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Extent of pre-harvest and post-harvest losses and their causes: identifying critical loss points in the dried bean supply chain of the school meals program in Kajiado and Kitui counties of Kenya

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Abstract: The extent of pre- and post-harvest losses in supply chains linked to the home-grown school meals program (HGSMP) is not documented. This study sought to fill this gap and determine critical loss points along the dried bean supply chain of the HGSMP. The study was conducted in Kajiado and Kitui Counties. Secondary and primary data were collected for this study. Primary data was collected from all the schools implementing the HGSMP and all other supply chain actors linked to the programme within the two counties through interviews and direct measurement of the losses (load-tracking). Data was analysed using the FAO case study methodology. Producers reported quantitative losses of about 18.4% and 6.6% in Kitui and Kajiado Counties, respectively. Traders estimated quantitative losses at 5.8% and 12.6% in Kajiado and Kitui, respectively. The study revealed that the storage stage is a critical loss point for both producers and traders. Promotion of awareness and appropriate technologies and practices for storage and post-harvest handling of food commodities procured for school meals can contribute to reducing losses. Capacity building of supply chain actors on proper pre-harvest agricultural practices and post-harvest management is also essential for the reduction of pre- and post-harvest losses.

Keywords: critical loss points; food loss; pre-harvest loss; post-harvest loss; quantitative loss; qualitative loss; dried bean; storage; school meals.

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1 Introduction

1.1 Background

Studies on the extent of post-harvest losses have been on the rise since 2011, when FAO released estimates of global post-harvest losses, prompting national governments and development agencies to seek to understand the extent and critical loss points (CLPs) of in-country losses for targeted interventions (Strecker et al., 2022). Although improved methods for estimating post-harvest losses have been proposed across the globe (Bellemare et al., 2017; Delgado et al., 2021) there remains a gap in understanding the extent of pre-harvest and post-harvest losses. Pre and post-harvest losses exist and depend on a number of factors, some of which are physical, environmental, biological, the level of technology used, and socioeconomic characteristics of households (FAO, 2019; Oliveira et al., 2014). Effects of pre-harvest factors at times manifest later after harvesting, leading to losses, making it essential to assess pre-harvest conditions that influence post-harvest quality and losses. Thus, the need to assess the entire supply chain with respect to agricultural practices and supply chain actor's characteristics when assessing food losses (Bundi et al., 2020).

In the East African Community (EAC), post-harvest losses are notably high, estimated at 30% in cereals, 50% in roots and tubers, and up to 70% in fruits and vegetables (EAC, 2022). These significant losses are primarily attributed to inadequate storage and processing technologies. Addressing this is crucial, especially when considering the potential effects of increased availability of food of good quality on food security and nutrition outcomes (FAO, 2019) at a time when undernutrition remains a critical public health concern, especially for young children (FAO et al., 2019). The prevalence of undernourishment in Eastern Africa (where nearly half of the people facing hunger in Africa live) fell by 1% in 2023 to 28.6% (138.5 million people) (FAO et al., 2024). Additionally, more than 148 million children aged below 5 years are stunted across the globe, with 43% of them reported in Africa. In Eastern Africa alone, 21.8 million children are affected, representing 30.6% of the sub-region's under-5 population (UNICEF et al., 2023). Globally, it is estimated that 45 million children under 5 are affected by wasting, with about 22% of severe cases found in Africa and 3.5 million cases in Eastern Africa. In developing countries, children from poor ethnic and minority groups are usually at higher risk (FAO et al., 2019). Undernutrition in young children undermines their cognitive and physical development, affecting their educational performance (Victora et al., 2008).

The WFP estimates that over 66 million children in developing countries, (out of which 23 million are in Africa) attend school hungry (WFP, 2015). Home-grown school meals programmes (HGSMPs) have been endorsed as an effective strategy to provide nutritious, locally sourced food to children, thereby enhancing food security and nutrition, increasing school enrolment, and supporting local farmers who supply the food (FAO and WFP, 2018; Tette and Enos, 2020). By offering smallholder farmers access to this market, HGSMPs help strengthen local economies, educational, and food security and nutrition outcomes (Bundy et al., 2018; Kyere et al., 2020; Metwally et al., 2020). In Kenya, the HGSMP was launched in 2003 and expanded by 2019 to serve 38,000 children in 1,777 schools across 66 semi-arid districts (Langinger, 2011). The HGSMP aims to provide locally produced food to schools in arid and semi-arid regions, thereby contributing to reducing food insecurity among pupils and providing a source of income through market access for local smallholder farmers. However, other supply chain actors sell produce to schools where the farmers cannot supply the quality and quantity of produce demanded by schools, as is the case for common beans in the study area. The ability of local farmers to consistently meet food quality and quantity demanded thereby benefiting from this new market requires enhanced performance.

While evidence suggests that the HGSMP can increase demand for agricultural commodities, raise farmer incomes, and improve livelihoods (Bhalla, 2023; Bundy et al., 2018), the program often face challenges, such as limited budget allocations and disbursements from the national government (Bhalla, 2023). Across countries, smallholder farmers generally encounter significant challenges, including limited access to productive assets, finance, and technology. These issues are compounded by the diverse and often low-return, high-risk nature of smallholder farming systems across different regions. To effectively support smallholders, interventions must address these underlying challenges and enhance essential infrastructure, such as transport, storage, and irrigation (Barret, 2008; Miranda, 2018).

Given that smallholders' integration into markets varies by household, location, and how markets are organised, the challenge lies in identifying key constraints for effective support strategies along the value chains (Miranda and Klug, 2018). For instance, in eastern and southern Africa, market entry barriers for staple grains have been described: households' insufficient access to productive assets, financing and improved production technologies required to generate adequate marketable surplus and to make market participation feasible and worthwhile and; high costs, including transaction costs, of engaging in commercialisation limiting price transmission and trade competition which leads to more volatile markets thereby reducing households' incentives to increase productivity; so as to generate marketable surpluses (Barret, 2008). To maximise the benefits of the HGSMP, it is also necessary to improve efficiency along supply chains, enhance food quality management, reduce food losses, and ensure compliance with procurement requirements based on food quality specifications (Miranda and Klug, 2021). However, there is limited knowledge about the extent of pre-harvest losses, post-harvest losses, and critical loss points (CLPs) along supply chains linked to the HGSMP, such as those for beans. This study aims to contribute to address this gap.

1.2 Status and the importance of the common bean subsector

Globally, common bean (*Phaseolus vulgaris* L.) is an important grain legume (Murube et al., 2021) which is also the main source of protein in the HGSMP in Kenya. Dry bean is produced in most parts of Kenya (Duku et al., 2020). Slightly over 1 million HA of land is under beans in Kenya (FAOSTAT, 2024). Between 2010 and 2019, bean production was on the rise in Kenya, reaching a peak (846,000 MT) in 2017. Since then, the area under dry bean production has stagnated at 1.2 million HA. The productivity of beans in Kenya has been steady, at an average 6,367 MT/HA. About 755,000 MT of dried bean is consumed in the country annually (KenInvest, 2020) against an average production of 684,467 MT a year. The deficit is imported from neighbouring countries and in the recent past, bean imports were about 7% of total food consumption in Kenya (KenInvest, 2020). Common bean is a food security crop whose per capita consumption is about 14 kg per year with up to, 66 kg/year per capita consumption in western Kenya (Duku et al., 2020).

2 Methodology

2.1 Conceptual framework

Mapping of the supply chain actors linked to the HGSMP was generated by working backwards from the ultimate supplier of beans to schools. Information on food loss was generated from each supply chain actor, providing estimates of the extent of food loss along the supply chain. The aim was to understand CLPs across value chains. These are nodes associated with significant losses, both quantitative (i.e., volume, mass) and qualitative (e.g., visual changes and other quality attributes) (FAO, 2019). Knowledge of CLPs allows for investment in FLW reduction interventions.

Some key definitions and concepts adopted from the FAO food loss analysis case study methodology employed in this study are as follows:

Food loss is the reduction in quantity or quality of food because of supply chain actors' decisions and actions, excluding retailers, food service providers and consumers. Quantitative food loss is a reduction in mass of food intended for human consumption following their removal from the food value chain. Qualitative food loss is the reduction in food attributes due to decisions and actions of supply chain actors, which reduce the value of food with regard to its intended use. It can result in reduced nutritional value and the economic value of food because of non-compliance with quality standards (FAO, 2019).

Produce damage and spillage result from improper or inadequate food quality management along the supply chain. These can be categorised into three main types of interlinked damages and spillage: physical damage refers to the impacts of organisms on the produce, such as bacteria, fungus, insects or rodents. Physical damage is linked to processes of decay, rotting and weight loss owing to consumption of produce by such organisms. Physiological and metabolic changes causing damage to produce are triggered or linked to inappropriate temperature or water loss of produce (Kader, 2002; Kays and Paull, 2004). For example, it includes over-ripening, wilting, chilling injury in fruits, discolouration, browning and yellowing in vegetable leaves, adverse flavours, moisture loss, discolouration and shrivelling of grains (Kader, 2002; USDA, 2016). Mechanical damage is caused by physical forces applied to the produce. It includes abrasions, cracking, punctures and bruises in fruits, and breakage of grains (Kader, 2002; USDA, 2016).

2.2 Analytical model

The FAO food loss analysis case study methodology was applied in the assessment of quantitative and qualitative losses from supply chain actors following Diei-Ouadi and Mgawe (2011), FAO (2018) and Ward and Jeffries (2000). The methodology integrates three data collection approaches and the analysis:

- Screening is based on a desk review of secondary data, including published reports, which are triangulated with expert consultations/informants. Screening is used to have a rough description of the supply chains, the range of losses and some main causes of the losses.
- Food loss assessment through a survey which targets all supply chain actors of the target supply chain and is complemented with keen observation of supply chain activities. The survey may also include experts who understand the target supply chain.
- Tracking a load of produce from the source to the destination while measuring quantitative and qualitative losses as the load moves.
- Triangulating findings from previous steps and discussing appropriate solutions to food loss based on evidence-based descriptions of practices enhancing food quality preservation for studied produce and associated technologies.

2.3 Study area and sampling

The focus counties and commodities were identified through stakeholder consultative workshops conducted in both counties. Kajiado and Kitui Counties were purposively selected because they are in the arid and semi-arid areas (ASALs) and have many schools benefiting from the HGSMP. All the schools implementing the HGSMP in the two selected counties were targeted for the study. These were 147 in Kajiado County and 397 schools in Kitui County. However, only 125 and 300 schools in Kajiado and Kitui Counties, respectively, were involved in the study due to poor road network (schools were unreachable) and non-responsiveness (schools refused to participate). Out of the schools that were reached, all bean producers (41 in Kajiado and 89 in Kitui) and all the traders (35 in Kajiado and 15 in Kitui) they supply to (of these traders, 15% were also transporters) were interviewed.

2.4 Data collection and analysis

Secondary data collection was done by a team of research assistants with expertise in agricultural economics, food science and technology, nutrition and horticulture between January 2021 and June 2021. Primary data collection involved expert consultation through telephone conversations, conducted between January and March 2021, followed by further face-to-face expert consultations during a stakeholder consultative workshop in March 2021. The face-to-face survey involving all supply chain actors was conducted between January and March 2022. For the survey, a detailed actor-specific questionnaire was developed for producers, traders/transporters and pre-consumers (schools). Load tracking for 1 bean trader was conducted during the month of March 2022. Quantitative and qualitative losses from three bags of beans were estimated as the bean load moved from the farm in Oloitoktok to the trader's store in Kitui town (280 km). The quantitative losses for the marked bags were established at various stages, including cleaning (before loading), loading, off-loading, sieving (cleaning) at the trader's store, weight at the beginning of storage and weight after 3 months of storage. The data collected using an open-source mobile data collection platform (ODK) was first cleaned to ease analysis and to remove outliers. STATA statistical analysis software was used for the analysis of means with standard deviations.

Quantitative and qualitative losses were computed for each supply chain actor by dividing self-reported losses by the quantity of beans handled at each stage following Baltazari et al., (2020).

$$\text{Post-harvest loss}\left(y_i\right)=\frac{Quantity\ lost_i}{Quantity\ handled_i}*100 \tag{1}$$

Food losses reported for each supply chain actor were a summation of the computed losses at all stages or activities the supply chain actor engaged in. The ordinary least square (OLS) regression model was used to assess underlying factors contributing to losses at the pre-harvest and harvest stages.

3 Results and discussion

3.1 Descriptive statistics of households

A summary of the socioeconomic characteristics of households involved in the study is shown in Table 1. The majority of the households in both Kajiado and Kitui Counties had approximately four family members headed by married middle-aged men with a primary level of education. Producers in both counties had experience in the production of beans, but those in Kitui County received higher incomes from supplying beans to schools. Tenders to supply produce to schools are based on producers' capacity to supply the required quality and quantity at a given time and producers in Kitui County had a higher capacity to do this. A higher number of producers in Kitui were members of agricultural groups and accessed credit. However, producers in Kajiado had higher access to infrastructure such as water, roads, markets and schools. Producers in both counties had access to an average of 1 acre for farming. Women mainly conducted pre-harvest activities while post-harvest activities such as storage and loading were mainly conducted by men in both counties.

Table 1 Descriptive statistics of households

Variable	*Kajiado*	*Kitui*
	Mean (std dev.)	*Mean (std dev.)*
Household characteristics		
Age (years)	42.02 (1.136)	44 (4.108)
Gender of household head (% males)	54.76	76.92
Marital status (% married)	88.09	100
Education of household head (% primary)	47.62	53.85
Experience in farming (years)	13.79	12.77
Household size	3.86 (0.9116)	4.23 (1.951)
Household income from supply of produce (beans) to school (KES)	39,201 (2,230.91)	100,296 (8,205.23)
External support services		
Group membership (% yes)	26.19	61.54
Access to credit (% yes)	16.67	38.46
Access to infrastructure		
Access to water source (km)	2.72	3.75
Access to roads (km)	1.96	4.08
Access to markets (km)	6.20	6.69
Access to transport to school (km)	2.39	1.79
Access to school (km)	3.54	20.93
Farm characteristics		
Total land size (acres)	1.16	1.15
Involvement in farming activities		
Pre-harvest (% males)	45	30.77
Storage (% males)	58.49	66.13
Loading (% males)	81.82	83.33

Note: km – kilometres.

Source: Authors' survey (2022)

3.2 *Extent of post-harvest losses and critical loss points along the dried bean supply chain*

3.2.1 *Extent of post-harvest losses and critical loss points at the producer level*

The extent of post-harvest losses and CLPs along the dried bean supply chain in Kitui and Kajiado Counties are presented in Table 2. According to the bean farmers in Kitui and Kajiado Counties, 18.37% and 6.61% of the beans are cumulatively lost at the producer level. Out of this, 4.46% and 1.99% are lost at the pre-harvest stage in Kitui and Kajiado Counties, respectively, due to attack by pests and diseases. These findings are in line with those of Affognon et al. (2015) who conducted a review of literature on the extent of post-harvest losses in sub-Saharan Africa and found that without any intervention, post-harvest losses in pulses such as beans and cowpea could reach

23.5% ± 22.0%. These losses could be lowered to 2.1% ± 3.0% when various types of loss mitigation strategies are applied. The CLP in this study was identified as the harvest, threshing and drying stage (on-farm processing), where 8.73% and 2.93% of the losses occur in Kitui and Kajiado Counties, respectively. Harvesting of beans at maturity ensures that they possess optimal nutrients and are easy to handle during immediate post-harvest handling activities. High losses at this stage can be attributed to over drying which leads to the shattering of the pods and subsequent spillage on the farm during harvesting. Qualitative losses were cumulatively (along the value chain: at pre-harvest, on-farm processing and on-farm storage) estimated at 10.14% and 3.55% for Kitui and Kajiado Counties, respectively. The harvesting, threshing and drying stages had the highest qualitative losses, estimated at 7.52% and 2.19% for Kitui and Kajiado Counties, respectively. Broken beans accounted for most of the losses according to 61.54% and 75.61% of the interviewed respondents in Kitui and Kajiado, respectively. The breakages of grains could be attributed to excess mechanical impact applied during manual threshing. Most published reports indicate pests (mainly weevils) as the major causes of quantitative and qualitative losses during storage (Berhe et al., 2022; Mng'ong'o, 2023). However, in the current study, only 14.6% and 7.7% of the respondents in Kajiado and Kitui, respectively, indicated pests as a major cause of losses. These results could be explained by the short storage period, during which pest damage may not have a significant impact on the losses.

Table 2 Extent of pre-harvest losses, post-harvest losses and critical loss points along the dried bean supply chain in Kajiado and Kitui Counties of Kenya

Supply chain actor	*Variable*	*Kitui (%)*	*Kajiado (%)*	*Produce damage or spillage and cause of loss at CLP*
Producer	Quantitative pre-harvest losses	4.46	1.99	Pests and diseases associated with inappropriate agricultural practices
	Qualitative pre-harvest losses	2.08	1.17	
	Cumulative quantitative post-harvest loss	18.37	6.61	
	Quantitative post-harvest loss at CLP (on-farm processing)	8.73	2.93	Shattering of the pods and subsequent spillage owing to/associated with over drying which leads to the shattering of the pods and subsequent spillage in the farm during harvesting
	Cumulative qualitative post-harvest loss	10.14	3.55	
	Qualitative post-harvest loss at CLP (on-farm processing)	7.52	2.19	Breakages owing to/associated with over drying and excess mechanical impact applied during manual threshing

Notes: CLP – critical loss point.
FA – farm to aggregation.
SM – storage to market.

Source: Authors' survey (2022)

Table 2 Extent of pre-harvest losses, post-harvest losses and critical loss points along the dried bean supply chain in Kajiado and Kitui Counties of Kenya (continued)

Supply chain actor	*Variable*	*Kitui (%)*	*Kajiado (%)*	*Produce damage or spillage and cause of loss at CLP*
Trader	Cumulative quantitative post-harvest loss	6.61	1.60	
	Quantitative post-harvest loss at CLP (storage)			Spillage due to/associated with the poor quality of storage bags and poor storage practices in general
	Cumulative qualitative post-harvest loss	5.60	2.15	
	Qualitative post-harvest loss at CLP (storage)			Pests/weevils attack due to/associated with poorly stored/packed produce and storage practices
Transporter	Cumulative quantitative post-harvest loss	6.02	4.19	
	Quantitative post-harvest loss at CLP (loading from FA)	1.42	0.35	
	Cumulative qualitative post-harvest loss	5.63	3.54	
	Qualitative post-harvest loss at CLP (transportation from SM)	2.38	1.61	
Pre-consumer (targeted schools benefiting from HGSMP)	Cumulative quantitative post-harvest loss	0.89	4.19	Spillage attributed to the use of low-quality bags which easily tear and spill the beans
	Cumulative qualitative losses	5.63	3.54	Pest/weevils owing to/associated with lack of appropriate storage facilities, packaging, and good storage practices for beans

Notes: CLP – critical loss point.
FA – farm to aggregation.
SM – storage to market.

Source: Authors' survey (2022)

3.2.2 *Extent of post-harvest losses and critical loss points at the trader level*

The cumulative quantitative loss for the traders was 6.61% and 1.6% in Kitui and Kajiado Counties, respectively. The CLP for the trader is during storage where the losses were estimated. This agrees with the assertion by Kumar and Kalita (2017) that in developing countries, although post-harvest losses in grains are reported at each stage of the supply chain, maximum losses occur at the storage stage due to lack of adequate infrastructure. However, in this study, while the storage stage remained the CLP for traders, these losses were reduced by the fact that the traders were linked to the HGSMP that assured them of market for their produce which were then stored for a shorter duration. The losses in the stores resulted from spillage due to the poor quality of storage bags and poor storage practices in general. The storage stage remained the CLP for qualitative losses among the traders. The losses are estimated at 5.60% and 2.15% in Kitui and Kajiado, respectively. The leading issue associated with quality loss at the CLP for traders (storage) was pests/weevils attacks, as revealed by 70.37% and 64.91% of the respondents in Kajiado and Kitui, respectively. This finding agrees with that of Njoroge et al. (2019), who found that the storage stage is a CLP in bean production, with insect pests being the most important driver of post-harvest losses. It is noteworthy that some of the issues associated with losses at the trader stage were transferred from the producer. Breakages in bean grains are caused by manual threshing at the producer level and rough handling of packed grains in bags. Broken beans are more susceptible to attack by weevils, hence the high losses. In addition, some of the varieties stored by the traders, like *Nyayo* beans, are very susceptible to weevil attack. Lack of proper store management may also contribute to the high levels of the pest attack. Unlike the producers, traders store the beans for some time as they scout for profitable market outlets. According to the traders and observations during the study, causes of quality loss include inappropriate use of packaging technology, humidity leading to fermentation and exposure to high sunshine intensity leading to bean discolouration. The entire bean supply chain is highly susceptible to contamination by aflatoxin (Lombard, 2014). Some factors driving the contamination are high temperature, humidity, lack of appropriate storage facilities and pest damage (Sowley, 2016).

In most cases, traders are yet to reinforce their stores besides not opting to use/adopt appropriate packaging options. Consequently, poorly stored/packed produce is prone to insects and other pests (e.g., weevils) infestation. Poor storage causes damage to stored beans due to biological, environmental and other factors (Kumar et al., 2007). Appropriate storage is required for beans to be at the right temperature and free from water and pests and for ease of cleaning (Okello et al., 2010). The right storage temperature and relative humidity for bean storage are 25–30°C and RH < 65%, respectively (Abay and Tolesa, 2023). Higher moisture content before storage causes bulkiness, rotting or decay and ease of breakage during initial post-harvest handling activities such as shelling. Drying of beans extends their shelf-life through reduction of relative humidity, which reduces microbial attack.

3.2.3 Extent of post-harvest losses and critical loss points at the transporter level

The cumulative quantitative loss for the transporters was 6.02% and 4.19% in Kitui and Kajiado Counties, respectively. Generally, losses were negligible at all stages of transportation. However, in developed countries grain post-harvest losses at the transport stage are much lower due to significant investment in road infrastructure and engineered facilities on the field and at the processing stage to load and unload tracks rapidly with minimal or no damage (Kumar and Kalita, 2017). Loading, transportation and offloading were considered for farm to aggregation (FA) and storage to market (SM). Quantitative losses at CLPs for Kitui were 1.42% (Loading FA), 1.10% (transportation SM) and 1.09 (transportation FA), whereas in Kajiado, lower percentages were recorded for transportation FA (1.12%), Offloading FA (1.06%) and transportation SM (0.75%).

Qualitative losses at CLPs for Kitui were 2.38% (transportation SM) and 1.13% (loading FA), while in Kajiado, lower percentages were recorded at transportation SM (1.61%) and offloading FA (0.86%).

3.2.4 Extent of post-harvest losses at the pre-consumer (school) level

The cumulative quantitative losses at the school level were estimated at 0.89% and 4.19% in Kitui and Kajiado Counties, respectively. Quantitative losses due to spillages at the school level were minimal because the quantities handled are small, and the duration of storage is short (most schools procured enough beans for 22 days). The spillage can be attributed to the use of low-quality bags, which easily tear and spill the beans. In Kajiado, about 52% of the teachers indicated that the beans were stored in reused bags. In Kitui, about 38% of the respondents indicated that gunny bags were used to store beans. Most schools use polythene bags, which most traders use to package the beans. Traders prefer polythene bags because they are cheap and readily available compared to gunny bags and hermetic bags, which are recommended for grain storage. In Kajiado, no school reported using hermetic bags to store beans while in Kitui, only 2.6% of the teachers reported use of the hermetic bags.

Most of the losses reported were qualitative in nature. Up to 5.63% and 3.54% qualitative losses were reported in Kitui and Kajiado Counties, respectively. According to teachers in Kitui and Kajiado, the leading issue associated with qualitative losses in schools is pests/weevils. The high level of pests/weevils reported is a cause for concern, as it could be because the schools purchase beans which are already infested. Since they do not apply any treatment to the beans because of the short storage duration, the pest multiply leading to more damage. This highlights the need for better quality control measures in the procurement process. Most schools lack appropriate storage for the beans. In most schools, the classrooms are used as temporary stores for the beans and other non-food items exposing the produce to attack by pests and rodents.

Another driver of losses in schools is the type of bean variety. Schools in Kajiado had more varieties of beans to choose from than in Kitui. This could be attributed to more farming activities in Kajiado County compared to Kitui County. However, the choice of bean varieties supplied to schools is limited by the prices. The cheaper varieties were commonly stocked by traders who supplied the schools. In Kitui, all the beans consumed were purchased from other counties. The *Nyayo* variety is the most preferred across the 2 counties because it is cheaper, makes a thick stew and blends well with maize in the maize/bean meal. However, *Nyayo* beans are highly susceptible to weevils hence the high losses reported to be attributed to pests. In both counties, fewer schools stock/cook the 'Rose coco' and 'yellow bean' varieties because of their high price. Schools in Kitui County shun the 'Wairimu' variety because it is associated (by the school community) with digestive issues and flatulence.

3.3 Load tracking of beans: extent and causes of losses at the critical loss point for the trader (Kitui)

The winnowing stage was observed as the CLP in the bean value chain involving traders who buy the beans from the producers at the farm level. At the winnowing stage, 7.60% of the initial weight was lost. The quantitative and qualitative losses were attributed to spillage and mixing with much chaff/dirt, respectively. This agrees with the results of the survey, which found that spillage is the main cause of quantitative losses at the trader level. Winnowing during the less windy days aggravated the problem of chaff/dirt remaining on the beans. Much dirt was observed at later stages of the supply chain including schools. The minimal losses recorded at the beginning of storage (3.58%) were mainly due to spillage in part attributed to low-quality packaging materials, which are mainly reused polythene/plastic bags. Follow-up of the stored beans after 3 months of storage showed that only 0.8% of the initial quantity had been lost. The quality of the beans was still very good, and no cases of pest damage were observed because the beans were treated with storage pesticides before storage. The cumulative quantitative losses from farm to storage after 3 months were estimated to be 12%. This is in line with findings of the survey, which found that the traders who also doubled up as transporters reported cumulative quantitative losses of up to 12.63%.

3.4 Correlation analysis of household characteristics

The Pearson correlation coefficient (R) was used to examine the statistical relationship between the independent variables. A correlation coefficient near +1 indicates a strong positive relationship between the variables. Tables 3 and 4 reflect variations of socio-economic dynamics within each region, most visibly concerning how educational levels, credit availability, and group affiliation intersect with other determinants. The region of Kitui reveals closer linkages of determinants within institutions that are formally defined (credit, group affiliation, schooling), while that of Kajiado reveals closer familial correlations. This explains why households in Kitui County have higher levels of education, larger household sizes, higher group membership, access to credit and incomes from supply of produce (beans) to schools.

3.5 Underlying household characteristics contributing to losses at the farm level

The R^2 values of the OLS model show that the model explains over 50% of the variation in the pre-harvest and harvest losses in Kajiado and Kitui Counties (Table 5). At the pre-harvest stage, some underlying factors associated with reduction of losses were land size, income, farming as the main occupation and group membership. At the pre-harvest stage, the main causes of losses were identified as pests and diseases. Households with large land sizes and higher incomes might enjoy economies of scale in the management of pests and diseases. Control of pests and diseases also requires close monitoring of the crop. Households with farming as the main occupation have more time for crop monitoring and scouting. Their group membership also possibly exposes them to better methods of preventing and controlling pests and diseases. At the harvesting stage, land size, group membership and main occupation of the household head were associated with reduction of losses. Possible explanation is that larger tracks of land allow mechanisation during the harvesting of beans. Additionally, group membership could expose households to improved or modern harvesting techniques (Finizola et al., 2024; Ma and Rahut, 2024). These technologies require close supervision, which households with farming as the main occupation could afford.

Table 3 Correlations between household characteristics – Kajiado County

Variable	*Family size*	*Gender*	*Age*	*Edu*	*Occupation*	*Marital status*	*Land size*	*Income*	*Credit*	*Group membership*	*Experience*	*Labour source*
Family size	1											
Gender	–0.1746	1										
Age	–0.0032	–0.2457	1									
Edu	0.5035	–0.0349	–0.0219	1								
Occupation	0.1818	–0.3984	0.2002	0.1267	1							
Marital status	–0.0486	–0.2312	0.0099	–0.0888	0.0276	1						
Land size	0.4574	–0.4872	0.1995	0.2864	0.5344	–0.0291	1					
Income	0.4530	–0.0302	0.0005	0.2259	0.2025	0.1138	0.2155	1				
Credit	–0.1233	0.0899	–0.1622	–0.0490	–0.2006	0.0624	0.0326	–0.0849	1			
Group membership	0.0280	0.3647	–0.1184	–0.0429	–0.0490	–0.1842	–0.0630	–0.1632	0.2466	1		
Experience	0.0204	–0.1100	–0.3292	0.0263	0.1556	–0.0484	0.0692	–0.2153	–0.1166	0.0143	1	
Labour source	0.3165	–0.1886	–0.1465	0.3280	–0.0991	0.3051	–0.0281	0.3406	–0.0639	0.0864	–0.1303	1

Table 4 Correlations between household characteristics – Kitui County

Variable	*Family size*	*Gender*	*Age*	*Edu*	*Occupation*	*Marital status*	*Land size*	*Income*	*Credit*	*Group membership*	*Experience*	*Labour source*
Family size	1											
Gender	0.0481	1										
Age	0.0508	0.0406	1									
Edu	0.0877	0.2024	–0.0437	1								
Occupation	0.0591	–0.0171	0.1323	0.2519	1							
Marital status	–0.4023	–0.3727	–0.1504	–0.1474	–0.2353	1						
Land size	–0.0128	0.2665	0.1311	0.4407	0.1001	0.0222	1					
Income	–0.0734	0.3249	–0.1514	0.1831	0.4163	–0.0127	0.4859	1				
Credit	0.0310	–0.2170	–0.0608	0.5563	0.2553	0.0389	0.4213	0.2768	1			
Group membership	–0.0402	–0.2842	–0.0340	0.4449	0.1935	0.1033	0.2941	0.3640	0.8656	1		
Experience	–0.1578	0.1962	0.5780	0.0737	0.2071	–0.1552	0.2157	0.0866	–0.1060	–0.2146	1	
Labour source	–0.0861	–0.1841	–0.1036	0.0948	0.0134	–0.0906	–0.0456	–0.1794	–0.0608	–0.2523	0.0018	1

Table 5 Underlying household characteristics contributing to losses at the farm level

Variable	*Kajiado*		*Kitui*	
	Pre-harvest	*Harvest*	*Pre-harvest*	*Harvest*
Family size	0.0796 (0.066)	–0.0217*** (0.0025)	–0.0227 (0.0821)	.0017339 (.0250599)
Gender	0.1182 (0.3033)	–0.0356 (0.1254)	–0.2375 (1.1555)	–.0908714 (.2756532)
Age	–0.0034 (0.00715)	–0.0042 (0.0026)	0.0165 (0.0441)	.0268369*** (.0095539)
Education	0.0411* (0.0217)	0.0181*** (0.00116)	–0.0967 (0.1529)	.015879*** (.00451519)
Occupation	–0.1341** (0.065)	–0.0717** (0.02829)	–0.3567* (0.1818)	–.1257968** (.053757)
Marital status	0.5004*** (0.1744)	0.1998** (0.0861)	0.1865 (0.07971)	.4569663* (.2508325)
Ln_land size	–0.6428** (0.2753)	0.08015*** (0.01126)	0.1903*** (0.06925)	–.3698523*** (.0238931)
Ln_income	0.08935 (0.2289)	–0.0014 (0.1121)	–0.6134*** (0.07884)	.3640592*** (.02166145)
Credit	–0.4982 (0.5509)	–0.1980 (0.1694)	0.7644 (0.9681)	–.3103716 (.2719305)
Experience	–0.00722 (0.00675)	–0.0088** (0.00397)	0.0001 (0.03379)	–.086098 (.2069294)
Group membership	.0303505 (.1771107)	.1068004 (.0725331)	–.2726749*** (.0757965)	–.1420617*** (.01894932)
Source of labour	–0.1475 (0.1096)	–0.0741 (0.049)	–0.2727 (0.7579)	–.0053085 (.0115281)
constant	2.6216 (1.4006)	0.2976 (0.5439)	3.9519 (5.4293)	.6452598 (1.419307)
R-squared	0.568	0.6452	0.5390	0.5132

Source: Authors' survey (2022)

4 Conclusions and recommendations

Results of this study reveal that, on average, quantitative and qualitative losses of 24% and 20%, respectively, occur along the dried bean supply chain linked to the HGSMP in Kenya from pre-harvest to the storage stage in schools. Critical loss points responsible for the reduction in quantity and quality for the producer, trader and pre-consumer (schools) are on-farm processing and storage stages. Post-harvest losses at the transporter level are negligible, with loading from farm to aggregation being a CLP for quantitative losses and transport from storage to market a CLP for qualitative losses. Interventions to address the challenges that affect quality management and contribute to food loss require a targeted approach. Interventions should target specific actors and supply chain stages identified as CLPs. At the producer level, there is need for capacity building initiatives to train farmers on good crop husbandry in the field, harvest and post-harvest handling practices. The

EAC is currently focusing on ensuring better storage, packaging and processing technologies for farmers and small and medium enterprises.

Reducing storage losses (quantitative and qualitative) at the trader level requires awareness creation on applicable storage facilities and technologies and their benefits and facilitating access to these technologies. This will, in turn, reduce losses during transportation. At the pre-consumer level (schools' storage), there is need for dedicated rooms for food storage. The dedicated storage areas should be complemented with suitable, context-specific storage technologies and enhanced practices for storage management, quality tests and management. For instance, in schools where rodents are prevalent, metallic or plastic silos could be promoted, while hermetic bags can be in schools where rodents are not a problem.

Previous studies associated quantitative losses to food insecurity due to the reduction in amount of available food, increase in food prices, lower producer income, wastage of resources employed in producing food, which is ultimately lost, increase in the cost of waste management and greenhouse gas emissions (Kumar and Kalita, 2017; Mujuka et al., 2021). According to global estimates, food loss and waste generate 8% to 10% of greenhouse gases contributing to climate change (Mbow et al., 2019).

Regarding qualitative losses, previous studies including Mannara et al. (2025) linked it to the presence of aflatoxin. The study reported aflatoxin B1 levels above 5 μg/kg (the maximum limit for Kenya) from maize and beans samples collected from 40% of the schools under the school meals program in Turkana, Kenya. In children, cumulative exposure to aflatoxin in low concentrations leads to micronutrient deficiency, chances of vaccine interference, immunity suppression and growth impairments (Khlangwiset et al., 2011).

Furthermore, the results of this study illustrate how multiple barriers influence smallholder farmers' efficient participation in the studied supply chains linked to the home-grown school meals program. For instance, land size, income, and farming as the main occupation and group membership are associated with adequate food quality management resulting in food loss reduction at the farm level which can lead to more efficient production of marketable surplus.

Overall, the findings suggest that without comprehensive interventions to address entry barriers constraining smallholder farmers' participation in staple markets, along with supply chain-specific measures to improve food quality management and loss reduction, the impact of merely adjusting procurement methods, qualification criteria, and simplifying requirements to include smallholder farmers in HGSMP's food procurement remains markedly limited and risks compromising food quality and safety.

Disclaimer

The views expressed in this publication are those of the author(s) and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations.

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