



Food loss for green leafy vegetable, rape (*Brassica napus* L), in a rural-to-urban supply chain in Zambia

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Abstract

Vegetables in Sub-Saharan Africa (SSA) play very important roles in food security and nutrition, household income, and livelihoods. The proportion of food-insecure people is higher in Africa than in other parts of the world, and one of the major factors attributed to this is food loss and waste. The green leafy vegetable rape (*Brassica napus* L), from the family *Brassicaceae*, is dominantly grown, traded, and highly consumed in Zambia. Yet, systematic evidence for food loss and waste of this vegetable in SSA remains limited. Therefore, this study aimed to determine the food losses, economic food losses and the critical loss points and underlying food loss causes in a rural-to-urban supply chain for rape in Zambia. Primary data was collected at the farm, transportation, and trading levels of the food supply chain using the FAO food loss assessment method, complemented by secondary data for the preparation of data collection tools. The study found that the harvesting stage incurs relatively high physical food losses, while the trading stage incurs the highest food losses in the supply chain. The quality, physical, and total economic food losses found for the supply chain are high, but within those reported in the literature. Based on the FAO guidelines, the harvesting and trading stages have been identified as the critical loss points in the supply chain. These findings suggest interventions that should include training in harvesting / postharvest handling, packaging in transportation, and product and environmental hygiene at the farm and trading levels.

Keywords Food loss · Critical loss points · Food supply chain · Green leafy vegetable · Rape · Zambia

1 Introduction

It has been estimated by the United Nations that 10% of the world population is prone to severe food insecurity. The proportion of people who are food insecure is higher in Africa than in other parts of the world, estimated at 19.1%,

equivalent to 250 million undernourished individuals (FAO, IFAD, UNICEF, WFP, and WHO, 2020). One of the major factors attributed to this global and African food insecurity picture is food loss and waste. The achievement of the UN Sustainable Development Goal (SDG) No. 2 - Zero Hunger by the year 2030 and SDG No. 12 - Achieving sustainable

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consumption and production patterns, is thus threatened by the global food loss and waste (FAO, IFAD, UNICEF, WFP, and WHO, 2020). Food loss holds significant importance in Africa, prompting the African Union to develop a Postharvest Loss Management Strategy in 2018. The primary aim of this strategy is to reduce postharvest losses by 50% by the year 2025. However, the introduction of this strategy appears to have been delayed (AUC, 2018). When food is lost or wasted, all the resources that were used to produce this food go to waste, including water, land, energy, labour, and capital.

Food loss has been defined as ‘the decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption (FAO, 2018). Food loss can be defined in quantitative and qualitative dimensions (Hodges et al., 2011; Strecker et al., 2022). According to Buzby & Hyman (2012), qualitative food loss, also known as quality food loss (Strecker et al., 2022), occurs when the food is injured or damaged to an extent where it has lost the quality [sensory (visual) or nutritional quality], such that the food can still be consumed but is more likely to be sold at a reduced price due to reduced quality; quantitative food loss, also known as physical food loss (Strecker et al., 2022), is when the food is injured or damaged to an extent that the food is either discarded because it is no longer fit for human consumption or the reduction in mass or weight.

Food losses can either be due to direct or underlying drivers (FAO, 2014; Flanagan et al., 2019). Direct causes are immediate determinants of poor food quality along the food supply chain, and usually also relate to the food safety of the product itself. Direct causes may be categorized into those due to mechanical, physiological, and or pathological damage. Mechanical damage, also known as physical injury, is a form of food loss as a result of bruising, skin breaking, etc. Physiological damage is a form of food loss as a result of weight loss due to loss of moisture, volatile substances, and leakage of juicy material. Pathological damage is a form a food loss as a result of pests, disease, fungal attacks, and other pathogens. Underlying drivers are factors leading to the direct causes, and can be categorized into technological, management, behavioural, and structural causes (FAO, 2014).

Various approaches have been used to determine the extent of food loss in different food supply chains (Delgado et al., 2021). The most commonly used methods include soliciting estimates from stakeholder-value chain actors, surveys based on recall methods, and objective measurements by sampling at supply chain stages (Ishangulyyev et al., 2019). FAO has recommended food loss assessment methods based on screening, survey, sampling (load tracking), and synthesis (FAO, 2014). Of these, the survey food loss assessment

method is based on recall through a questionnaire differentiated for different categories of actors along the food supply chain. The FAO recommended methods are similar to the Informal Fish Loss Assessment Method (IFLAM), Load Tracking (LT), and Questionnaire Loss Assessment Method (QLAM) recommended by Diei-Quadi & Mgawe (2011) for the fish value chain. The IFLAM method is also called the Informal Food Loss Assessment method (IFLAM) when used to assess foods other than fish (Strecker et al., 2022). The FAO (2014) food loss assessment method recommends that critical loss points (CLP) be determined in the food supply chain. Strecker et al (2022) have termed the CLPs as hotspots. FAO (2014) defines CLPs as the points in the food supply chain where food losses have the highest magnitude, the highest impact on food security, the highest number of actors affected, and the highest effect on the economic food loss result of the food supply chain. The IFLAM, LT, and QLAM methods have been used for food loss assessments for different food value chains, including vegetable value chains (Shee et al., 2019; Strecker et al., 2022).

Vegetables in Sub-Saharan Africa play very important roles in food security and nutrition, income, and livelihoods. Globally, Africa has had the largest increase (32%) in the production of primary vegetables between 2008 and 2018 (Ebert, 2020). The green leafy vegetable, rape (*Brassica napus* L), belonging to the *Brassicaceae* family (Sadowski & Kole, 2016) is highly consumed in southern African countries including Zambia (Ganya et al., 2018). Data from Mukarumbwa et al (2017) reports that green leafy rape is among the dominantly grown vegetable (by 51% of households) in Zimbabwe, which has a similar diet pattern to Zambia. There are different varieties of green leafy vegetable rape grown in Zambia and Zimbabwe, with the most commonly grown and traded in open-air markets being English giant and Hobson varieties (Ganya et al., 2018).

Green leafy rape has been grown and consumed by households in Zambia for a very long time (Nkhungulu & Msikita, 1985). A more recent food consumption study in two rural districts of Zambia based on 24-h recall found up to 49% households (Alamu et al., 2019), and a CUTS & WFP (2018) study in the capital of Zambia – Lusaka found that up to 97% of the households consumed green leafy vegetables. The Alamu et al (2019) study, further found that children consumed up to a mean value of 82 g/day (range of 15 to 313 g/day) of green leafy rape and a mean of 64 g/day (range of 13 to 184 g/day) of rape soup in Zambia. Female adults consumed a mean value of up to 151 g/day (range 20 to 341 g/day). A study by Tschirley & Hichaambwa (2010), reported that vegetables account for 14% of total food expenditure in Lusaka and within the 14% of vegetable consumption, rape has the highest consumption share. In Zambia, because of the green leafy rape’s high demand,

it is grown by many small-to-medium scale farmers in peri-urban areas and supplied to various open-air markets in the cities (Tschirley & Hichaambwa, 2010). Data on the nutrition composition of the rape (*Brassica napus* L) leafy vegetable is scarce. In Zimbabwe, Lewu & Kambiza (2014) have reported macronutrients of 14.76% ash, 13.79% protein, 14.66% crude fibre, 6.32% fat, and 50.46% carbohydrate on a dry basis and a moisture content of 84.72%. The leafy vegetable is moderate in major mineral elements with 0.56% phosphorus, 3.2% potassium, 2.81% calcium, 0.36% magnesium, and 355 mg/kg sodium. It is high in minor mineral elements: 15 mg/kg manganese, 94.00 mg/kg iron, 4 mg/kg copper, and 52.33 mg/kg zinc.

Green leafy vegetables supply chains in Zambia face many challenges, like other African countries. At the agro-nomic stages, green leafy rape vegetable has a seasonal peak of supply falling between May and October, as this is the dry season for Zambia. Growing green leafy vegetables in the dry season minimizes the challenges of pests and disease, which are prevalent during the rainy season (Hichaambwa & Tschirley, 2006; Mandiriza-Mukwirimba et al., 2016; Makule et al., 2024). Cultivation of green leafy vegetables in the dry season comes with a challenge of a lack of irrigation technologies and high seasonal price fluctuations, happening at peak supply periods, leading to high postharvest losses due to oversupply of the market (Hichaambwa & Tschirley, 2006; Mukarumbwa et al., 2017; Makule et al., 2024). The farmers lack appropriate storage facilities for in-transit leafy vegetables, while there are no proper storage facilities at the trading stage as well (Makule et al., 2024). According to Phiri (2010) and Makule et al (2024), transportation challenges for vegetable farmers in Africa range from the use of non-refrigerated transportation vessels, poor road infrastructure, to poor packaging.

In Zambia, the rural–urban supply chain of the green leafy vegetable, rape (*Brassica napus* L) is central to its availability and cost in the urban markets as 98% of the vegetable consumed by urban dwellers is sourced from the urban markets (Tschirley & Hichaambwa, 2010). Although there is a growing trend of green leafy vegetables being sold through supermarkets, over 90% of the rural–urban supply chain of the green leafy rape vegetable is channeled through open air markets, also known as a traditional marketing system. Data collected between 2007 and 2009 showed that Chongwe district had the highest supply of rape vegetable to Soweto open air market, estimated at 71% of the share, while the remaining 29% was shared among other surrounding rural areas (Tschirley & Hichaambwa, 2010).

According to Taglioni et al (2023), reliable and systematic evidence for food loss and waste for several food commodities and their whole supply chains is still missing. Green vegetables have been reported to have high

food losses in Africa (Kitinoja & Kader, 2015; Parfitt et al., 2021; Strecker et al., 2022; Taglioni et al., 2023). Despite rape being important to Zambia and other African countries including Zimbabwe (Ganya et al., 2018; Mukarumbwa et al., 2017), South Africa (Mandiriza-Mukwirimba et al., 2016) and Botswana (Munthali & Tshogofatso, 2014) from a food security and nutrition point of view, there is still a dearth of data in specific loss of green leafy vegetables from a food loss perspective. According to Delgado et al. (2021), measuring food loss and identifying which stages in the supply chain it occurs in is the first and most important step in addressing the problem of food loss.

Therefore, the main purpose of this study was to estimate the quality, physical and economic food losses of green leafy rape in a rural-to-urban supply chain. This research paper gives findings of a food loss study of an under-researched and yet important vegetable rape (*Brassica napus* L) to Southern Africa. It is one of the few studies (Shee et al., 2019; Strecker et al., 2022) that have reported the proportion of actors incurring food losses at each stage of the supply chain in line with the recommendation of FAO (2014). This is useful in determining the critical loss points. Further, this work has reported a rare conversion of physical and quality food losses into economic food losses (Strecker et al., 2022), which is an important piece of data in cost–benefit analysis for evaluation of interventions to reduce food losses (Tonini et al., 2022). Finally, underlying drivers or causes of the food loss have been identified as these are more useful in determining strategic interventions to reduce food loss than direct drivers (FAO, 2014; Flanagan et al., 2019).

2 Methodology

2.1 Study design

The study was based on a descriptive cross-sectional study design. Data was collected on qualitative and quantitative food losses of green leafy rape in a supply chain between a rural production area and an urban market area. The approach for the food loss data collection was based on the FAO survey method (FAO, 2014) and the Informal Food Loss Assessment method (IFLAM) (Diei-Ouadi & Mgawe, 2011; Strecker et al., 2022), which are recall-based methods. The surveys were conducted at the farm, transportation, and trading stages of the supply chain in October 2021.

2.2 Study site

The study was conducted in Chongwe and Lusaka districts of Lusaka province, Zambia (Fig. 1). The farm and

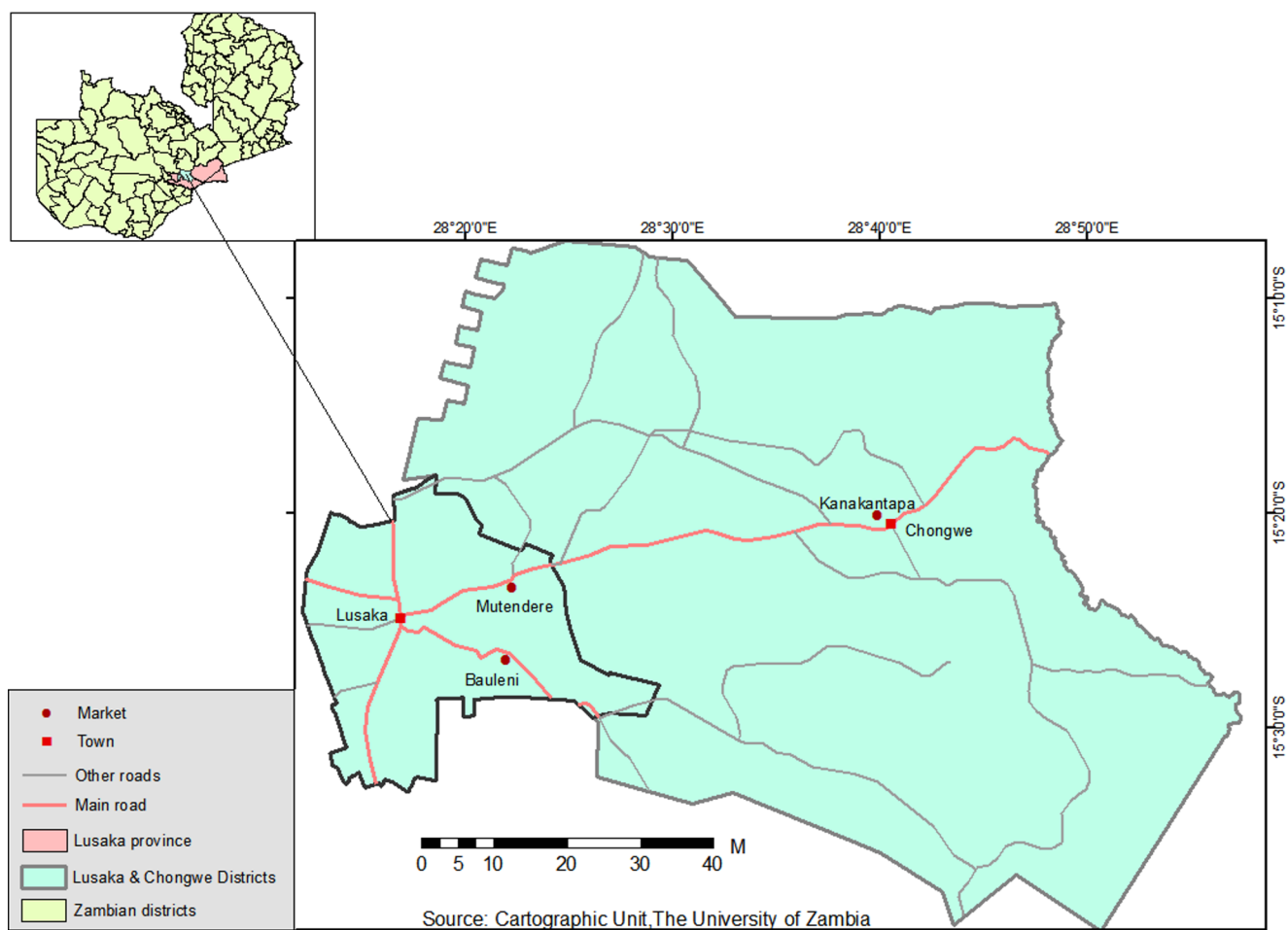


Fig. 1 Map of the study locations

transportation level surveys were conducted in the Kanakantapa Settlement Scheme of the Chongwe district of Zambia. Kanakantapa area was purposively selected as a Food Systems Lab (FSL) within the framework of the Healthy-FoodAfrica (HFA) project in consultation with HIVOS (Zambia), which coordinated activities in this FSL.

The trader-level survey was conducted in the Chongwe district and Lusaka city. Chongwe, Bauleni and Mutendere open air markets were purposively selected in Chongwe and Lusaka, respectively, as key informants indicated that these were among the main market channels for Kanakantapa leafy rape farmers. Ministry of Agriculture Extension Officers in Chongwe district were the key informants, based on their extension knowledge of the area.

2.3 Sampling green leafy rape farmers, transporters and traders

The green leafy rape farmers from the Kanakantapa area of Chongwe district, were purposively sampled. Ministry

of Agriculture Extension Officers, assisted in tracing all the possible green leafy rape farmers in the Kanakantapa Resettlement Scheme. A total of twenty-four transporters involved in the transportation of green leafy vegetables were selected from the transport hubs at Chongwe and Mutendere open-air markets, with twelve from each location. The green leafy rape traders were also purposively sampled from each selected markets: Mutendere and Bauleni open air markets of Lusaka city, and the Chongwe open air market in the Chongwe district. A total of 224 traders were sampled for this study, 85 from Mutendere market, 89 from Bauleni market, and 50 from Chongwe open-air markets. The entire population of the transporters found and available at the transport hub on the day of data collection and who self-reported to be involved in transportation of rape vegetables, were interviewed for the study. Similarly, all traders found trading in rape leafy vegetable and who were available for interview on the data collection day, were recruited as participants of the study. Singh & Masuku (2014) advised the census approach in sampling for small populations.

2.4 Data collection

Three separate semi-structured questionnaires for collecting data at the farm, transportation, and trading stages were developed. The questionnaires were used to collect data on the socio-demographic characteristics of the farmers, transporters and traders. The questionnaires were primarily used to collect data on green leafy rape losses and the actor's perspectives of the causes of the food losses. The farmers and traders were asked to estimate the proportions of the food losses based on the initial quantities at each stage. Prices of green leafy rape were also collected for use in the calculation of economic food losses. The semi-structured questionnaires were digitally configured on tablets using the CSEntry application *version 7.6.2.*, developed using the Census and Survey Processing System (CSPro). The data collection was informed by a comprehensive review of existing literature focusing on postharvest losses in Zambia, which served as a basis for the questionnaires' design. Primary data was collected through one-on-one interviews of the sampled farmers, transporters and traders of the green leafy vegetables.

2.5 Data analysis

The data collected on Android tablets using the CSEntry application *version 7.6.2* (US Census Bureau, USA, 2021) was uploaded to MS Excel 2013. The data was cleaned in Excel and subsequently exported to *Statistical Package for Social Sciences (SPSS) version 25* to generate the descriptive statistics for the demographic variables of the farmers, transporters and traders. Additionally, quality, physical and economic food loss rate estimates at various stages in the supply chain were also calculated using the equations given below. The calculated descriptive statistics also included the proportion of actors at each stage of the supply chain experiencing the food losses. This information was instrumental in identifying the critical loss points where food losses were most significant within the supply chain.

2.6 Measurement of food losses

In this study, several metrics based on Strecker et al. (2022) were used to quantify food losses. Measurements were taken for physical food loss, which refers to the actual decrease in the volume or weight of the food product. Quality food loss was assessed based on the deterioration in the food product's condition, which might affect its marketability or consumer acceptability. Economic quality food loss calculations took into account the reduced value of the product due to quality deterioration. Lastly, total economic food loss combined

both the decrease in quantity and the loss of value from quality degradation to provide a comprehensive financial impact assessment.

2.7 Physical food loss calculations

Physical food loss was determined based on the respondent's estimates of the volume or weight percentage of the green leafy rape discarded at a particular stage, compared to the initial quantity of the produce at that stage.

$$\begin{aligned} \text{Physical food loss (\%)} \\ &= \frac{\text{Mean volume or weight of discarded vegetable at the stage}}{\text{Mean initial volume or weight at the stage}} * 100 \quad (1) \end{aligned}$$

2.8 Quality food loss calculations

Quality food loss was determined by asking the respondent to estimate the volume or weight percentage of the green leafy rape that had deteriorated in sensory (visual) quality, but remained saleable at a reduced price at a particular stage of the supply chain. Essentially, this was calculated as the ratio of the proportion of the quantity deemed visually to be of poor quality relative to the initial quantity present at that specific stage of the supply chain. This approach aims to quantify the impact of the diminished quality on the market value of the produce, even when it did not lead to outright physical loss.

$$\begin{aligned} \text{Quality food loss (\%)} \\ &= \frac{\text{Mean volume or weight of visually poor quality vegetable at the stage}}{\text{Mean initial volume or weight at the stage}} * 100 \quad (2) \end{aligned}$$

2.9 Economic quality food loss calculations

The economic quality food loss was determined according to Strecker et al (2022) by first determining the economic quality food loss in Zambian currency, the Zambian Kwacha (ZMW) and the maximum value of the green leafy rape after the removal of the physical food loss (ZMW).

$$\begin{aligned} \text{Economic quality food loss (ZMW)} \\ &= [\text{Mean volume or weight of visually poor quality vegetable at the stage}] \\ &\quad * [(\text{Best price (ZMW)} - \text{Reduced price (ZMW)})] \quad (3) \end{aligned}$$

$$\begin{aligned} \text{Maximum value of green leafy rape after removal of physical food loss (ZMW)} \\ &= [\text{Mean initial volume or weight at the stage} - \text{Mean volume or weight of discarded vegetable at the stage}] \\ &\quad * [\text{Best price at the stage (ZMW)}] \quad (4) \end{aligned}$$

$$\text{Economic quality food loss (\%)} = \frac{[3]}{[4]} * 100 \quad (5)$$

2.9.1 Total economic food loss calculation

The total economic food loss was calculated according to Strecker et al (2022) and it is defined as the percentage of total revenue lost due to physical and quality food losses. The total economic food loss was calculated by first calculating the economic physical food loss and the original maximum value of the food in monetary terms.

$$\begin{aligned} & \text{Economic physical food loss (ZMW)} \\ &= \text{Mean volume or weight of discarded vegetable at the stage} \\ & * \text{Best price per volume or weight at the stage (ZMW)} \end{aligned} \quad (6)$$

$$\text{Economic physical food loss (\%)} = \frac{[6]}{[4]} * 100 \quad (7)$$

$$\begin{aligned} & \text{Initial maximum value of green vegetable (ZMW)} \\ &= \text{Mean initial volume or weight at the stage} \\ & * \text{Best price per volume or weight at the stage (ZMW)} \end{aligned} \quad (8)$$

$$\text{Total Economic Food Loss (ZMW)} = [6] + [3] \quad (9)$$

$$\text{Total Economic Food Loss (\%)} = \frac{[9]}{[8]} * 100 \quad (10)$$

2.9.2 Ethical considerations

The study was approved by the Tropical Diseases Research Centre (TDRC) Ethics Review Committee in Zambia, with ethical clearance TRC/C4/10/2020.

3 Results

3.1 The green leafy rape supply chain

The study examined a green leafy rape (*Brassica napus* L.) supply chain from a rural origin to urban markets, identifying four critical stages where food loss could occur: harvesting and handling, on-farm storage, transportation, and market trading. The primary farming site was in the rural Kanakantapa Resettlement Area, Chongwe district, while trading was focused on open-air markets in Chongwe and two in Lusaka city, approximately 47 km away. Data in Table 1 indicates that half (50%) of the green leafy rape farmers reported to be supplying their harvested vegetables to the Chongwe open air market within the rural Chongwe district and Soweto open air market in the city centre of Lusaka city. The other 28% of the farmers supplied their harvested green leafy rape to Mutendere open air market in the east of Lusaka city. Further, six (6) % of the farmers supplied to the Bauleni open-air market, 6% to other open air

Table 1 Profile of green leaf rape farmers and transporters

Variable	Farmers	Transporters
Gender (number, %)	50 (100)	24 (100)
Male	24 (48)	24 (100)
Female	26 (52)	-
Marital status of Household Head (number, %)	50 (100)	24 (100)
Married	41 (82)	20 (83.3)
Single	5 (10)	4 (16.7)
Divorced/Separated	1 (2)	-
Widowed	3 (6)	-
Highest level of education (number, %)	50 (100)	24 (100)
None	2 (4)	-
Primary	13 (26)	8 (33.3)
Secondary	25 (50)	16 (66.7)
Tertiary	10 (20)	-
Age (Years) (mean, range)	47.6 (24–70)	-
Age (Years)	-	24 (100)
21–30	-	4 (16.7)
31–40	-	9 (37.5)
41–50	-	7 (29.2)
51 and above	-	4 (16.7)
No. of cycles of growing rape per annum (mean, SD)	2.6 ± 0.8	-
Quantity of 50 kg Rape harvested per cycle (mean, SD, range)	124.1 ± 16.5 (1–600)	-
Marketing channels (number, %)		
Chongwe district		
Chongwe open air market	25 (50)	
Kanakantapa, Walk-in customers/ household neighbors	3 (6)	
Lusaka city		
Soweto open air market	25 (50)	
Mutendere open air market	14 (28)	
Bauleni open air market	3 (6)	
Garden, Chalala, Chilenje and Katende	3 (6)	

markets in Lusaka city including Garden, Chalala, Chilenje, and Katende, while another six (6) % supplied to walk-in customers or neighboring households within the farmers' vicinity. Table 1 further shows that green leafy rape marketing channels for this supply chain are short, where the commodity moves directly from the producer (farmer) to the trader and the consumer.

3.2 Profiles of green leafy rape farmers, transporters and traders

There were fifty (50) farmers at the production stage of the supply chain, all from the Kanakantapa farming area of Chongwe district. Fifty-two (52%) were from female-headed households and 48% were from male-headed households. Most of the farmers were married (82%) (Table 1).

The mean age of the farmers was 48 years, with a range of 24 to 70 years.

Most of the households (70%) had attained a minimum of secondary level education, and the rest had attained primary education, with only 4% not having been to school. The green leafy rape farming stage of the supply chain is in a rural setup, where it is expected to have a high proportion of academically lowly attained farmers. On the contrary, a high proportion of household head farmers of green leafy rape in the study area had attained a minimum of secondary level education. The high proportion of academically educated farmers in this study area can be explained by the fact that the Kanakantapa farming area is a farming settlement created by the Government of Zambia, meant for retirees from formal employment to engage in farming. The farmers had an average of 2.6 farming cycles of the green leafy rape vegetable per year. The farmers had a mean harvest of 124 bags ("50 kg") per cycle with a range of 1 to 600 bags. The average weight of a "50 kg" bag used for packaging and trade of the green leafy rape was found to be 23.0 ± 2.5 kg with a range of 19.7 to 26.4 kg.

At the transportation stage of the supply chain, twenty-four transporters, 12 from Chongwe district and 12 from Lusaka city, took part in the study. Table 1 shows that the transportation business was entirely dominated by the male gender (100%). The majority were married (83%), all had attained some level of formal education, and the majority were aged between 21 and 50 years.

The survey at the trading stage of the supply chain sampled 224 green leafy rape traders from the three open air markets. Bauleni open-air market had the highest sample size of 39.7%, Mutendere had 37.9%, and Chongwe had 22.3% (Table 2). All available rape leafy vegetable traders were sampled in each of the markets and therefore these proportions largely depict the size of each market. In the overall sample, 96.9% were female and 3.1% were male. Most of the traders were married (56.3%), followed by the single (18.3%), widowed (16.1%), and the rest were divorced/separated and cohabiting. Most of the traders had attained a primary school level of education (50.9%), followed by secondary level of education (36.5%), while there were only 0.4% at tertiary level of education, and the rest 12.5% did not attain any level of formal education. The mean age of the traders was 39.7 years, with a range of 14 to 70 years.

The farmers typically package green leafy vegetables into polypropylene "50 kg" bags for delivery to open-air markets using a variety of transportation methods. Market traders then buy these bags and repack the contents into smaller bundles for sale. On average, traders reported procuring 109 bundles from farmers, which is equivalent to 2 bags labeled as "50 kg". The traders further indicated that one such "50 kg" bag can be repackaged into 60 smaller bundles.

Table 2 Profile of green leafy rape traders

Variable	Traders
No. of Traders per open air market	224
Mutendere (number, %)	85 (37.9)
Bauleni (number, %)	89 (39.7)
Chongwe (number, %)	50 (22.3)
Gender of Household Head (number, %)	
Female	217 (96.9)
Male	7 (3.1)
Marital status of Household Head (number, %)	
Married	126 (56.3)
Single	41 (18.3)
Widowed	36 (16.1)
Divorced/Separated	20 (8.9)
Cohabiting	1 (0.4)
Highest level of education (number, %)	
None	28 (12.8)
Primary	114 (50.9)
Secondary	81 (36.5)
Tertiary	1 (0.4)
Age (Years) (mean, range)	39.7 (14 to 70)
Quantity (number) of bundles/bunches of rape ordered per batch per trader (mean, SD, range)	109.3 $\pm$ 5.6 (60–600)
Mean sales days (mean, range, median) ^a	
November to April (wet & warm season)	1.6 (1–5)
May to August (cold & dry season)	3.0 (1–7)
September to October (dry & warm season)	1.4 (1–3)

^aOn normal days, how long do the rape sales per batch last?

However, we found that at the market, green leafy vegetable bundles are sold in three different sizes: large bundles average 525 g each, medium bundles 350 g, and small bundles 200 g. Based on these average weights, a 23 kg bag, commonly referred to as a "50 kg" bag in the markets, would contain approximately 44 large bundles, 66 medium bundles, or 115 small bundles.

Table 2 further shows that the average number of days it takes to sell the green leafy rape in cold and dry season (May to August) was 3 days per batch, followed by wet and warm season (November to April) at 1.6 days and dry and warm season having the least of 1.4 days.

3.3 Quality and physical losses in the supply chain

In the supply chain of green leafy rape, four key stages were identified where food losses occur: harvesting and handling, on-farm storage, transport to markets, and trading. Quality food losses at the harvesting stage were challenging to quantify, as farmers typically harvested only marketable quality produce. However, physical food losses at this stage were on average 6.4%, varying between 1 to 33%. A substantial 76% of farmers acknowledged experiencing physical food losses during harvest.

Fig. 2 Quality and physical food losses of green leafy vegetable - rape in the Kanakantapa farms – to- Lusaka open-air market supply chain

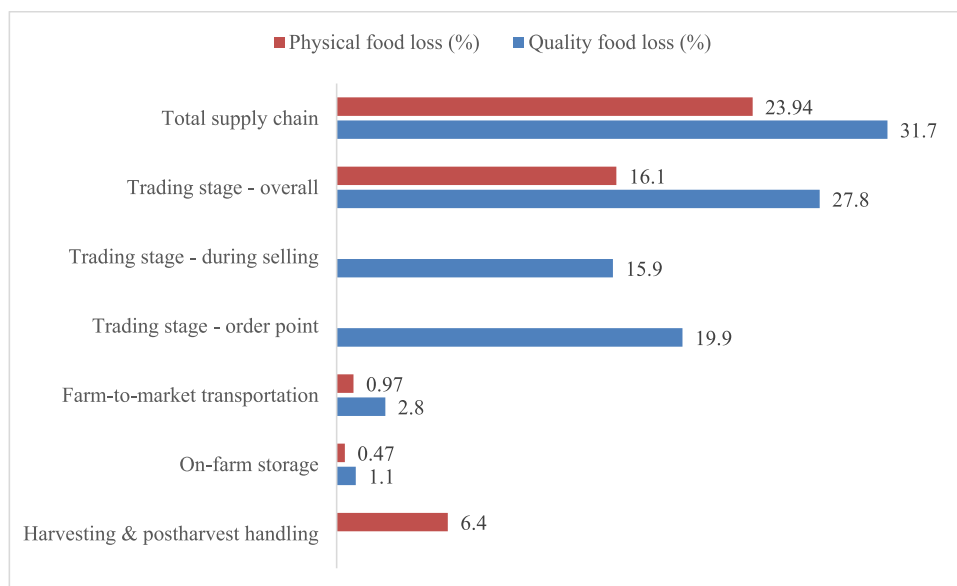
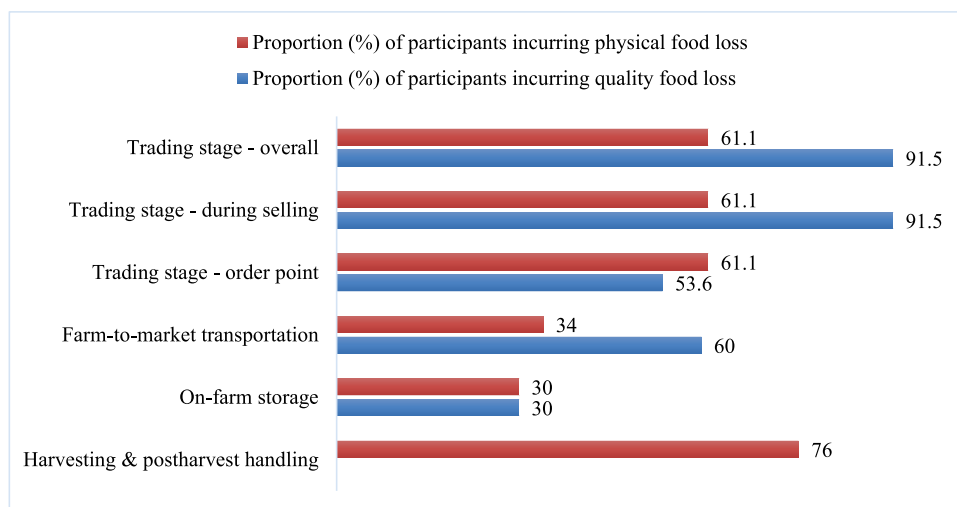


Fig. 3 Proportion of actors incurring physical and quality food losses in the supply chain stages



The green leafy rape farmers incur 1.1% quality food losses at the on-farm storage stage based on harvested quantities, with a range of trace amounts to 3% (Fig. 2). There were only 30% of the farmers who reported to incur quality food losses at the on-farm storage stage (Fig. 3). Only 0.4% was reported to be discarded at the on-farm storage stage when calculated based on harvested quantity, with a range of trace to 3%. Thirty percent (30%) of farmers reported incurring physical food losses at the on-farm storage stage.

The mean green leafy rape quality food losses at the farm-to-market transportation stage were found to be 2.8% based on harvested quantities, with a range of 0.01 to 25%. At the farm-to-market transportation stage, 60% of the farmers incurred quality food losses. The physical food loss at the transportation stage – farm to the markets- was

estimated at only 0.97%, with a range of 0.01 to 7% being estimated to be discarded when calculated based on harvested quantities. A low proportion of the farmers (34%) incurred the physical food losses at the transportation stage (farm to market).

The trading stage of the supply chain was broken down into two major sub-stages, the order (point of off-loading from transportation vessel and purchase by market traders) and during selling stages, bringing the total number of stages where food losses can occur to 5 points. The mean quality food loss of green leafy rape at the point of purchase from the farmers directly from the transportation vessels was determined to be 19.9%, with a minimum and maximum food loss of 1.7 to 50%, respectively based on purchased quantity or what is normally known as order quantity

by the open-air market traders. At the point of purchase by market traders from the farmers, about 54% of the market traders incurred quality food losses in the green leafy rape.

The mean quality food loss of green leafy rape during the selling sub-stage was 15.9% when calculated on ordered quantity, with a minimum of 1.7% and a maximum of 50%. This quality food loss rate is 19.3% when calculated on the marketable quantity of green leafy rape, with a range of 1.7 to 75%. The quality food loss of the green leafy rape is incurred by a higher proportion of market traders (91.5%) during the selling sub-stage than at the order point (54%) of the trading stage.

The overall mean quality food loss of the green leafy rape during trading, that is, the combined food loss at the point of purchase and during selling, was found to be 27.8%, with a range between 1.7 to 83.3% when calculated on the ordered quantity. The proportion of market traders who incurred quality food loss is 91.5% in the overall trading stage. The proportion of green leafy rape discarded (physical food loss) by the traders at the trading stage was estimated at 16.1% of the ordered quantity with minimum of 0.8% and a maximum of 66.7%. When the discarded is calculated on the marketable quantity, the proportion is 22% with a range of 0.9% to 100%. There was a relatively high proportion of traders (61.1%) who reported to incur physical food losses at the trading stage.

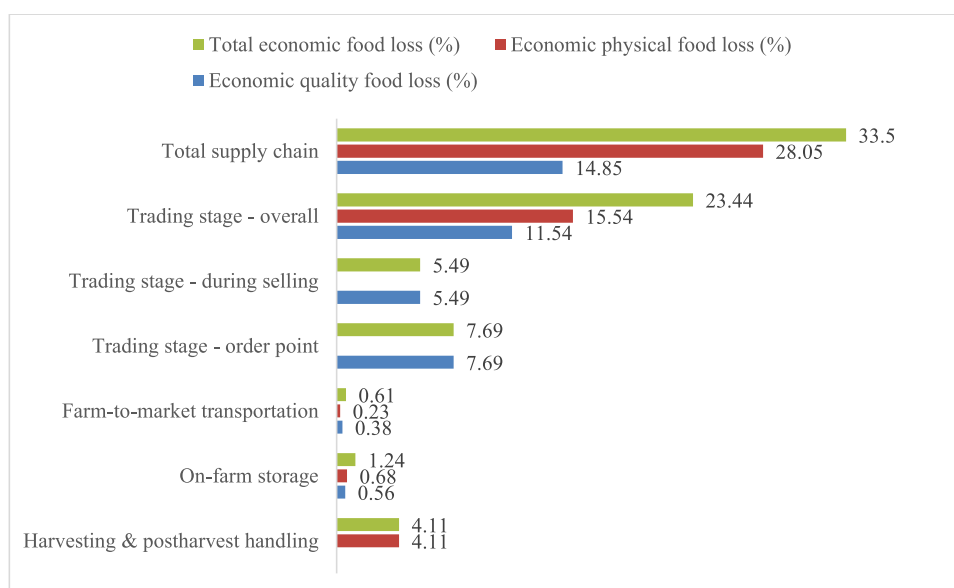
The green leafy rape overall mean quality food loss in the supply chain, when food losses at on-farm storage, transportation (farm to markets) and overall trading stages are summed up, is estimated at 31.7%. The green leafy rape overall mean physical food loss or discarded from the supply chain (combined farm level and trading stages) was estimated at 23.4%.

3.4 Economic food losses of green leafy rape in the supply chain

Economic food losses have been categorized into economic quality food losses, economic physical food losses, and total economic food losses (Strecker et al., 2022). Economic quality food losses are the food losses in monetary value of the produce due to quality food loss. The economic physical food loss is the monetization of the food losses in quantity due to discarding because of complete quality food loss or loss in weight of the produce in the supply chain. Total economic food loss is the combined economic quality and physical food losses in monetary terms of the produce in the supply chain. At the farm stage, the survey found that on average, green leafy rape incurred a 50.3% price reduction due to quality food losses, and a bag of market quality green leafy rape was selling at an average of ZMW70 at the time of the survey.

At the farm level, the harvesting/postharvest handling stage had the highest total economic food loss of 4.1%, all contributed by the economic quality food loss, compared to on-farm storage and farm-to-market transportation stages, which had about 1% or less (Fig. 4). The trading stage had the highest total economic food loss estimated at 23.4% in the entire supply chain, almost equally contributed by both economic quality and physical food losses. The economic quality food loss at the trading stages was higher at the ordering sub-stage, estimated at 7.7%, than at the selling stage, estimated at 5.5%, with an overall trading stage food loss of 11.5%. The green leafy rape overall mean total economic food loss in the entire supply chain was estimated at 33.5%, with the highest contribution coming from the economic physical food loss than the economic quality food

Fig. 4 Economic quality, economic physical and total economic food losses of leafy vegetable—rape in the Kanakantapa farm – Lusaka open-air market supply chain



loss, although it is also high. The overall supply chain economic quality food loss was 14.8%.

3.5 Critical loss points in the supply chain

Based on the FAO (2014) definition of critical loss point (CLP) and food loss estimates determined in this study, the trading and harvesting stages were identified as the CLPs in the studied supply chain. The food loss estimates show that the highest physical food losses were recorded at the trading (order) stage (~20%) being incurred by 54% of the traders, followed by the food loss at trading (selling) stage (16%) and an overall quality food loss of nearly 28%, incurred by 91.5% of the traders. The trading stage also had the highest economic quality food loss of 11.5%. The trading stage had the highest food losses, even in terms of quality food losses estimated at 16% and total economic food loss of about 23%, incurred by 61% of the traders. The second CLP was the harvesting and handling stage, with a physical food loss of about 6%, being incurred by 76% of the farmers.

3.6 Farmers' perspective of the underlying causes of the food losses

The results in Table 3 shows that the farmers' perspective of the top underlying causes leading to the food losses of green leafy rape as cited by at least 50% of the actors who responded, is lack of training in good postharvest practices. About 89% and 60% attributed physiological and mechanical damages to a lack of good postharvest practices, respectively, while 55% of the farmers cited poor packaging at the harvesting stage. The farmers' perspective of the underlying causes of the green leafy rape losses at the on-farm storage stage cited by at least 50% of the actors who responded, were topped by lack of training in good postharvest management as identified by 87% and 80% of the farmers who reported to incur the green leafy rape losses in form of mechanical and physiological damage, respectively. Poor packaging and lack of or inadequate disinfection were cited by 80% and 60% of the farmers as the underlying cause for mechanical damages and pathological damages, respectively.

The major underlying causes of the mechanical damage of the green leafy rape at the transportation stage (farm to markets) as identified by least 50% of the farmers include poor packaging (70%), poor transportation vessels (63%) and lack of postharvest training (57%). On the other hand, inability to control environmental conditions at the transportation stage was identified by 100% of the farmers as a factor responsible for the physiological damage of the produce. Relatively lower proportions of farmers identified a lack of or inadequate disinfection (60%) as a major cause of pathological damage to the produce at the transportation stage.

Table 3 Underlying causes of mechanical, physiological and pathological damages to green leafy vegetable rape at the farm and transportation stages

Farmers' perspectives of the underlying causes	Mechanical damage ^a	Physiological damages ^a	Pathological damages ^a
Harvesting stage	(38)	(38)	(38)
Lack of training in good post-harvest practices	60.2 (23)	89.5 (34)	47.8 (18)
Poor packaging	55.3 (21)	31.6 (12)	15.8 (6)
Poor transportation	44.7 (17)	7.9 (3)	36.8 (14)
Inappropriate harvesting equipment	34.2 (13)	31.6 (12)	-
Inability to control environmental conditions	-	26.3 (10)	10.5 (4)
Poor road network	-	7.9 (3)	-
Lack of or inadequate cleaning	-	-	26.3 (10)
Lack of or inadequate disinfection	-	-	42.1 (16)
Contaminated packaging			36.8 (14)
On-farmer storage stage	(15)	(15)	(15)
Lack of training in good PH practices	86.7 (13)	80.0 (12)	6.7 (1)
Poor packaging	80.0 (12)	6.7 (1)	13.3 (2)
Inability to control environmental conditions	-	6.7 (1)	40.0 (6)
Poor road network	-	-	-
Lack of or inadequate cleaning	-	-	26.7 (4)
Lack of or inadequate disinfection	-	-	60.0 (9)
Contaminated packaging	-	-	33.3 (5)
Poor storage facilities	33.3 (5)	6.7 (1)	26.7 (4)
Transportation stage – farm to markets	(30)	(30)	(30)
Lack of training in good PH practices	56.7 (17)	26.7 (8)	26.7 (8)
Poor packaging	70 (21)	40 (12)	6.7 (2)
Poor transportation vessel	63.3 (19)	33.3 (10)	13.3 (4)
Inability to control environmental conditions	33.3 (10)	100 (30)	50.0 (15)
Lack of or inadequate cleaning	-	-	40.0 (12)
Lack of or inadequate disinfection	-	-	60.0 (18)

^aNumbers without brackets are percentages and number of farmers (in parentheses) who cited the cause

3.7 Traders' perspective of the underlying causes of the food losses

Table 4 gives the green leafy rape traders' perspective of the top underlying causal factors as cited by at least 50% of the actors who responded. The traders' perspective of the major underlying causes of the mechanical damage of the green leafy rape at the trading stage is poor transportation vessels as identified by 69% of the traders. The inability to control the environmental conditions was cited by a high proportion of traders (88%) as the underlying cause for physiological

Table 4 Underlying causes of mechanical, physiological and pathological damages to green leafy vegetable rape at trading stage

Traders' perspectives of the underlying causes	Proportion of traders ^a
Traders' perspectives of factors leading to mechanical damages	(205)
Poor transportation vessels	69.3 (143)
Lack of training in good PH practices	44.9 (92)
Inability to control environmental conditions	15.6 (32)
Lack of or inadequate disinfection	1.5 (3)
Traders' perspectives of factors leading to physiological damages	(205)
Inability to control environmental conditions	88.3 (181)
Lack of training in good PH practices	29.8 (61)
Poor packaging	7.8 (16)
Traders' perspectives of factors leading to pathological damages	(205)
Inability to control environmental conditions	58.0 (119)
Lack of or inadequate disinfection	35.6 (73)
Lack of training in good PH practices	24.4 (50)
Poor transportation vessels	16.6 (34)
Lack of or inadequate cleaning	5.4 (11)
Contaminated packaging	2.0 (4)

^aNumbers without parentheses are percentages and number of traders (in parentheses) who cited the cause

damages to the green leafy rape at the trading stage. On the other hand, 58% of the traders cited inability to control environmental conditions as the underlying cause of pathological damage to the produce at the trading stage.

4 Discussion

4.1 Introduction

The study sought to estimate the quality, physical and total economic food losses in a green leafy vegetable rape (*Brassica napus* L) rural-to-urban supply chain in Zambia. It was also the purpose of the study to determine the critical loss points and underlying causes of food loss from the perspective of the supply chain actors. Overall, the green leafy rape supply chain incurs 33.5% quality food loss, 23.9% physical food loss and 33.5% total economic food loss of the green vegetable. The critical loss points have been identified as the harvesting stage at the farm level, which incurs 6.4% physical food loss, and the trading stage, which incurs 16.1% physical food loss and 27.8% quality food loss. The proportion of actors incurring food losses at the critical loss points is also high.

4.2 Gender considerations

The study has found that there was almost an equal number of female and male headed households involved in the production of green leafy vegetable rape at the farm stage of the supply chain. The study has further found that transportation business for green leafy rape, like any other transportation business in developing countries, is dominantly operated by the male gender. The green leafy vegetables in Africa, including Zambia, are predominantly traded in open-air markets. This study of 224 green leafy rape traders in three open-air markets in Chongwe district, a rural district, and Lusaka city, an urban area, has found that this trade business is a female dominated business. These proportion variations in gender participation at different stages of the supply chain are not unique to Zambia as similar findings have been reported in Tanzania (Andersson et al., 2016; Fischer et al., 2017), Uganda (Strecker et al., 2022), and Ghana (Kushitor et al., 2022). Therefore, any interventions to reduce food loss at the farm, transportation, and trading stages of the supply chain should take into consideration gender proportion variations at each supply chain stage.

4.3 Market channels

The Kanakantapa farming area is an important source of vegetables, contributing to the food security and nutrition requirements of the rural district, Chongwe, and the capital city of Zambia, Lusaka. The green leafy rape farmers of Kanakantapa area of Chongwe predominantly supply to open-air market channels which include Chongwe within Chongwe district, Soweto, Mutendere and other open-air markets in Lusaka city. According to Tschirley & Hichaambwa (2010), rural-urban supply chains are central to the supply of vegetables to urban markets, with the peri-urban-to-urban chain being important for green leafy rape. These open-air markets are the major sources of vegetables and fruits for both low and high-to-middle class vegetable consumers of Chongwe district and Lusaka city at large (Tschirley & Hichaambwa, 2010). A study by CUTS & WFP (2018) in Lusaka, found that 79% of the low income earners and 70% of the medium-to-high income earners purchase their green vegetables from the local markets (open air markets), although Tschirley & Hichaambwa (2010) reported higher proportions of over 90% of green leafy rape being purchased by Lusaka consumers.

The distance to the markets is short, from Kanakantapa to Chongwe market being about 17 km, while from Chongwe to Lusaka city is about 47 km. This study has found that the green leafy rape marketing channel is short, that is, the vegetable moves directly from the farmer to the trader. This is similar to the findings by Tschirley & Hichaambwa (2010) who reported that green leafy rape has a short marketing

channel, with 65% of the commodity moving directly from the farmer to the trader. Short food supply chains are more sustainable from a social, economic, and environmental sustainability perspective (Doernberg et al., 2022; Stein & Santini, 2022).

4.4 Shelf life of green vegetable rape at open-air markets

The study has found that the average number of days it takes to sell the green leafy rape at the trading stage was dependent on the season of the year with cold and dry season (May to August) having the longest mean sales days of 3 days per batch, followed by wet and warm season (November to April) at 1.6 days and, dry and warm season having the least of 1.4 days. The findings in this study agree with Gogo et al. (2018), who reported that most farmers in Kenya indicated that African indigenous vegetables had a shelf life of between 1 and 2 days at ambient conditions. In this study, the shortest sale days are in the hot and dry season because of the high environmental temperatures and low humidity, which leads to high water evaporation from the green leafy vegetables. On the other hand, sale days are longer in cold and dry seasons because of low environmental temperatures and high environmental relative humidity, which leads to reduced water evaporation from the green leafy vegetables.

4.5 Green leafy rape losses in the supply chain

The physical food loss rate of 6.4% found in this study at the harvesting implies that farmers could have potentially harvested an additional 6.4% beyond the actual yield. The green leafy rape losses at harvesting and handling stage could be because of produce damaged during harvesting, pests damaging mature produce, edible produce left on the field, poor timing of harvest, inability to harvest or decision not to harvest the produce among other causes of food loss (Verma et al., 2019). In this study, in comparison to the harvesting stage, the on-farm storage stage has a very low food loss. According to Parfitt et al. (2021) and WWF (2021), globally, food losses at the agricultural production level have been estimated at 15% at harvest or immediately after harvest, with low-income countries estimated to contribute about 54% of global on-farm postharvest losses. Farm stage food losses for sub-Saharan Africa are estimated at 16.7% of the global production.

In this study, the farm-to-transportation stage green leafy rape quality food losses of 2.8% and 0.97% physical food losses are relatively lower than expected because the real food loss or damage incurred during transportation, is observed at the trading stage when the product is off-loaded at the point of sale to the trader. Other studies (Verma et al., 2019) have reported a lack of temperature control and

rough handling during loading and off-loading as some of the direct causes of food loss at this stage.

The high-quality food losses found in this study at the order sub-stage of the trading stage (19.9%) are highly attributed to the previous stages, transportation to markets, and on-farm storage, as the food loss effects are only observed at the trading stage. The food losses at these two stages are only noticed at the trading (order) stage when the trading transactions between the farmer and the traders have occurred. In other words, the food loss recorded at the order sub-stage of the trading stage is essentially an accumulated food loss caused by the on-farm storage stage and transportation stage from the farm to the market. The quality food loss of the green leafy rape is incurred by a higher proportion of traders (91.5%) during selling sub-stage than at the order point (54%) of the trading stage. There was also a relatively high proportion of traders (61.1%) who reported to incur the physical food loss at the trading stage. The present study is one of the few studies (Shee et al., 2019; Strecker et al., 2022) that have reported food loss findings as recommended by FAO (2014).

A high overall quality food loss (31.7%) and physical food loss (23.4%) have been found for the entire supply chain in this rural-to-urban supply chain study. Research studies indicating the food loss rates for leafy vegetables in Africa are scanty, but a few studies show that the extent of food loss is very high (Kitinoja & Kader, 2015; Strecker et al., 2022), with leafy green vegetables such as amaranth recording food losses as high as 89% (Kitinoja & Kader, 2015). A recent study estimates that sub-Saharan Africa lost about 27% of fruits and vegetables in 2021 (Taglioni et al., 2023). Further, recent global food loss estimates for FAO by Taglioni et al. (2023) revealed that globally, 13.2% of food was lost before the retail or trading stage in 2021, with sub-Saharan Africa's fruits and vegetables having the highest food losses of 19.9% and 31.2%, respectively.

In this study, it has been found that the total economic food losses (23.4%) at the trading stage are much higher than the total economic food losses at the farm level (<5%). Other studies have found much higher total economic food losses of 42% in a leafy vegetable, nightshade value chains (Strecker et al., 2022). Few papers have translated and reported the physical and quality food losses into economic food losses (Strecker et al., 2022). It is important to report the food losses in the form of economic food losses, as this data is useful for cost–benefit analysis of any proposed intervention to reduce food losses in the supply chains (Tonini et al., 2022).

4.6 Critical loss points in the supply chain

The critical loss points (CLP) identified in the rural-to-urban supply chain for this study are the trading and harvesting stages. This identification is based on the FAO

(2014) definition of the critical loss points (CLP) of food losses with the highest magnitude, the highest impact on food security, the highest number of actors affected, and the highest effect on the economic result of the food supply chain. In this study, the highest green leafy rape losses were recorded at the trading stage and second highest food loss at harvest stage, coupled with high proportions of actors incurring food losses at these two stages. However, it must be re-emphasized that the trading (order) stage food losses are highly attributed to the previous stages, transportation to markets, and on-farm storage, as the actors at these two stages do not estimate the food losses. Like this study, Strecker et al (2022) also reported farm level (harvesting and postharvest handling) as the critical loss point for the bush bean value chain, while, on the contrary, for a leafy vegetable, nightshade, it was the consumption level due to the short supply chain.

4.7 Farmers' and traders' perspectives of the underlying causes of the food losses

This study used the approach of the actor to identify the underlying causes of the food loss in their food supply chain. At the farm level, the farmers identified the lack of training in good postharvest practices, poor packaging for causing mechanical and physiological damages of the green leafy rape at the harvesting stage. In addition to the causes at the harvesting stage, lack of or inadequate disinfection was identified for the on-farm storage as the cause of mechanical, physiological, and pathological damage to the produce. This highlights the farmers' identified need for postharvest training, use of proper packaging, and disinfection at the farm level. Although in this study we used compound terms such as mechanical and physiological damage, similar studies such as Mukarumbwa et al (2017), have reported pest/disease, wilting, decay, rough handling, over maturation and delayed marketing as among the major direct causes of green leafy vegetable losses at the farm level.

At the transportation stage (farm to markets), the farmers identified poor packaging, poor transportation vessels, and the lack of postharvest training as the underlying causes of mechanical damage to the produce. Inability to control environmental conditions at the transportation stage was identified as a key factor responsible for the physiological damage to the produce. The farmers further identified a lack of or inadequate disinfection as a major cause of pathological damage to the produce at the transportation stage. Verma et al. (2019) reported high costs for transportation, lack of temperature-controlled transport vessels, and piling of food commodities on transportation vessels as some of the underlying causes of food losses at the transportation stage in Africa.

At the trading stage, the traders identified poor transportation vessels as a major cause of the mechanical damage of the green leafy rape. The inability to control the environmental conditions was identified as the cause for physiological damage and pathological damage of the produce at the trading stage. Similar studies in Africa have identified wilting and loss of green colour as the direct cause of food loss of green leafy vegetables at the trading stage (Yeshiwas & Tadele, 2021). Wilting occurs because of the trading of green leafy vegetables in hot environmental conditions without adequate temperature and humidity control.

According to Flanagan et al (2019) and FAO (2014), identifying underlying drivers or causes of food loss is more important than direct causes, because these are used to derive strategic interventions to reduce food loss. In this study, the underlying causal findings point to the need for interventions at the farm and trading stages of the green leafy rape rural-to-urban supply chain. Based on the causal levels identified in this study, the interventions should include training in harvesting/postharvest handling management, packaging in transportation, and product and environmental hygiene at the farm level. On the other hand, the trading stage actors require interventions in the form of supplier management and environmental hygiene. There is also a need to increase access to the source of funding for the farmers and traders to invest in infrastructure for transportation and food establishments.

4.8 Implications for interventions and policy

The underlying causes of food losses identified, ranging from inadequate postharvest handling to environmental control challenges, suggest a multi-faceted approach to interventions. Training in best practices, infrastructural improvements, and access to financing emerge as pivotal areas for reducing food losses and enhancing supply chain efficiency. Policy recommendations should thus focus on enabling access to resources, education, and infrastructure development, particularly in transportation and market facilities, to support the sustainable management of green leafy rape supply chains.

5 Conclusion

The study has found high green leafy rape quality and physical food losses along the rural-to-urban supply chain, especially at the harvesting stage of the farm level and trading stage of the marketing level. It has also been found that the harvesting and trading stages are the critical loss points, as they incur high food losses and affect many actors at those stages. Although the supply chain is demarcated into several stages to calculate

food losses and identify the actors at each stage, this study has found that the food losses found at one stage can also be an accumulation from the previous stage(s). The high overall supply chain food losses recorded in this study call for the need to develop interventions to reduce the food losses in leafy vegetable rural-to-urban supply chains. However, it has been found that the critical loss points in this supply chain are the harvesting and trading stages. Further, the interventions sought to reduce food losses for the trading stage should consider the previous stages as well. Therefore, even if this study has found that the total economic food losses are higher at the trading stage than at the farm level, it becomes imperative to have simultaneous interventions at both supply chain stages to effectively minimize food losses. The possible interventions include training in harvesting/postharvest handling management, packaging in transportation, product, and environmental hygiene at the farm and trading levels. This study was not without limitations. Food loss data based on recall methods by the farmers and traders used in this study poses a limitation of either under- or over-estimation of the food loss data. The actors involved in this supply chain do not keep records of their trade transactions, which can be utilized for accurate food loss quantification studies. The best method for the accurate determination of food losses would be the load tracking method as recommended by FAO (2014).

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Authors contributions **John Shindano:** design, conception of the work, acquisition of data, analysis of data, interpretation of data and manuscript writing; **Twambo Hachibamba:** design, conception of the work, acquisition of data and reviewing the manuscript; **Lukonde Mwelwa-Zgambo:** acquisition of data and reviewing the manuscript; **Chiza Kumwenda:** acquisition of data and reviewing the manuscript; **Mercy Mukuma:** acquisition of data and reviewing the manuscript; **Vincent Nyau:** acquisition of data and reviewing the manuscript; **Mangiza Chirwa:** acquisition of data; **Aubrey Sadoki:** acquisition of data; **Bernard H. Moonga:** reviewing the final version of the manuscript.

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Data availability Interview data and postharvest loss calculation are available upon request.

Declarations

Conflict of interest The authors declare that there are no conflicts of interest.

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