Food Security
https://doi.org/10.1007/s12571-021-01244-x

ORIGINAL PAPER

Critical stages for post-harvest losses and nutrition outcomes in the value chains of bush beans and nightshade in Uganda

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Received: 16 March 2021 / Accepted: 10 November 2021

Abstract
The reduction of post-harvest losses (PHLs) has been identified as a key pathway to food and nutrition security in sub-Saharan Africa. However, despite policy prioritisation, knowledge about the severity of PHLs remains scant, especially when it comes to nutrient-dense crops such as African nightshade and bush beans. Therefore, this paper identifies loss hotspots, causes and effects throughout the value chains of nightshade and bush beans in eastern Uganda. Primary data collected following the Informal Food Loss Assessment Method, combined with small-scale load tracking and secondary data, allows for an analysis of physical, economic, quality, and nutritional losses throughout the value chains of both crops. Results show that in the bush bean value chain, severe physical and quality losses occur during post-harvest handling by farmers, leading to high economic losses at this stage of the chain. Nutritional losses are not expected to be significant in the bush bean value chain. By contrast, due to the shortness of the nightshade value chain, where produce is moved from harvest to consumption within one or two days, physical losses in most parts of the chain are relatively minor. Only at consumption stage, high physical losses occur. This is also the stage where economic losses and potential nutritional losses are most pronounced. The results of this study offer a deeper understanding of the value chain dynamics of bush beans and nightshade, including underlying gender relations, and identify concrete loss hotspots, upon which further research and practical interventions can build.

Keywords Post-harvest losses · Loss hotpots · Value chains · African nightshade · Bush beans · Uganda, Nutrition-sensitive

1 Introduction

Particularly in sub-Saharan Africa, the debate on reducing post-harvest losses (PHL), i.e. potential food crops which leave farmers' fields but never reach the consumers' plate (Sheahan & Barrett, 2017, p. 1), is ongoing in academia and policy-making. The issue of PHL reduction has increasingly become a central element of international and national development goals. Large amounts of food are lost annually on the continent – with severe consequences for food and nutrition security, food system efficiency, resource use, producer income, and consumer prices (Morgan & Larson, 2011; Schuster & Torrero, 2016; FAO, 2019).

However, limited knowledge about the magnitude of food losses remains a key barrier to addressing the problem (Lipinski et al., 2013; Schuster & Torrero, 2016). There is little coherence in research conducted, and data is often fragmented and unreliable (Affognon et al., 2015). Challenges include non-uniform measurement for the occurrence of PHL, a strong focus on estimating losses during on-farm storage, and a lack of variety of crops studied, which are mostly grains and cereals (Affognon et al., 2015; Sheahan & Barrett, 2017). Knowledge on PHL in other crops which are also important for food and nutrition security is still scant. Moreover, when investigating the causes of PHL, studies tend to concentrate on storage problems and insect infestations (Affognon et al., 2015), whereas other relevant factors, such as socioeconomic and context-specific dynamics

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that impact the handling of crops, are largely understudied (Tröger et al., 2020).

In this study, we analyse the extent and causes of PHL in two nutrition-sensitive value chains in Uganda (African nightshade and bush beans), thereby responding to recent calls for more research on PHL in nutrient-dense crops to complement the literature on grains and staples (Affognon et al., 2015; Stathers et al., 2020). Analysing where and why PHL occur by identifying critical loss points can help guide interventions to those parts of the value chain where losses are highest and reductions for positive nutrition outcomes are most promising (Peña & Garrett, 2018; FAO, 2019). We take a value chain perspective for the identification of loss hotspots, which serves to uncover contextual dynamics and interactions of value chain actors in PHL (Affognon et al., 2015; Sheahan & Barrett, 2017; Tröger et al., 2020). Finally, we attempt to bring in a gender lens, by examining to what degree gender relations play a role in PHL, which is considered an under researched issue in the literature (Cole et al., 2020). This is not only important to gain an understanding of the (gendered) causes of PHL, but is also critical for the development of intervention options to address PHL that fit women's practical and strategic needs, and address constraints that may limit them from technology adoption (Affognon et al., 2015).

Uganda is a country where PHL are considered to be high at smallholder level (Tibagonzeka et al., 2018; Tröger et al., 2020). By investigating PHL in the African nightshade and bush bean value chains, we focus explicitly on traditional food value chains. These are the predominant value chains in rural areas and have high potential for nutrition by offering low-priced vegetables and legumes to alleviate micronutrient deficiencies and undernourishment of the rural population (Gomez & Ricketts, 2013). African (or black) nightshade, an Aresults of IFLAM can stand alone as a case study (Torrelfrican indigenous vegetable mostly cultivated in kitchen gardens, has recently gained prominence in East African markets (Gogo et al., 2017). Nightshade commercialisation is increasing due to growing recognition for the vegetable's richness in vitamins, iron and protein, as well as its drought resistance and ability to adapt to the local environment and climate (Bioversity International, 2015). Bush beans, on the other hand, are one of the most widely produced crops in eastern Africa. Like nightshade, they are a major component of smallholder agriculture in Uganda, and fall under the same category of nutrient-dense crops (David et al., 2000). Bush beans are a crucial part of the Ugandan diet because, as the 'meat of the poor', they are the second-most important source of protein for locals (FAO et al., 2019).

For the PHL analysis, a common framework for fish loss assessment is applied, namely the Informal Fish Loss Assessment Method, used as the Informal Food Loss Assessment Method (IFLAM) in this case (Diei-Ouadi & Mgawe, 2011). This method generates qualitative and indicative quantitative PHL data, including reasons for losses and their relative importance. IFLAM thus creates an in-depth understanding of the local situation, which is needed before precise measurements can be made.

2 Literature review

2.1 Post-harvest losses

There is no common definition of food loss and waste. In a broad sense, food loss and waste can be understood as "the decrease in quantity or quality of food along the food supply chain" (FAO, 2019, p. 4). PHL is a sub-section of this, focusing on losses which occur during the interconnected activities from the time of harvest to the time when food is ready for final consumption (Affognon et al., 2015; Morgan & Larson, 2011). Thus, in line with general consensus in PHL literature, losses occurring during harvesting activities are included in this definition, whereas non-yields from pre-harvest stages are excluded.

Different types of PHL have been identified and defined in different ways by different authors. In this paper, we make a distinction between four different types of food losses, namely physical, quality, economic, and nutritional loss. *Physical* loss is the decrease in the mass of food destined for human consumption as it is removed from the food supply chain (FAO, 2019, p. 5). *Quality* losses occur when food is contaminated (e.g. presence of microbiological, chemical or physical hazards) or otherwise downgraded reducing its market value, e.g. due to deterioration in texture, flavour or colour (Gogo et al., 2017). Physical and quality losses lead to *economic* losses when parts of the produce are lost or when monetary value decreases because of quality deterioration (Affognon et al., 2015). Quality losses as well as preparation and handling practices can also lead to *nutritional* losses, i.e. a loss of micronutrients in food, which are typically more difficult to detect (Sheahan & Barrett, 2017). To increase nutrition and decrease hunger it is crucial to find suitable interventions for all types of losses (Peña & Garrett, 2018). Hence, this paper acknowledges the importance of all four kinds of losses and studies them individually.

Studies have shown that PHL occur during all stages of the value chain (see Fig. 1) and are more or less severe at certain stages depending on the crop. During harvesting a number of factors play a role in food loss: unsuitable harvesting times can lead to over-maturity and hence spoilage of food, and weather patterns can rush or postpone harvesting activities (Kikulwe et al., 2018). Moreover, inadequately performed field sorting can lead to already-harvested, high-quality crops being left on the field, and therefore going to waste. Poor post-harvest handling techniques and lack of suitable storage facilities can, particularly in developing countries,

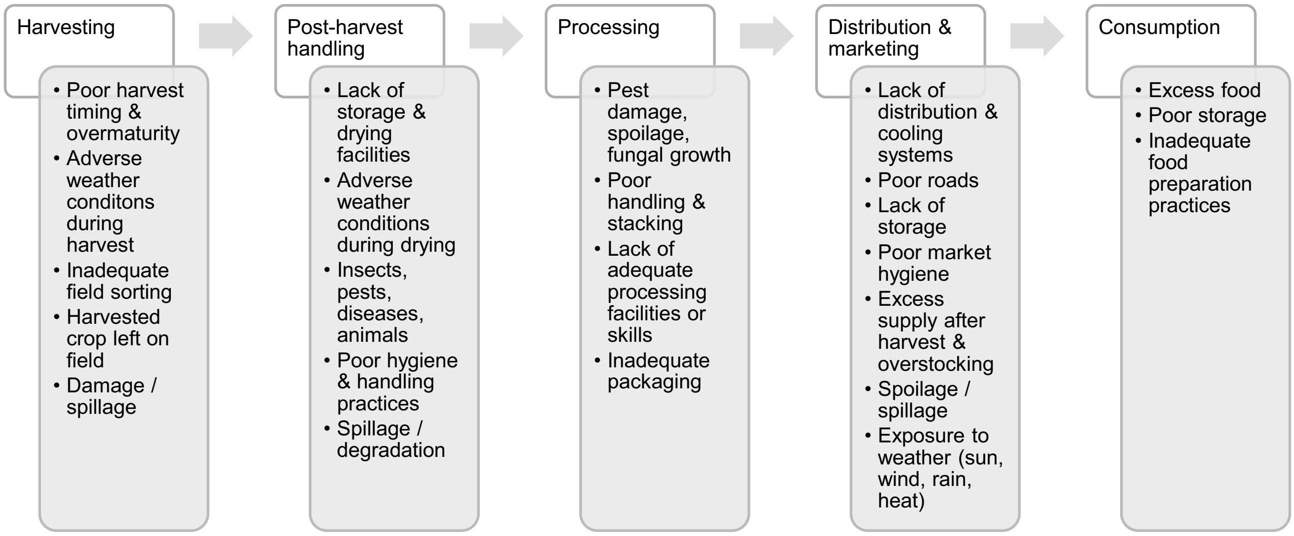


Fig. 1 Reasons for PHL in value chains. Source: Adapted from Lipinski et al. (2013) and Tröger et al. (2020)

lead to significant losses. This is often where the majority of losses occur (Affognon et al., 2015). For example, inadequate handling, such as drying, threshing, shelling or winnowing, can lead to quality deterioration (e.g. breakage of grains) and physical losses (e.g. spillage) (Tefera, 2012). Moreover, smallholder farmers often store their crops in houses without proper protection, making them vulnerable to pests and fungal growth (Chegere, 2018). Packaging, transport means, road conditions, and distance to market are further problems that increase PHL (Kikulwe et al., 2018). Also during marketing, losses are common due to a lack of market hygiene, proper distribution and cooling systems, and storage during retailing (Tröger et al., 2020). A problem that cuts across most of these stages is that value chain actors often lack appropriate knowledge and incentives to engage in PHL management, particularly when formal quality standards are absent (Bustos & Moors, 2018). Finally, food losses occur during food preparation and consumption, e.g. due to poor storage at home or bad food quality, although there is consensus that this is not the most critical stage for physical PHL in sub-Saharan Africa (Sheahan & Barrett, 2017). However, preparation practices such as cooking over long periods of time at high temperatures can lead to severe micronutrient losses and therefore are a nutritional loss hotspot.

Gender relations play an important role in PHL because they do not only influence intra-household division of labour, but also shape opportunities and constraints in the value chain, as well as who benefits (Cole et al., 2020; Lusiba et al., 2017). Gender analysis therefore can support an understanding of why women and men carry out certain activities in a value chain, or how they divide their time between economic activities and (unpaid) domestic tasks, and therefore who may be affected most by PHL (Cole et al., 2018).

2.2 African nightshade and bush beans

African nightshade (*Solanum nigrum*) is a green leafy vegetable rich in vitamins A and C, protein, iron and calcium, and other minerals (Ojiewo et al., 2015). In the past, indigenous African vegetables, such as nightshade, were not very prevalent on African markets because they were not promoted by seed companies (Cernansky, 2015). Crops introduced by colonial powers enjoyed greater popularity, so that preparation techniques for indigenous vegetables were lost over time and needed to be actively re-introduced. Due to increasing promotional activities by non-governmental organisations and research institutes, the demand for nightshade has been increasing in sub-Saharan Africa, including Uganda, and the vegetable can even be found in bigger supermarkets in large cities (Cernansky, 2015; Ojiewo et al., 2015). A number of seed companies have also started selling improved seeds. Nevertheless, nightshade farming, as well as post-harvest handling, and marketing, is mostly done by women in small-scale kitchen gardens with low input use, as it is perceived as a women's crop (Mampholo et al., 2016).

Research on nightshade in Kenya has shown that nutritional, physical, and economic losses throughout the supply chain are severe (Gogo et al., 2017). Identified reasons for these post-harvest losses are the "lack of certified seed varieties, unfavourable weather, inadequate post-harvest handling practices and technologies as well as insect pest and diseases" (Gogo et al., 2017, p. 39). From a PHL perspective, nightshade is thus a typical perishable crop, requiring effective intervention techniques to reduce losses. At the same time, the high nutritional value of nightshade and its perceived character as a women's crop, make it a particularly interesting crop for improving food and nutrition security through loss reduction (see Peña & Garrett, 2018;).

Bush beans (or common beans, *Phaseolus vulgaris*) are an important cash crop in eastern Africa, and a critical source of proteins, minerals (especially iron, zinc, calcium and phosphorus), vitamins B and carbohydrates (Broughton et al., 2003; Hayat et al., 2014). Uganda is among the largest producing countries of bush beans in East Africa, where they are mostly grown by small-scale farmers on less than two acres of land, typically in intercropping with maize with low input use and low productivity (Ronner et al., 2018). Bush beans have also often been considered a women's crop, as they were traditionally grown for subsistence (David et al., 2000). However, since their increasing commercialisation, men have become involved in different production activities, especially those that require more energy (Nakazi et al., 2017). At the same time, a displacement of women's labour does not seem to have taken place – instead beans have become a 'mixed crop' from a gender perspective, not only at production level, but at different nodes of the value chain (Nakazi et al., 2017).

Due to widespread demand and export trading, bush beans have become the second most cultivated crop in Uganda (FAO et al., 2019). Demand is expected to increase, also in view of Uganda's rapidly growing population – however, there are concerns that production will not be able to satisfy demand. Major challenges include poor agronomic practices, declining soil fertility, lack of improved seeds, poor seed selection, and high PHL. Research suggests that PHL have a variety of causes, including poor drying and sorting techniques by farmers, and inadequate storage practices by both farmers and traders (FAO et al., 2019). This places considerable pressure on food and nutrition security of poor and rural households, who can rarely afford alternative sources of protein, such as animal products (David et al., 2000).

African nightshade and bush beans are both crucial sources of nutrients in Uganda, and hence make up significant portions of local diets. Table 1 summarises their main characteristics and the gender division of labour for comparison.

3 Methodology

3.1 Measurement tools

The paper draws on the Informal Food Loss Assessment Method (IFLAM) and uses load tracking as a supplementary tool to assess and obtain insights into underlying reasons for PHL in the nightshade and bush bean value chains.

The IFLAM framework helps to develop a qualitative understanding of losses and provides indicative quantitative data on losses (Diei-Ouadi & Mgawe, 2011). Different studies have used the framework (Kruijssen et al., 2020), showing that IFLAM generates data that describes the types, causes, timing, impacts, and trends of post-harvest losses, as well as the stakeholders affected by these losses and their perceptions of the impacts (Torell et al., 2020). Loss assessment is based on a participatory approach, focusing on the

Table 1 Bush beans and nightshade: key characteristics and gender division of labour in Uganda

	Bush beans	Nightshade
Key characteristics		
Food group	Legumes	Green leafy vegetables
Purpose	Cash and food crop	Food crop
Final product	Fresh or dried (dried is most common)	Fresh
Seasonality	2 × per year (rainy and dry season)	Mostly during the rainy season
Growing period	3 months until harvest	2.5–3 months until harvest; can be harvested weekly by cutting tender stems
Gender division of labour		
Production	Both men and women (land clearance, ploughing & spraying done by men; sowing & weeding done by women)	Women (only spraying is done by men)
Harvesting	Both men and women	Women
Post-harvest handling	Mostly women (drying, threshing, sorting, storing as post-harvest activities)	Women (only washing as post-harvest activity)
Marketing	Larger quantities sold by men; smaller quantities sold by women	Women
Trading	Both men and women, but selling to different buyers (women sell to local retailers; men sell to institutional buyers, e.g. schools, and larger buyers/retailers)	Women
Retailing	Both men and women	Women
Food preparation	Women, unless at restaurants (both men and women)	Women, unless at restaurants (both men and women)

Source: Authors' data

active involvement of relevant actors who are knowledgeable about PHL at different stages of the value chain. The results of IFLAM can stand alone as a case study (Torrel et al., 2020), or, as has been done in this case, can be supported by load tracking (Kruijssen et al., 2020).

Load tracking is a quantitative loss assessment method used to measure specific losses along the value chain or losses related to specific activities, such as post-harvest handling, processing, transportation and marketing (Diei-Ouadi & Mgawe, 2011). It relies on both measurable quantity and quality losses at each stage of the value chain by evaluating quality and weight of a load of food product. Where IFLAM relies on interviews to ask questions about perceived losses, load tracking complements this by weighing samples of the same food item at different nodes in the chain, and observing its quality. In this case, load tracking was applied to a limited number of batches, providing indicative quantitative data on losses to supplement the loss estimations identified through IFLAM.

3.2 Operationalisation of losses

For this research, PHL were measured across four stages of the value chain: harvest; post-harvest handling; distribution and marketing; and consumption (food preparation). It should be noted that in the case of nightshade, harvest losses (e.g. degraded or rotten leaves) are sorted out directly in the field and are thus distinguishable from post-harvest handling losses. In the case of bush beans, however, harvest losses (e.g. degraded or rotten beans) are only sorted out during post-harvest handling, thereby making harvest losses and post-harvest handling losses indistinguishable.

3.3 1) Physical loss

Physical losses are measured in weight lost from one value chain stage to the next. The losses are calculated by subtracting the weight of crops discarded from the initial total weight of the crops. This is done either by weighing the unit of crop at the beginning and end of each stage or activity, or by weighing the starting volume and then collecting and weighing the losses directly. For this research only the second approach was used.

Physical losses are computed as follows:

Physical loss (%) = (Spoilage/ spillage of crop (kg) / Weight at beginning of stage (kg) × 100 [A]

3.4 2) Quality loss

Quality loss refers to quality deterioration, food safety hazards, and contamination. Local buyers follow clear quality criteria for both crops and pay a reduced price for crops which do not fulfil these. For nightshade observable quality criteria include no wilting, no discolouring of the leaves and no visible damage caused by pests. For bush beans criteria include no dirt, no mixing of different kinds of beans, no sprouting, no moulds and no visible damage caused by pests. Quality loss is measured in monetary value, which means that a loss is the deviation from the potential best price of a product with the best quality (Ward & Jeffries, 2000, p. 6). This is based on an estimate of the lost percentage of revenue that could have been generated, based on information on the usual price of the same product at its best quality (in Ugandan Shilling, UGX). Variations of best price between different traders and locations were taken into account for the calculations. Quality losses are calculated based on the starting quantity of food after deducting any physical loss in a particular value chain stage.

Quality losses are computed as follows:

Economic quality loss (UGX) =

weight sold at low price (kg) × (Best price per kg (UGX)—Reduced price per kg (UGX)) [B]

Maximum value of food after physical loss (UGX) =

[Weight at beginning of stage (kg) – Spoilage/ spillage of crop (kg)] × Best price per kg (UGX) [C]

Economic quality loss (%) = ([B] / [C]) × 100 [D]

3.5 3) Economic loss

The total economic loss is the percentage of total revenue lost due to physical and quality losses. Both loss of whole food and food depreciation (quality loss) can be measured by the deviation from the best price (again in UGX), which can be obtained for the best quality product at a given time (this does not include the difference between the current price and the highest possible price across the season). Consequently, the physical loss and quality loss calculated in the previous step are the basis for the assessment of the economic loss. However, they are not simply the sum of the two, as quality losses are calculated after physical losses are deducted. The total economic loss is based on the starting quantity at the beginning of the stage, before physical losses.

Economic losses are computed as follows:

Economic physical loss (UGX) = Physical loss (kg) × Best price per kg (UGX) [E]

Original maximum value of food (UGX) =

Weight at beginning of stage (kg) × Best price per kg (UGX) [F]

Total economic loss (UGX) = [E] + [B] [G]

Total economic loss (%) = ([G] / [F]) × 100 [H]

3.6 4) Nutritional loss

The assessment of nutritional loss is challenging because data on nutrient content of different crops and how nutrients are lost in the different stages of the value chain are rarely available, and there were resource constraints to conduct lab analyses to assess nutrient content. Therefore, the assessment of nutritional losses is approximated based on primary data on post-harvest handling and cooking practices, combined with secondary data (scientific studies) on the impact of these practices on the nutritional value of nightshade and bush beans. Here we focus on the impact of heat, light and water exposure on the nutrient content of these crops, by specifically looking at drying, soaking, washing, storage, and sun exposure during trading and preparation methods. Of course any physical loss brings with it a nutritional opportunity loss. However, in this study the focus lays on the abovementioned practices and their impact on nutritional losses.

3.7 Research site

Research was conducted in Kapchorwa in eastern Uganda, the country's second most populated district. Agriculture is the main income-generating activity in the area, and predominant crops include maize, beans, bananas, and coffee (Oduol et al., 2016). Bush beans are among the most commonly farmed crops in Kapchorwa, frequently planted on 0.5–1 acre, whereas nightshade is planted on a much smaller scale (mostly around 0.25 acres). Most agricultural produce is sold without any value addition, largely because of lack of storage and post-harvest processing equipment (Oduol et al., 2016). Both the nightshade and bush bean value chains are illustrative examples of traditional food value chains, where smallholder farmers primarily sell to traders, who typically sell to other traders in local markets and directly to consumers (Gomez & Ricketts, 2013).

3.8 Data collection

The IFLAM framework is a set of methodological steps designed to gather relevant information for the operationalisation of losses, consisting of the following seven stages (Diei-Ouadi & Mgawe, 2011).

3.9 1) Secondary data

An in-depth literature review was conducted, including previous case studies on PHL and data on the research site. Based on this, an indication of common PHL hotspots and underlying reasons and effects was obtained, which formed the basis for developing targeted interview guidelines for the field research.

3.10 2) Field observations

Field observations provided insights into the magnitude of losses and the socio-economic and infrastructural context in Kapchorwa. A checklist was used to guide observations on the following topics: hygiene of surroundings and people interacting with crops; storage facilities; measures taken to protect crops from rain, sun, and other contaminators; handling equipment and methods; types of crops sold; general market dynamics and practices; food preparation; and loss reduction measures. For each of the criteria, observation was used to assess the quality of crops as good or poor. All field data were collected in June 2019, which was during the rainy season in Kapchorwa.

3.11 3) Focus group discussions (FGDs)

Three FGDs were conducted with male farmers (12 participants), female farmers (11 participants) and a mixed group of young farmers (12 participants). The three groups were located in the lowland, midland, and highland of Mount Elgon in Kapchorwa, respectively, to represent all agro-ecological zones of the area. Hence, the FGDs gave insights into how relevant social groups who work under a variety of environmental conditions. These discussions served as an introduction to PHL and to discuss reasons for losses during harvest, transport, cleaning, drying, sorting, packaging, storage and food preparation. This was done via a group process in which all participants wrote down their own challenges and presented them to the group. These findings were then mapped out step-by-step to visualise the reasons for PHL in each value chain stage using a flow diagram.

3.12 4) Semi-structured interviews

In addition to the FGDs, forty-three interviews were conducted with different value chain actors: 20 interviewees were part of the bush bean value chain, 14 of the nightshade value chain, and 9 were actors in both. Actors were split into four categories: farmers; farmers who are also traders; traders; and restaurant owners (as consumers) (Table 2). Farmers and traders were also interviewed on their food preparation practices to inform the nutritional loss analysis. Interviewees were mostly identified via snowball sampling, which proved to be efficient in the local village culture.

3.13 5) Key informant interviews

Interviews with local experts were used to confirm and cross-check the findings of the interviews with value chain actors and the FGDs. Six expert interviews were conducted with local extension agents (to provide input on physical, quality and economic losses) and with two food scientists from Makerere University (to provide input on nutritional losses).

3.14 6) Load tracking

Four load tracking sessions complemented the interviews and FGD findings. Using a common kitchen scale for smaller amounts and a suitcase scale for heavier loads, the

Table 2 Interviews conducted in the bush beans and nightshade value chains

Category	Bush beans			Nightshade		
	Total	Women	Men	Total	Women	Men
Farmers	5	5	0	8	6	2
Farmer-traders	7	4	3	7	7	0
Traders	13	8	5	4	4	0
Restaurant owners	4	1	3	4	2	2
Total	29	18	11	23	19	4

Interviews with stakeholders active in both the bush beans and nightshade value chains were counted separately, as all interview questions were asked double (for bush beans and nightshade).

crops were weighed at the beginning (at harvest), and end (at consumer-level) of the value chain and at every stage in between. Moreover, losses during transportation were collected and weighed. The entire nightshade value chain from harvest to consumption was tracked during three of the four load tracking sessions. Because the bush bean harvest was delayed due to drought and because distribution and marketing of beans often extend over long periods of time, tracking of the entire value chain was not possible during field research. The load tracking session therefore focused on specific activities during post-harvest handling of bush beans.

3.15 7) Flow diagrams

Flow diagrams were first used during the FGDs to visualise PHL and trigger discussion. Based on the findings, advanced flow diagrams were then created to illustrate interconnections between the stages. To this purpose, the flow diagrams incorporate a set of categories: types and levels of losses, affected stakeholders, value chain stages and loss hotspots.

4 Results

To understand PHL along the value chains of bush beans and nightshade, the analysis follows the different value chain stages from harvest until consumption (food preparation). The processing step is not included because neither of the two crops go through processing as value addition other than by the final consumer (apart from post-harvest handling). Figures 2 and 3 summarise the loss estimates as percentages, based on the averages of the numbers reported by all interviewed value chain actors. The results indicate physical losses of 42.6%, quality losses of 13.8% and financial losses of 51.4% along the bush bean value chain. For nightshade, physical losses amount to 39.6%, quality losses are at 5.4% and financial losses reach 42.3% along the value chain.

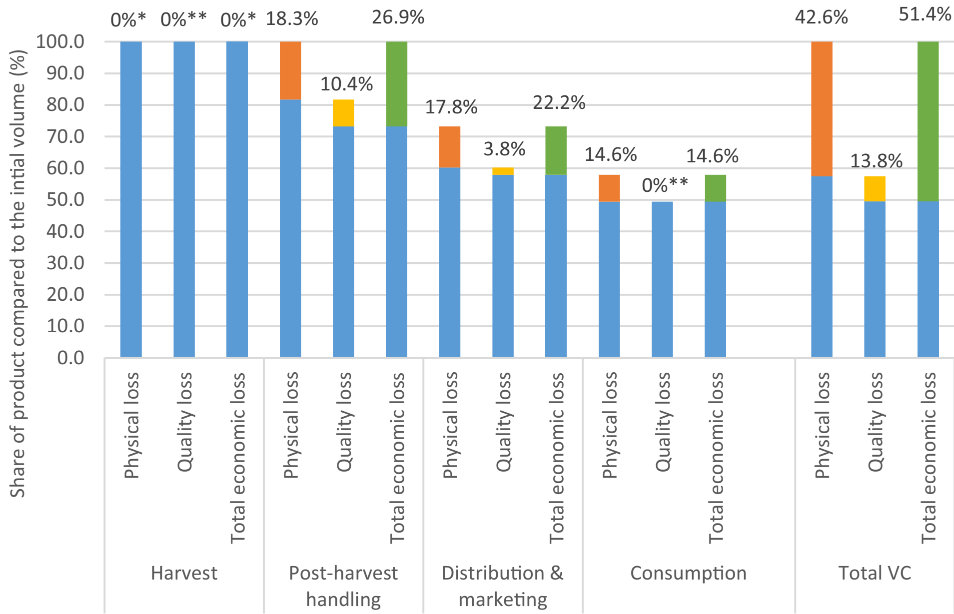
4.1 Bush bean value chain

Harvesting and post-harvest handling Bush beans are harvested via uprooting the whole plant. Harvest losses during uprooting are closely linked to the timing of the harvest: if the beans are left on the field for too long in dry weather, they tend to dry to such a degree that the pods pop open and spill the beans. If the beans are left on the field for too long in rainy weather, they will start rotting. Hence, the farmers reported great variety in harvest losses, ranging from minimal when harvest was timed well, to significant losses when harvest was delayed. Still, uprooting does not allow for precise selection of the beans on the field, so farmers simply uproot all plants, only sorting out rotten or germinated beans during post-harvest handling. This makes the distinction between harvest and post-harvest handling losses for bush beans difficult, which is why this paper merges them (see Fig. 2).

Another reason for harvest losses in bush beans is a lack of labour capacity to harvest efficiently, so that farmers are forced to leave crops behind on the fields to spoil. This is despite the fact that harvesting is usually a shared responsibility between men and women, regardless of whether the plot is managed by women (small plots with beans for home consumption) or men (usually larger plots with beans as cash crops).

Once the beans are uprooted, they are transported to the farmer's home for further handling. This was mostly done by women farmers interviewed, who typically carried the harvested beans on their heads and walked home, often for hours, since the fields were several kilometres from their homes. Only few women were able to afford motorised transport. Since the beans were piled up and tied together with bags or banana leaves, physical losses during transport can be significant. Moreover, during transport the beans are exposed to adverse weather conditions, particularly heavy rains, which can cause the beans to start rotting or germinating.

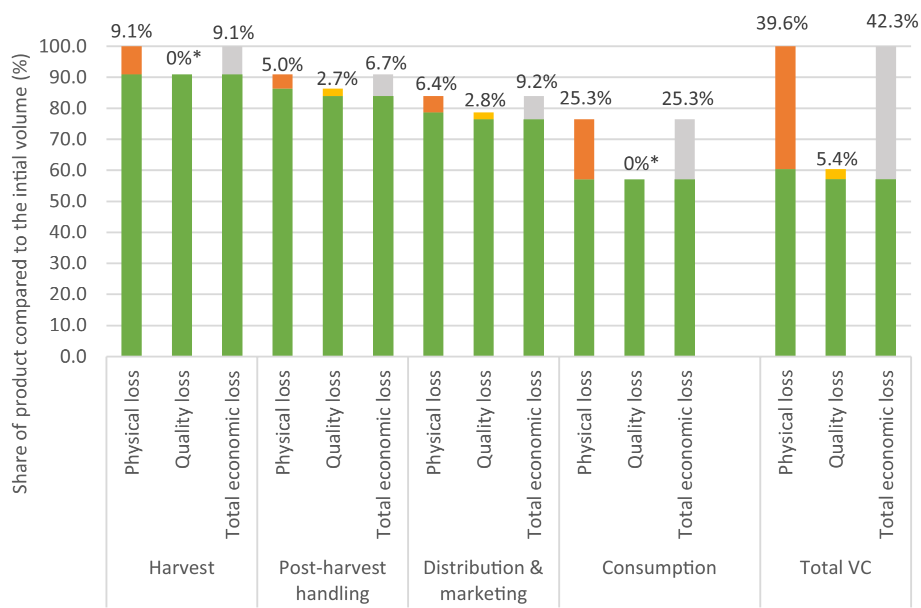
Fig. 2 Loss estimates for the bush bean value chain. Source: own data based on farmers self-reports. Note: Total economic loss entails physical and quality losses *Physical losses at harvest time could not be assessed. However, everything is harvested including beans unsuitable for consumption, which are then sorted out later. This way many potential harvest losses are carried through to the post-harvest handling stage, which is why those physical losses are relatively high. **Quality losses are not included at harvest and consumption stage as they are based on losses compared to the value of sales, which does not occur at these stages



Source: own data based on farmers self-reports. Note: Total economic loss entails physical and quality losses *Physical losses at harvest time could not be assessed. However, everything is harvested including beans unsuitable for consumption, which are then sorted out later. This way many potential harvest losses are carried through to the post-harvest handling stage, which is why those physical losses are relatively high. **Quality losses are not included at harvest and consumption stage as they are based on losses compared to the value of sales, which does not occur at these stages.

After transport to the farmers' homes, post-harvest handling – usually done by women supported by their children – takes place by means of drying (of pods), threshing, sorting, drying (of beans) and winnowing. This is when the beans that are rotting or germinating due to poor harvest timing are sorted out. Post-harvest handling activities offer several opportunities for high losses due to inadequate post-harvest equipment (e.g. few or old tarpaulins), post-harvest

Fig. 3 Loss estimates for the nightshade value chain. Source: own data based on farmers self-reports. Note: Total economic loss entails physical and quality losses *Quality losses are not included at harvest and consumption stage as they are based on losses compared to the value of sales, which does not occur at these stages



Source: own data based on farmers self-reports. Note: Total economic loss entails physical and quality losses *Quality losses are not included at harvest and consumption stage as they are based on losses compared to the value of sales, which does not occur at these stages.

techniques (e.g. threshing the beans by beating with sticks leading to spillage, breakage and contamination) and external factors (wind, rain, animals eating the crops, etc.). Losses during storage, usually in simple bags in farmers' homes, are also common, especially because of pests (weevils, rats, termites) and moisture.

Based on farmers' estimates, the total physical loss for farmers is around 18.3% of the entire yield. This estimate only included actual beans, not weight lost due to pod removal. In addition, quality losses are estimated at 10.4% of the remaining volume, leading to a total economic loss of 26.9%. These numbers include the losses that occur during harvest, transport, handling, and storage to show the total loss impact on farmers.

To validate these findings, some of the harvest and post-harvest activities were measured during load tracking. Harvesting, sorting before threshing and after drying, and threshing itself were tracked. Loss during harvest was minimal (1%), but increased during post-harvest handling. Due to heavy rains many beans started germinating and rotting, so they had to be removed. This led to a physical loss of 9–23%, excluding the crops lost during drying. Hence, the measured loss is comparable to the estimated loss of 18.3% by farmers.

Nutritional loss during harvest and post-harvest handling is not to be expected. Critically, protein, iron and zinc are neither heat- nor light-sensitive (Deol & Bains, 2010; Satpute & Annapure, 2013). Consequently, sun exposure during post-harvest handling activities does not impact their levels. In Kapchorwa, beans were dried by sun exposure, sufficiently reducing their moisture content to enable storage for long periods of time without germination or deterioration.

Distribution and marketing Most interviewed traders went directly to farmers' homes to purchase dried beans and sell them to consumers and other traders in shops in Kapchorwa or in small stands on the local market. Traders who come to the farm are usually men using motorbikes as transport, whilst traders on local markets can be female or male. During transport from farmers' homes to the market place, physical losses occur due to the same reasons mentioned in the post-harvest stage, i.e. leaking sacks, poor roads, rain impacting the beans' quality and accidents. Traders also complained about careless loading and unloading by the people hired for transport, leading to spillage of beans. Many traders dry and winnow the beans again before selling, to avoid visible quality deterioration which could lead to price reductions. Since many traders buy in bulk, they need to store beans for up to one year. Storage is done in sacks on wooden pallets, and while their shops or storerooms, usually built from stone, offer more protection from pests and moisture than farmers' homes, losses still occur, e.g. due to water leakages and spillage when moving bags.

Generally, traders experienced the impact of the losses less severely than farmers. Loss hotspots still occur during storage and transport. Overall, traders estimated a total physical loss of 17.8% during distribution and marketing, combined with a 3.8% quality loss of the remaining volume, resulting in a total economic loss of 22.2%. Thus, the total economic loss of traders is around 4% less than that of farmers. Nutritional losses are not expected because transportation, sun exposure, and storage do not impact the nutritional content of beans.

Consumption Interviews with farmers, traders and restaurant owners (both men and women) provided insights into the local consumer culture. Before preparation, the beans are sorted to separate broken or rotten beans. This is the only point during preparation where physical loss occurs, in addition to occasional losses during transport (from the market or shop to the kitchen). Storage losses are rare, as beans are bought in relatively small quantities on a frequent basis. Respondents estimated that about 14.6% of the beans are lost from purchase until food preparation. During load tracking, the sorting of good and poor quality beans resulted in a loss of 8%.

The nutritional content of beans can be impacted by preparation and cooking methods. Most restaurant owners reported to wash and cook the beans without soaking, often resulting in cooking times of more than three hours. Only three interviewees (out of 29) indicated to soak the beans prior to boiling. After boiling, the beans are usually fried for up to 30 min in a pan together with additional ingredients, such as tomato and onion as spice ingredients.

Studies indicate that cooking beans in water increases protein content (Wang et al., 2010) and protein digestibility (Bressani, 1993) by reducing antinutrients such as phytic acid and tannins (Ranilla et al., 2009). Minerals, such as iron and zinc, do not seem to be impacted significantly and studies confirm high levels of minerals also after cooking (Carvalho et al., 2012; Wang et al., 2010). The same holds for antioxidant compounds (López et al., 2013). Other nutrients, however, such as vitamins B, are more heat-sensitive and reduce during cooking (Barampama & Simard, 1995). As it is common practice in Kapchorwa to use the bean sauce created during cooking, water-soluble vitamins can be retained to some extent, unless they evaporate during cooking due to the use of ill-fitting or no lids.

4.2 Nightshade value chain

Harvest and post-harvest handling Harvesting and post-harvest handling of nightshade are considered the responsibility of women in the household. After the plant has reached a height of around 20 cm, mature leaves can be picked off on a weekly basis, usually by hand. This way, new leaves keep growing and the plant can be harvested for up to three months until it lignifies.

The harvesting technique itself does not usually lead to losses because careful handpicking is rather precise and prevents unnecessary spillage, compared to the uprooting technique used for bush beans. However, as nightshade is grown during the rainy season, harvest losses due to pests can be significant, with interviewees estimating that they need to sort out approximately 9.1% of the nightshade leaves during harvest, i.e. those leaves affected by pests.

Most women interviewed, cultivated nightshade within the compound of their home in kitchen gardens; therefore, there are no transport-related losses after harvest. Cleaning is the only post-harvest activity completed, usually by washing the leaves and leaving them in the sun to drip for a short period of time. Farmers reported that occasionally some leaves fall off during washing, but generally the losses are minimal. Particularly young nightshade rarely loses leaves, while older plants are more prone to losses. Nightshade is not stored, but rather sold directly after harvest so that farmers do not face any storage losses.

When asked about their loss hotspots, all interviewed farmers indicated challenges on the field and stated that post-harvest handling usually does not cause significant losses for them. Based on farmers' estimates, the physical loss of nightshade during post-harvest handling is 5%, including losses during transporting, washing and packaging. Quality losses are around 2.7% of the remaining volume, which can mostly be traced back to issues caused during the production stage on the field, such as insects and pests, impacting the overall quality of the nightshade. Total economic loss during post-production is 6.7%, which leads to a total economic loss of around 15% experienced by farmers, including harvest losses due to pests.

During load tracking, no physical losses of nightshade could be observed during the handpicking on the field and only 0–3% of losses during washing, drying and packaging. Overall, the women involved in the process were very careful to minimise losses.

Nutritional losses during the post-production stage can be expected to be insignificant (Kirigia et al., 2019). Firstly, according to the interviewed food scientists, during washing of nightshade, only minimal losses of water-soluble vitamin C are expected to occur, as the only open channel in the plant through which vitamins can pass is the cut end where the branches were snipped off the nightshade plant (Lee & Kader, 2000). Secondly, sun exposure during dripping of nightshade after washing is mostly not long enough to have a significant impact on the nutritional value. However, extensive exposure to heat and sun could significantly reduce vitamin C content (Santos & Silva, 2008).

Distribution and marketing Compared to bush beans, nightshade is traded on a much smaller scale. Many farmers sell to neighbours or women traders from the village, who buy the produce at farmers' fields and walk to town to sell it at the local market. For transport, the nightshade is usually packed into large white sacks, which, according to traders interviewed, usually does not lead to physical losses. However, it can lead to quality losses if the nightshade is packed too tightly. At the market, traders spread the nightshade out on sacks on the ground, or wooden market stands. Physical and quality losses are only experienced if nightshade is exposed to full sun for too long, e.g. if demand for the produce is low or if nightshade is passed from trader to trader before reaching the consumer. Based on traders' estimations, they experience an average total physical loss of 6.4%, including transport and trading. Thus, the physical loss is not as significant for nightshade as it is for beans. The quality loss of nightshade is 2.8% of the remaining volume, leading to a total economic loss of 9.2% for traders. Hence, around one-third of this total can be allocated to quality reductions. Wilting or signs of pests force traders to sell for lower prices or to sell bigger bundles for a regular price.

The nutritional loss during distributing and marketing can be expected to be more significant than the physical loss. Particularly at the market, nightshade could potentially lose all its vitamin C when exposed to sun all day. Consequently, the level of the loss depends on time and intensity of exposure (Santos & Silva, 2008).

Consumption Nightshade is typically prepared the same day as it is purchased, since storage at ambient temperatures leads to quick quality deterioration. From a nutrition perspective, this is also sensible, since nightshade has been found to lose different nutrients during storage in non-refrigerated conditions (Kirigia et al., 2019).

Different losses occur during food preparation, starting with physical losses while sorting and cleaning. Many respondents reported throwing away large parts of the purchased nightshade, including fruits and hard stems (which are despite being palatable not eaten) as well as wilted and damaged leaves. This results in a physical loss of 25.3% at consumption level, based on interview estimates. During the load tracking, the average loss due to sorting was 40%.

All interviewees were asked about their cooking practices, as cooking is necessary to increase bioavailability of nutrients but can also be a significant source of nutritional loss. Most interviewees reported boiling nightshade for 30–60 min until it is "very soft" and pouring out the boiling water up to three times to reduce the bitter taste. Many respondents then fry the nightshade with additional ingredients such as milk or peanut paste to further reduce bitterness.

Boiling and stir-frying improve palatability and reduce antinutrients in nightshade, such as tannin, as opposed to the raw vegetable (Managa et al., 2020; Sivakumar et al., 2020). Cooking also eliminates risks of bacterial or fungal contamination while not reducing the anticancerogenic properties of nightshade (Odongo et al., 2018). Frying can also improve the availability of fat-soluble vitamins, such as vitamin E, in nightshade. At the same time, studies suggest that nutritive properties can leach from nightshade with long boiling times and when discarding the boiling water – a common practice among respondents (Moyo et al., 2018; van Jaarsveld et al., 2014). Studies have shown significant losses after extensive boiling for vitamin C (Dappah et al., 2019), β-carotene (Traoré et al., 2017) and for minerals such as calcium, iron and magnesium (Dappah et al., 2019). Detailed lab analysis comparing different preparation methods and their impact would be needed to give more detailed accounts of nutrient gains and losses.

5 Discussion

5.1 Loss hotspots in comparison

Physical losses Total physical losses in the bush bean and nightshade value chains are relatively similar, with 42.6% and 39.6%, respectively. The findings on nightshade are close to the general loss estimations of 50% of vegetables in sub-Saharan African (FAO, 2011, p. 7; Chaboud, 2017). However, extant estimates of losses of pulses in sub-Saharan Africa (FAO et al., 2019; Tibagonzeka et al., 2018) are around 25% less compared to what this study has found. One explanation for this discrepancy could be that this research was conducted during the rainy season, during which losses are higher than in the dry season. Furthermore, various factors such as sample size, crops studied, geographic location, and data points used could contribute to this discrepancy.

While nightshade is a highly perishable crop, physical losses for most actors are limited by the short value chain – the produce can go from harvest to consumption within a single day, as it is sold fresh and distribution occurs close to production. Consequently, there are few activities where losses can occur. The largest share of physical losses occurs during food preparation: 25.3% of the food bought by consumers is lost – a volume which makes up nearly half of the food physically lost over the whole value chain. This suggests that consumption-related losses warrant closer attention in future research, rather than focusing predominantly on losses at farm level.

Contrasting the nightshade value chain, the bush bean value chain is much longer and offers different loss opportunities, particularly for farmers and traders. Harvesting and post-harvest handling are time-consuming activities that take around one week, which can compound losses. Significant losses are also experienced during transport and storage. As bush beans can be stored for up to one year, this offers a long timeframe for additional losses to occur. However, the long-term storage of beans enables farmers as well as traders to strategically sell their beans when they can get a higher price for the product. This is not the case for nightshade. The consumption stage makes up the smallest proportion of total physical losses, as opposed to the largest proportion in nightshade.

Quality and economic losses As opposed to the similar total physical loss estimates for both value chains, the total economic loss for bush beans is higher than that of nightshade (51.4% versus 42.3%) due to higher quality losses. However, what is important to note are the differences in development of quality losses throughout the value chains. In general, for nightshade the quality loss remains at the same level of 2.7–2.8%, while for bush beans it decreases from 10.4% during post-harvest handling to 3.8% during distribution. Nightshade is highly perishable and value chain actors lack cooling facilities and sun protection to maintain high quality throughout the value chain. Thus, the quality loss hotspot is mostly during the late stage of marketing. For beans, storage during post-harvest is the quality loss hotspot due to pests and moisture. At the same time, the observable quality of bush beans can continuously be improved by sorting out bad beans, by removing dust, stones and other particles, and by re-drying and re-winnowing. This is often done by traders to avoid price discounts.

In line with this, the economic losses for bush beans, despite being overall higher, continuously decrease throughout the stages of the chain, while they increase in the case of nightshade. Hence, nightshade consumers experience the highest financial loss out of all value chain actors (25.3%), while the opposite holds for bush bean consumers (14.6%). The high sorting loss of nightshade, due to inedible parts and poor quality, leads to high economic losses, as consumers pay for parts of the plant that are not eaten. In the bush bean value chain, farmers are the actors experiencing the highest economic loss. Overall, there is the potential to improve bush bean quality throughout the value chain, which is currently not the case for nightshade often causing a continuous reduction in quality.

Nutritional losses. Nutritional losses greatly depend on preparation methods by local consumers, including pre-cooking (washing, cutting), cooking (boiling, frying, etc.), soaking and use of soaking water, boiling and use of boiling water. Food processing at restaurant and household level can add nutritive value – e.g. by making nutrients more available – as well as reduce nutrients (e.g. vitamin C). The significance of these losses for local nutrition requires further assessment, especially in light of local forms of preparation and the bioaccessibility of nutrients. Moreover, the general contribution of bush beans and nightshade to local diets and health should be investigated further. For example, nightshade, while being rich in vitamins, seems to be most interesting for its bioactive plant compounds, including anticancerogenic and antidiabetic values (Managa et al., 2020; Moyo et al., 2018; Odongo et al., 2018). Locals might not know the exact nutrient components of nightshade, but they are well aware of its general health benefit which often motivates nightshade cultivation.

5.2 Gender relations and PHL

Gender relations play an important role in PHL, and affect the degree to which men and women experience PHL, as they vary in their engagement in value chains. This results from gendered roles and responsibilities, access and control over resources, decision making power, and gender norms. As such, unequal gender relations also affect the adoption of PHL reduction technologies and practices (Cole et al., 2018). As technical innovations often favour men over women due to differentiated access to resources (Doss et al., 2001; Quisumbing & Pandolfelli, 2010), any intervention needs to be sensitive to the needs and preferences of these women, without displacing them as important value chain actors.

The investigated nightshade value chain in Kapchorwa is dominated by women, from cultivation, harvest and post-harvest handling, to trading and marketing. Income gained is also kept by the women involved. This value chain thus holds important potential for economic empowerment of women farmers, as their roles in cultivation and trading are culturally accepted, and PHL losses, due to the shortness of the value chain, are relatively limited, except for the consumption stage. Nonetheless, reductions in PHLs can still be achieved. For example, harvest losses averaged around 9.1%, but can amount to higher losses in years with high pest and disease incidence. Buying pesticides may not be an option for many women, as nightshade cultivation is typically considered as part of the housework, rather than an economic activity, and may therefore not warrant the expenditures of pesticides. Even if pesticides were bought, spraying is part of the men's tasks in agricultural production, which may set in motion undesired intra-household decision-making dynamics in what is typically the women's responsibility. Using locally available plants to produce plant-based pesticides (Stevenson et al., 2017) may therefore be more responsive to women's situations.

Furthermore, quality losses during distribution and marketing warrant further attention, as women traders purchase nightshade at farmers' fields and carry the produce to the nearest market, where they market nightshade under full sun exposure. Wilting and other visible signs of reduced freshness lower the price that women are able to obtain, while the strenuous transport also limits the quantities that women are able to sell. Yet, transport by hired motorbike – which is quicker and can increase the volume traded – or market stands that offer shade are often beyond the financial means of women traders. Such constraints thus need to be taken into consideration in PHL interventions.

In the bush bean value chain, gender relations are even more complex, in that bush beans are considered a mixed crop, with both male and female labour input. However, it should be noted that the decisions on how and by whom labour input is spent, are traditionally made by men, influenced by perceived physical energy requirements, control over resources and gender norms (Cole et al., 2018; Lusiba et al., 2017).

In the bush bean value chain, one of the hotspots of PHL, especially physical and quality losses, can be found during activities typically conducted by women: firstly, during transport from the fields to farmers' homes and secondly, during post-harvest handling, i.e. drying, threshing and sorting. This has implications on how to reduce PHL during these activities. On the one hand, the use of technologies, such as motorised transport or threshing machines may be insensitive to the women in charge of these tasks and rather reinforce dynamics of male dominance (Lusiba et al., 2017). On the other hand, the dominance of men in decision-making on labour allocation and control over the income earned from bush beans, may also discourage and reduce women's commitment to participate in and undertake practices that may reduce post-harvest losses (Lusiba et al., 2017). It may also deny women the opportunity to express their own ideas for reducing PHL (Jahan & Sarker, 2015). Thus, integrating women into PHL innovations is critical, while taking into account and perhaps challenging prevailing household decision making structures.

This also holds when addressing another hotspot of physical losses in the bush bean value chain, namely distribution and marketing. While both women and men are involved in trading, they show particular differences in the quantities traded (men usually deal with larger quantities than women) and targeted market outlets (women generally sell at local markets or small shops, compared to men who have access to larger markets and institutionalised buyers). This is often due to women's mobility constraints, seeing that women always depend on and often need to pay men for the motorised transport of beans, and other household responsibilities translating into time constraints. As such, approaches to reduce PHL can focus on the practical needs of women and men, but they can also aim to overcome gender-based constraints in the value chain, challenging socio-cultural norms around women's mobility and household responsibilities. This is what Cole et al. (2020) refer to as 'gender-transformative' PHL reduction approaches.

5.3 PHL interventions

While the previous section focused on the gender dimensions of the studied supply chains and the importance of 'gender transformative' PHL reduction approaches, this section introduces preliminary ideas on product and process interventions. It is important to note that all interviewees considered a lack of financial means to be their primary constraint in implementing any PHL reduction measures. Therefore, affordability needs to be a key criterion in selecting locally appropriate interventions. These interventions can target various steps of the value chain.

One way to affordably reduce physical and nutritional losses would be to explore alternative food preparation and processing methods. For example, research has shown that sprouting of legumes can increase the bioavailability of nutrients (Masood et al., 2014). Currently, sprouted bush beans are sorted out as they do not fulfill local quality criteria. Making use of sprouted beans could therefore be a powerful intervention to reduce losses and enhance nutrition and requires further investigation. With regard to nightshade, many of the stems, which are palatable, are sorted out before consumption. Additionally, locals used nightshade berries exclusively to generate seeds. The local nightshade berries, however, have proven to also have nutritional benefits (Kamau et al., 2020). Alternative ways of food preparation that include the stems and the berries could reduce physical and nutritional losses and could help unfold the full potential of nightshade as a nutrient dense crop. These interventions would need to go hand in hand with trainings to inform locals about them.

Secondly, the implementation of an information tool for weather and market forecasting could reduce physical and economic losses at relatively low financial costs (Shafiee-Jood & Ximing, 2016). Harvest and post-harvest handling depend strongly on weather conditions. Adequate forecasting would give farmers the possibility to adjust their harvesting schedules according to local forecasts, especially for bush beans. For nightshade, market forecasts can help farmers and traders avoid oversupply, which can reduce losses as nightshade needs to be sold straight after harvest.

Another important hotspot for interventions that was stressed by interviewees is storage. For bush beans, improved insecticide-impregnated storage bags would be a strong alternative to the currently-used storage sacks (Jones et al., 2015). These improved bags prevent pest infestations for dried crops such as beans, and thus they reduce losses at storage level. insecticide-impregnated bags bags make the purchase of additional pesticides unnecessary. Further, they reduce toxins at market level and do not require large scale behaviour changes by locals. However, supply of even normal bags was broadly mentioned as a constraint, and would therefore need to be upscaled. Further exploring alternative local storage interventions and educating people about them could be another affordable and locally accepted approach.

All of these interventions offer starting points for the reduction of PHL. Still, they require sensitisation of local farmers, traders, and consumers to create awareness of loss hotspots and potential improvements. Most importantly, awareness of the impact of factors such as sun exposure and cooking on the nutritional value of particularly nightshade needs to be spread.

6 Conclusion

In view of the inherent differences in the post-harvest handling, perishability, and length of the value chains of bush beans and nightshade, their physical, quality, economic and nutritional loss hotspots vary greatly.

The bush bean value chain is spread out over a longer period of time, resulting in severe physical and economic losses. The main loss hotspot is at the level of farmers, as harvest and post-harvest handling activities result in considerable physical losses. Quality losses occur particularly during storage in view of pests and rot-causing moisture. Such damage decreases the value of the product, leading to high economic losses for farmers. Traders are also affected by high physical and economic losses, albeit to a lower degree. Here the main cause of losses is related to the storage of beans for longer periods of time. Overall, the bush bean value chain offers few opportunities for significant nutritional losses.

In the nightshade value chain, produce is moved from harvest to consumption within one or two days, offering fewer opportunities for PHL to occur – at least from the perspective of farmers and traders. While quality and nutritional losses can occur during marketing, as heavy sun exposure causes wilting and vitamin reductions, the economic losses for traders resulting from these are limited. PHL are most impactful at consumption level. Consumers receive a product whose quality is lesser due to prior marketing, and they further need to sort out large parts of the vegetables as non-palatable. The physical, economic, and nutritional loss hotspots therefore occur during food preparation, making consumers the actors most affected by PHL in the nightshade value chain.

Both nightshade and bush beans therefore offer substantial opportunities for loss reductions, at essentially all stages of the value chain. Partially, these losses are affected by unequal gender relations, as women's and men's engagement in the two value chains differs. At the minimum, interventions should take these differences into account, but there is also potential to reduce losses while overcoming gender-based constraints. Loss interventions put forward in this paper offer starting points for affordable and locally feasible loss reduction.

The data underlying this study is qualitative and measurements are mostly based on approximations rather than precise quantification. Nonetheless, the approach of combining IFLAM with Load Tracking offered a strong starting point for a more quantitative analysis of local loss situations. More exact measurements can be targeted towards the identified loss hotspots now that there is a deeper understanding of the value chain dynamics of bush beans and nightshade. Future research could also focus on quantifying nutrient losses in bush beans and nightshade from a food science perspective. Moreover, the relevance of nutrient losses on malnutrition levels in Uganda requires further assessment.

Finally, the seasonal timeframe of this study needs to be taken into account when interpreting its results. Research was conducted during the rainy season, when PHL are more severe than during the dry season – although the latter has its own potential challenges. A comparative analysis between the local loss situation during dry and wet seasons would give insights into the local impacts of extreme weather conditions on losses, particularly from a foresight perspective in times of climate change.

Acknowledgements The authors would like to thank Dr Irmgard Jordan from Justus Liebig University Giessen for her expert advice on nutritional losses in the nightshade and bush bean value chains. They would also like to thank Andrew Cheptoek for facilitating the interviews and focus group discussions. They express their gratitude to all interviewed nightshade and bush bean farmers, traders, retailers, restaurant owners, extension officers and anyone else who offered their expertise. Finally, the authors are thankful to Galen Dole for his support in calculating the losses across the value chains.

Authors' contributions Klara Strecker was in charge of research design, data collection, data analysis and writing of findings. Verena Bitzer contributed to research design, interpretation of findings and writing of findings. Froukje Kruijssen contributed to research design, calculations of post-harvest losses and writing of findings.

Funding The research leading to these results was conducted in the project "Education and Training for Sustainable Agriculture and Nutrition in East Africa", funded by the Long Term EU-Africa research and innovation Partnership on food and nutrition security and sustainable Agriculture (LEAP-Agri). This specific study received funding from the Dutch Research Council (NWO) under Grant Agreement No W 09.03.102.

Availability of data and material Interview data and post-harvest loss calculations are available upon request.

Code availability Not applicable.

Declarations

Conflicts of interest The authors declare that there are no conflicts of interests.

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