -0.0469 |
| | (0.210) | (0.226) | (0.263) | (0.251) |
| Maize harvest (in 50kg bag) | 0.00263 | -0.00678 | 0.000647 | 0.00925 |
| | (0.00737) | (0.00886) | (0.00935) | (0.00988) |
| District | -0.491** | -0.578*** | -0.852*** | -0.655** |
| | (0.200) | (0.198) | (0.222) | (0.314) |
| Intercept/cut1 | 0.315 | -0.534 | -0.368 | -0.347 |
| | (0.475) | (0.485) | (0.570) | (0.545) |
| Intercept/cut2 | 1.058** | 0.287 | 0.318 | 0.466 |
| | (0.479) | (0.485) | (0.571) | (0.550) |
| Intercept/cut3 | 1.697*** | 0.867* | 0.932 | 0.995* |
| | (0.487) | (0.497) | (0.571) | (0.565) |
| How[Bare hands] | | | | |
| Hit cobs in sack with sticks | 0.501** | | | |
| | (0.221) | | | |
| Sheller | 0.316 | | | |
| | (0.251) | | | |
| Other (Specify) | 0.104 | | | |
| | (0.567) | | | |
| How[Living room in the house] | | | | |
| Brick & mortar store room | | -0.198 | | |
| | | (0.292) | | |
| Other (Specify) | | -0.626** | | |
| | | (0.271) | | |
| How[Commercial hammer mill] | | | | |
| Manual milling | | | -1.553*** | |
| | | | (0.526) | |
| Where[Farmgate] | | | | |
| Local Market | | | | 0.586** |
| | | | | (0.317) |
| From home | | | | -0.591* |
| | | | | -0.519 |
| Observations | 185 | 161 | 151 | 150 |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 7 Marginal effects of factors at milling stage of the maize value chain

| Marginal effects: Maize Milling stage | Low loss (0-1 percent) | Moderate loss (1-3 percent) | High loss (3-7 percent) | Very high loss (>7 percent) |
|---|---|---|---|---|
| Female respondent | 0.080 | -0.026 | -0.029 | -0.025 |
| | (0.085) | (0.028) | (0.031) | (0.027) |
| % of married respondent | -0.026 | 0.008 | 0.009 | 0.008 |
| | (0.101) | (0.033) | (0.036) | (0.032) |
| Age of respondent | -0.005 | 0.002 | 0.002 | 0.002 |
| | (0.003) | (0.001) | (0.001) | (0.001) |
| Avg years of education of respondent | 0.011 | -0.004 | -0.004 | -0.003 |
| | (0.014) | (0.005) | (0.005) | (0.004) |
| Total land size (Acre) | 0.006 | -0.002 | -0.002 | -0.002 |
| | (0.017) | (0.006) | (0.006) | (0.005) |
| Training received on PHL | 0.300*** | -0.098*** | -0.107*** | -0.095*** |
| | (0.102) | (0.042) | (0.043) | (0.038) |
| Maize harvest (in 50kg bag) | 0.000 | 0.000 | 0.000 | 0.000 |
| | (0.004) | (0.001) | (0.001) | (0.001) |
| District | 0.330*** | -0.108*** | -0.118*** | -0.105*** |
| | (0.087) | (0.039) | (0.040) | (0.035) |
| Manual milling | 0.449*** | -0.206*** | -0.143*** | -0.100*** |
| | (0.082) | (0.059) | (0.035) | (0.028) |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Note: Although we provide the estimation of marginal effects only for one stage we estimated marginal effects for all 8 stages of maize value chain. The marginal effect estimations for all stages are consistent with their main parameter estimates. To save space we omit 7 other similar tables of marginal effect estimation, nonetheless, they are available upon request.

### 5.2 Determinants of postharvest physical losses along WFSP value chain

We assess WFSP quantity losses at piece-meal harvest, entire harvest, transport to homestead, storage, transport to market, and selling. Cross sectional survey data was collected from 181 WFSP farmers from Omoro and Mpigi districts. The results of the determinants of postharvest losses for each node of WFSP value chain are presented in Table 8 (A and B). Results from piece-meal harvest stage show that farmers who received training on PHL and the dummy variable for district have statistically significant negative coefficients. This means, during piece-meal harvest stage, farmers who received training on PHL and farmers from Omoro district are less likely to perceive they experience higher levels of loss. Age of respondent being significantly positive, we conclude that at this stage the older the respondent the higher the likelihood of their being in the higher perceived loss category. Although female respondent variable is not statistically significant, the sign is negative, indicating that female farmers might be less likely to perceive they experience higher categories of losses compared to their male counterpart. Although not statistically significant at 90 % confidence level, the positive sign may mean using knife and spears for piece-meal harvesting is more likely to incur higher perceived losses compared to just using the hands.

Results from Table 8 (A and B) show that female respondent is significant and negative for entire harvest, indicating that at this stage female farmers are less likely to perceive high loss compared to their male counterpart. Average years of education is significant and negative for entire harvest and transport to market, suggesting that at these stages, more educated farmers are less likely to be related to higher loss categories. Farmers who received training on PHL management are less likely to incur high losses at piece-meal harvest and storage stage. The dummy variable for district is consistently negative for piece-meal and entire harvest stages. Apart from these socio-economic variables, the methods used in each stage of the value chain influence postharvest losses. At transport to home stage, roots carried in containers (typically woven baskets) and transported by motor cycle are more likely to be related to higher loss compared to roots placed in sacks and carried by hand. On the other hand, storing in a kitchen hut or in brick and mortar store rooms are less likely to be related to higher losses compared to storing in living room in the house. It may be because brick and mortar store rooms are exclusively used for storage, whereas living rooms are usually shared with livestock (e.g., goats and chicken).

We provide marginal effects only for one stage (piece-meal harvest) as an example in Table 9. From the four sets of marginal effects presented in the Table 9, we see that farmers who received training on PHL are 17.7 % more likely to perceive their losses are minimal, 3.7% less likely to be in low loss category, 5% less likely to be in moderate loss category, and 9% less likely to be in high loss category. This is consistent with the results presented in Table 8 (A and B). Marginal effects of age of the respondent show that one-year increase in age is associated with being 0.7 % less likely to be in the minimal loss category, 0.1 % more likely to be in low loss category, 0.2 % more likely to be in moderate loss category, and 0.3 % more likely to be in high loss category. As the order probit model predicted, these marginal effects sum up to zero for each variable.

Table 8 A Determinants of PHL along a White Fleshed Sweetpotato value chain

| Variable | 1Piecemeal | 2Entireharvest | 3Transport home |
|---|---|---|---|
| Female respondent | -0.155 | -0.431** | -0.175 |
| | (0.214) | (0.237) | (0.235) |
| % of married respondent | 0.183 | 0.0991 | -0.0929 |
| | (0.251) | (0.281) | (0.272) |
| Age of respondent | 0.0171** | -0.00327 | 0.00100 |
| | (0.00792) | (0.00887) | (0.00882) |
| Avg years of education of respondent | 0.0140 | -0.0899** | 0.00326 |
| | (0.0294) | (0.0372) | (0.0322) |
| Total land size (Acre) | 0.0133 | -0.00487 | -0.0120 |
| | (0.0419) | (0.0340) | (0.0392) |
| Training received on PHL | -0.451** | 0.237 | -0.367 |
| | (0.233) | (0.245) | (0.262) |
| Fresh WFSP harvest (in 100kg bag) | 0.00614 | 0.0137 | 0.000772 |
| | (0.0127) | (0.0144) | (0.0125) |
| District | -0.519*** | -0.400* | -0.0537 |
| | (0.219) | -0.245 | (0.248) |
| Intercept/cut1 | 0.730 | -1.068* | 0.735 |
| | (0.560) | (0.619) | (0.600) |
| Intercept/cut2 | 1.258** | -0.406 | 1.367** |
| | (0.564) | (0.616) | (0.606) |
| intercept/cut3 | 1.730*** | 0.143 | 1.911*** |
| | (0.567) | (0.617) | (0.618) |
| How[Hands] | | | |
| Stick | -0.0280 | | |
| | (0.214) | | |
| Knife, Spear etc. | 0.141 | | |
| | (0.358) | | |
| How[Hoes] | | | |
| Hoes and hands | | 0.394 | |
| | | (0.306) | |
| How[Roots placed sacks and carried by hand] | | | |
| Containers | | | 0.935*** |
| | | | (0.332) |
| Oh head (headload) | | | 0.368 |
| | | | (0.271) |
| Bicycle | | | 0.258 |
| | | | (0.442) |
| Other (Specify) | | | 0.814* |
| | | | (0.419) |
| Observations | 163 | 112 | 169 |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 8 B Determinants of PHL along a White Fleshed Sweetpotato value chain

| Variable | 4Storage | 5Transport to market | 6Selling |
|---|---|---|---|
| Female respondent | 0.381 | -0.399 | -0.197 |
| | (0.389) | (0.386) | (0.246) |
| % of married respondent | 0.117 | 0.176 | 0.131 |
| | (0.391) | (0.418) | (0.285) |
| Age of respondent | -0.00237 | -0.000432 | -0.0148 |
| | (0.0136) | (0.0145) | (0.00956) |
| Avg years of education of respondent | 0.0208 | -0.164*** | -0.0367 |
| | (0.0609) | (0.0610) | (0.0346) |
| Total land size (Acre) | 0.0688 | 0.0243 | -0.0591 |
| | (0.101) | (0.0483) | (0.0422) |
| Training received on PHL | -0.142* | 0.637 | 0.230 |
| | (0.075) | (0.394) | (0.261) |
| Fresh WFSP harvest (in 100kg bag) | 0.00296 | 0.0159 | 0.00526 |
| | (0.0184) | (0.0143) | (0.0121) |
| District | -0.165 | 0.297 | -0.257 |
| | (0.383) | (0.440) | (0.314) |
| Intercept/cut1 | -0.174 | -0.0213 | -0.502 |
| | (0.983) | (1.066) | (0.584) |
| Intercept/cut2 | 0.676 | 0.902 | 0.156 |
| | (0.987) | (1.062) | (0.583) |
| intercept/cut3 | 1.867* | 1.576 | 0.735 |
| | (1.035) | (1.066) | (0.589) |
| How[Living room in the house] | | | |
| Kitchen hut | -0.943** | | |
| | (0.447) | | |
| Other (Specify) | -0.961** | | |
| | -0.517 | | |
| How[Sacks in vehicle] | | | |
| Head loads | | 0.445 | |
| | | (0.974) | |
| Bicycle | | 0.0793 | |
| | | (0.888) | |
| Motorbike | | -0.159 | |
| | | (0.873) | |
| Where[Farmgate] | | | |
| Local Market | | | 0.229 |
| | | | (0.312) |
| Urban Market | | | 0.379 |
| | | | (0.664) |
| Observations | 58 | 72 | 130 |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 9 Marginal effects of factors at piece-meal harvest stage of WFSP value chain

| Marginal effects: WFSP Piecemeal harvest stage | Low loss (0-1 percent) | Moderate loss (1-3 percent) | High loss (3-7 percent) | Very high loss (>7 percent) |
|---|---|---|---|---|
| Female respondent | 0.061 | -0.013 | -0.017 | -0.031 |
| | (0.084) | (0.018) | (0.024) | (0.043) |
| % of married respondent | -0.072 | 0.015 | 0.020 | 0.036 |
| | (0.098) | (0.021) | (0.028) | (0.050) |
| Age of respondent | -0.007** | 0.001** | 0.002** | 0.003** |
| | (0.003) | (0.001) | (0.001) | (0.002) |
| Avg years of education of respondent | -0.006 | 0.001 | 0.002 | 0.003 |
| | (0.012) | (0.002) | (0.003) | (0.006) |
| Total land size (Acre) | -0.005 | 0.001 | 0.001 | 0.003 |
| | (0.016) | (0.003) | (0.005) | (0.008) |
| Training received on PHL | 0.177** | -0.037** | -0.050* | -0.090** |
| | (0.092) | (0.022) | (0.029) | (0.048) |
| Fresh WFSP harvest (in 100kg bag) | -0.002 | 0.001 | 0.001 | 0.001 |
| | (0.005) | (0.001) | (0.001) | (0.003) |
| District | 0.204*** | -0.043** | -0.058** | -0.103*** |
| | (0.086) | (0.021) | (0.029) | (0.045) |
| Stick | 0.011 | -0.002 | -0.003 | -0.005 |
| | (0.084) | (0.018) | (0.024) | (0.042) |
| Knife, Spear etc. | -0.056 | 0.010 | 0.015 | 0.031 |
| | (0.142) | (0.023) | (0.039) | (0.081) |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Note: Although we provide the estimation of marginal effects only for one stage we estimated marginal effects for all 6 stages of WFSP value chain. The marginal effect estimations for all stages are consistent with their main parameter estimates. To save space we omit 5 other similar tables of marginal effect estimation, nonetheless, they are available upon request.

### 5.3 Determinants of postharvest losses along OFSP value chain

We assess perceived OFSP quantitative postharvest losses at piece-meal harvest, entire harvest, transport to homestead, storage, transport to market, and selling. Cross sectional survey data was collected from 86 OFSP farmers from Omoro and Mpigi districts. The results of the determinants of postharvest losses for each node of OFSP value chain are presented in Table 10 (A and B).

Results from panel 1 show that the coefficient of the number of years of education is statistically significant and negative, suggesting that at piece-meal harvest stage, more educated farmers are less likely to be related to perceiving they have higher losses. Similarly, the coefficient estimate of the number of years of education variable at all other nodes of OFSP value chain is negative, however apart from piece-meal stage, the coefficient is significant only for transport to homestead, transport to market, and selling stages. Hence, improving education and awareness will be an important policy intervention for loss reduction at all the stages of OFSP value chain. Among the methods practiced in value chain stages, at the transportation to homestead stage the significance of the variables suggests that transporting OFSP roots to the homestead using motorcycle is more likely to be related to perceived higher losses compared to roots placed in sacks and carried by hand.

We provide marginal effects only for one stage (selling) as an example in Table 11. From the four sets of marginal effects presented in the Table 11, we see that a one-year increase in education is associated with being 4.6 % more likely to be in the 'minimal loss' category, 2 % less likely to be in 'low loss' category, 1.7% less likely to be in 'moderate loss' category, and 0.8% less likely to be in 'high loss' category. This is consistent with the results presented in Table 10 (A and B). As the order probit model predicted, these marginal effects sum up to zero for each variable.

Table 10 A Determinants of PHL along Orange Fleshed Sweetpotato

| Variable | 1Piecemeal | 2Entireharvest | 3Transport home |
|---|---|---|---|
| Female respondent | 0.148 | 0.0374 | 0.315 |
| | (0.351) | (0.366) | (0.450) |
| % of married respondent | 0.910* | 0.464 | 1.528** |
| | (0.467) | (0.415) | (0.705) |
| Age of respondent | 0.0171 | -0.00725 | 0.0206 |
| | (0.0139) | (0.0124) | (0.0139) |
| Avg years of education of respondent | -0.121** | -0.0278 | -0.108* |
| | (0.0578) | (0.0599) | (0.0651) |
| Total land size (Acre) | 0.0531 | -0.000531 | 0.00803 |
| | (0.0584) | (0.0401) | (0.0506) |
| Training received on PHL | -0.288 | 0.391 | 0.262 |
| | (0.325) | (0.318) | (0.402) |
| Fresh OFSP harvest (in 100kg bag) | 0.00416 | 0.00540 | 0.00388 |
| | (0.0119) | (0.0110) | (0.0154) |
| District | 0.339 | -0.215 | -0.501 |
| | (0.329) | (0.370) | (0.424) |
| Intercept/cut1 | 2.308** | -0.139 | 2.745** |
| | (1.003) | (1.051) | (1.384) |
| Intercept/cut2 | 2.768*** | 0.550 | 3.488** |
| | (1.014) | (1.049) | (1.402) |
| Intercept/cut3 | 3.135*** | 0.928 | 4.361*** |
| | (1.029) | (1.055) | (1.457) |
| How[Hands] | | | |
| Stick | 0.0354 | | |
| | (0.353) | | |
| Spear | 0.862 | | |
| | (0.636) | | |
| How[Hoes] | | | |
| Hoes and hands | | 0.396 | |
| | | (0.445) | |
| How[Roots placed sacks and carried by hand] | | | |
| Containers | | | 0.441 |
| | | | (0.799) |
| Oh head (headload) | | | 0.961* |
| | | | (0.536) |
| Motorcycle | | | 1.733*** |
| | | | (0.553) |
| Observations | 75 | 58 | 73 |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 10 B Determinants of PHL along Orange Fleshed Sweetpotato value chain

| Variable | 4Storage | 5Transport to market | 6Selling |
|---|---|---|---|
| Female respondent | -0.415 | -0.156 | -0.150 |
| | (0.499) | (0.531) | (0.370) |
| % of married respondent | 0.249 | 1.942** | 0.170 |
| | (0.715) | (0.835) | (0.429) |
| Age of respondent | -0.000947 | -0.0150 | -0.0111 |
| | (0.0183) | (0.0201) | (0.0146) |
| Avg years of education of respondent | -0.113 | -0.260*** | -0.124** |
| | (0.104) | (0.110) | -0.0607 |
| Total land size (Acre) | 0.0793 | -0.0746 | -0.0209 |
| | (0.0636) | (0.0858) | (0.0445) |
| Training received on PHL | 0.601 | 0.672 | 0.650 |
| | (0.531) | (0.580) | (0.456) |
| Fresh OFSP harvest (in 100kg bag) | 0.00967 | -0.0309 | 0.0152 |
| | (0.0244) | (0.0260) | (0.0119) |
| District | 0.102 | 0.573 | -0.753* |
| | (0.456) | (0.777) | -0.426 |
| Intercept/cut1 | 0.123 | 0.932 | -1.700 |
| | (1.413) | (1.990) | (1.480) |
| Intercept/cut2 | 0.859 | 1.620 | -0.935 |
| | (1.419) | (1.984) | (1.465) |
| Intercept/cut3 | 1.064 | 2.084 | -0.212 |
| | (1.419) | (2.011) | (1.480) |
| How[Living room in the house] | | | |
| Kitchen hut | -0.179 | | |
| | (0.519) | | |
| Other (Specify) | 0.634 | | |
| | (0.678) | | |
| How[Head loads] | | | |
| Bicycle | | -0.422 | |
| | | (1.201) | |
| Motorbike | | 1.050 | |
| | | (1.067) | |
| Where[Farmgate ] | | | |
| Local Market | | | -0.508 |
| | | | (0.680) |
| Urban Market | | | 0.599 |
| | | | (0.636) |
| Observations | 33 | 41 | 63 |

Standard errors in parentheses    *** p<0.01, ** p<0.05, * p<0.1

Table 11 Marginal effects of factors at the selling stage of OFSP value chain

| Marginal effects: OFSP Selling stage | Low loss (0-1 percent) | Moderate loss (1-3 percent) | High loss (3-7 percent) | Very high loss (>7 percent) |
|---|---|---|---|---|
| Female respondent | 0.055 | -0.025 | -0.020 | -0.010 |
| | (0.137) | (0.062) | (0.050) | (0.026) |
| % of married respondent | -0.063 | 0.028 | 0.023 | 0.012 |
| | (0.158) | (0.071) | (0.059) | (0.030) |
| Age of respondent | 0.004 | -0.002 | -0.002 | -0.001 |
| | (0.005) | (0.002) | (0.002) | (0.001) |
| Avg years of education of respondent | 0.046** | -0.020* | -0.017* | -0.008 |
| | (0.026) | (0.011) | (0.011) | (0.006) |
| Total land size (Acre) | 0.008 | -0.003 | -0.003 | -0.001 |
| | (0.016) | (0.007) | (0.006) | (0.003) |
| Training received on PHL | -0.240 | 0.107 | 0.088 | 0.044 |
| | (0.151) | (0.069) | (0.055) | (0.031) |
| Fresh OFSP harvest (in 100kg bag) | -0.006 | 0.003 | 0.002 | 0.001 |
| | (0.004) | (0.002) | (0.002) | (0.001) |
| District | 0.278* | -0.124 | -0.102 | -0.051 |
| | (0.151) | (0.112) | (0.089) | (0.049) |
| Local Market | 0.184 | -0.083 | -0.067 | -0.034 |
| | (0.248) | (0.106) | (0.094) | (0.056) |
| Urban Market | -0.233 | 0.039 | 0.097 | 0.097 |
| | (0.239) | (0.062) | (0.104) | (0.123) |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Note: Although we provide the estimation of marginal effects only for one stage we estimated marginal effects for all 6 stages of OFSP value chain. The marginal effect estimations for all stages are consistent with their main parameter estimates. To save space we omit 5 other similar tables of marginal effect estimation, nonetheless, they are available upon request.

## 6. Concluding comments

Postharvest loss reduction throughout commodity value chains is an important pathway to food and nutrition security in SSA. Large quantities of food crops are physically lost at different stages as food commodities move along their often complex and dynamic value chains. Lack of understanding of the location of losses and associated factors within the postharvest value chains remains a major challenge to operationalizing postharvest loss mitigation strategies. We assess the extent and determinants of perceived postharvest losses in each stage of maize, WFSP and OFSP value chains for smallholder farmers using cross-sectional data from two districts in Uganda. We estimate an ordered probit model at each stage to identify the determinants of self-reported perceived postharvest losses along the value chains for the three crops. Identification of the factors influencing perceived postharvest losses at each node of value chains through rigorous estimation is an important contribution of the paper.

The results show that postharvest physical losses at different stages of the commodity value chains are influenced by socio-economic factors as well as the postharvest methods currently practiced. Among socio-economic variables, more years of education and having received training on PHL management are related to lower (perceived) PHL at key stages of value chains. Gender also plays an important role at some key stages in the value chains, female farmers are found to be less likely to perceive they incur losses compared to their male counterparts. For the postharvest maize value chain, the average number of years of education is associated with a lower likelihood of (perceived) high losses at harvest, transport to homestead, drying, shelling, and selling. Farmers who received training on PHL are less likely to be related to high losses at transport, drying, and milling stages. For WFSP value chain, female respondent, years of education, and farmers who received training on PHL are less likely to be related to high losses at key stages of postharvest value chain. For postharvest OFSP value chain, more educated farmers are found to be less likely to be related to perceived higher loss categories at piece-meal harvest, transport to home stead, transport to market, and selling stages.

We also identified the postharvest handling practices which are more likely to be related to (perceived) high losses at each stage, and which, if improved, could generate more effective value chains for smallholder producers. With respect to maize value chain, our results suggest a number of sensitive stages: (1) at de-husking stage, use of sticks, knives etc. versus bare hands, (2) at transport to home stage, use of trucks versus bicycle, (3) at drying stage, use of plastic sheets versus tarpaulin, (4) at shelling stage, beating cobs in sack with sticks versus shelling with bare hands, (5) at storage stage, storing in brick and mortar store rooms versus storing in living room in the house, (6) at selling stage, selling in local market versus selling at farmgate, and (7) at milling stage, use of manual milling versus commercial hammer mills. With respect to fresh WFSP value chain, our findings indicate two sensitive stages: (1) at transport to home stage, roots carried in containers (or baskets) versus roots placed in sacks and carried by hands, and (2) at storage stage, storing in kitchen hut or in brick and mortar store rooms versus storing in living room in the house. With respect to fresh OFSP value chain, our results suggest one sensitive stage: (1) at transport to home stage, using motorcycle versus roots placed in sacks and carried by hands. At each of these stages, the use of alternate methods could generate statistically significant gains.

These findings indicate that farmers could improve the efficiency of value chains through changes in postharvest practices. These practices could include the use of covered or raised drying areas, of accurate techniques for assessing grain moisture content, of drying and shelling machines, and of improved storage protection methods. Alongside the improvement of farmers' postharvest methods, awareness and training on postharvest management can help reduce quantitative postharvest losses along each node of the commodity value chains.

Finally, it is important to recognise that this study, like many others is based on respondents' self-reported perceptions of the postharvest losses occurring at each postharvest value chain stage. The loss figures presented are thus 'perceptions' and thus subjective and not to be confused with 'measured assessments of postharvest loss'. We carefully designed the questionnaire and elicited farmers perception of postharvest losses at each stage of commodity value chains through a visual exercise implemented by trained enumerators proficient with local languages.

## Conflict of interest

The authors declared that they have no conflict of interest.

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