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POSTHARVEST PRACTICES AND LOSS DETERMINANTS FOR INTERVENTIONS AMONG SMALLHOLDER POTATO FARMERS IN *TIYO* DISTRICT, ARSI ZONE, ETHIOPIA

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ABSTRACT

Postharvest loss reduction, which will contribute to several sustainable development goals (SDGs) including SDG 1, 2, 3, 9, 12 and 13, is an important strategy for food and nutrition security. It requires interventions designed based on timely and reliable statistical data. However, lack of produce-specific loss data and associated factors along the postharvest value chain stages remains a challenge to implement appropriate interventions. Therefore, a survey was conducted on socio-demographic characteristics, postharvest practices, extent and causes of losses, and factors influencing postharvest loss of potato crops in *Tiyo* district of Arsi Zone, Ethiopia in 2022. A multistage sampling method was used to select a total of 209 smallholder potato farming household heads through a combination of purposive and simple random sampling techniques. Quantitative data collection was carried out online using computer-assisted personal interviewing (CAPI) by programming a semi-structured questionnaire in KoboCollect software for tablets. Descriptive statistics and ordinal *probit* regression model were used to analyze the collected data and determinant factors influencing postharvest loss of potatoes at various farm-level stages, respectively. An aggregate of 15-46% loss exists between harvesting and marketing. Losses during harvesting, sorting, cleaning, packaging, field-to-storage transport, storage, and storage-to-market transport were 58.9%, 6.2%, 2.9%, 2.4%, 3.8%, 20.1%, and 5.7%, respectively. Elevated loss during harvesting and storage in the area is likely to reflect poor handling and storage practices. The primary causes of losses were poor harvesting and handling techniques, poor storage facility, and insects and worms. Moreover, regression model estimations of categorical losses, as perceived by farmers, reveal that socio-demographic variables and postharvest factors influenced potato loss. During the harvest stage, working family members significantly ($p<0.01$) increased loss while years of schooling ($p<0.05$) significantly reduced loss. In addition, harvesting using leaf color change observation as a criterion had significantly ($p<0.01$) mitigated potato loss. In storage, female respondents ($p<0.05$), land size ($p<0.05$), and lack of training ($p<0.1$) had accentuated loss. During transport, the age of household reduced ($p<0.1$) loss whereas farming experience promoted ($p<0.1$) it. To reduce the existing losses, farmers' awareness should be increased concerning each stage. The study recommends the need for stakeholders' intervention focusing on postharvest knowledge and skill capacity building, demonstration of simple innovative ventilated storage construction using locally available materials, appropriate packaging (such as reusable plastic crates) and transport methods, and simple value addition methods (such as potato drying using indirect solar dryers and potato flour processing for fortifying local cereals).

Key words: CAPI, Ethiopia, ordinal *probit* regression, postharvest practices, potato loss determinants

INTRODUCTION

Agriculture is the most important sector in Ethiopia; it accounts for 46% of GDP, 80% of export value, and about 73% of employment [1]. Vegetable production is becoming an increasingly important activity in the Ethiopian agricultural sector. In addition to their nutritional value, vegetable crops play an important role in contributing to household food security and generating employment opportunities for poor households [2, 3].

Potato (Solanum tuberosum L.) is the fourth most important food crop, after maize, rice, and wheat, in the world with annual production accounting for nearly 300 million tons [4]. Out of these, over half of production occurs in developing countries [4]. During the production year of 2020, potato yield was 924528.361 tons (70362.22 ha), with a productivity of 13.13 ton/ha^{-1} in Ethiopia [5]. Potato is considered by the government as one of the strategic commodities for ensuring food security in Ethiopia. It is one of the prioritized commodities by the government, which will lead to inclusive, sustainable, and stronger agricultural value chains in the Central-Eastern Oromia region, where Arsi zone is located [2]. Thus, it has a significant impact on providing nutrition to families, increasing household income, and providing a surplus to the wider market [6].

In the Arsi zone, potatoes cover about 69.85% of the root crop area and 46.49% of the vegetable production [7]. Yet, the existence of postharvest handling and storage-related problems [8] and frequent losses at the farm level [2] require appropriate interventions in the area. Postharvest losses of horticultural crops can range from about 15 to 70% at various stages in Ethiopia [9]. Given the short postharvest life of potatoes, the percentage losses of potatoes due to poor postharvest handling practices are estimated to be 20-25% in Ethiopia [10]. Thus, whether the gain in potato crop yield in the target area is marginal or significant, its availability could be negatively affected because of inappropriate postharvest management practices.

Postharvest loss reduction of fruit and vegetable produces is a very effective strategy for ensuring food and nutrition security. The reduction of postharvest loss of fruit and vegetables can compensate for the need to increase production of fruits and vegetables. It involves less cost on interventions than required to increase production to cope with the current growing demand in developing countries like Ethiopia [11]. Moreover, proper postharvest handling and storage also help to ensure household and community food security until the next harvest and help producers to avoid selling at low prices during the glut period that often follows the harvest.

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In many developing countries, the major causes of fresh fruit and vegetable loss are the lack of appropriate postharvest practices (poor harvesting, transportation, storage, and processing technologies) at the producer level while fruit and vegetable losses in developed countries occur largely at the consumer stage [12]. Poor postharvest practices occur in developing countries throughout the produces value chain, especially during farm-level handling and storage activities [13]. Farm-level losses are considered most critical due to limited availability of cold storage facilities, inadequate packaging for storage and transport, poor infrastructures, lack of processing facilities and poor handling practices [2]. In Ethiopia, there is a lack of awareness of postharvest handling practices and less consideration of the cumulative effect of every single cause of loss [14]. Research to quantify the extent and understand the causes of losses of specific crops as well as identify determinant factors of produce losses in specific value chain stages is needed to identify the most cost-effective interventions to address postharvest loss. Generating farm-level survey data is one way of producing reliable estimates of harvest and postharvest losses, to orient decision-making and monitor progress towards reducing food losses [15]. Socio-economic factors as well as the existing postharvest practices influence postharvest physical losses at different stages of produce value chains [16]. So far, few studies have been attempted to assess postharvest loss along the potato value chain in different study areas in Ethiopia [9, 10]. However, these studies were limited to some postharvest potato handling practices or farm-level stages. Therefore, the evaluation of handling practices, the extent of technology use, and the associated impacts on the existing produce loss in the postharvest farm-level potato value chain in Arsi zone, Ethiopia was conducted.

Objectives

The general objective of the survey was to collect baseline data on postharvest practices, extent and causes of losses, and factors influencing postharvest loss of potato crops in *Tiyo* district of Arsi Zone, Ethiopia with the following specific objectives: (1) to systematically assess and characterize the postharvest losses for potato crop in the target area, (2) to assess the existing harvest, postharvest handling, storage, and transport practices for potato crop, (3) to identify the determinant factors influencing producer-level postharvest loss of potato crop in the area, and (4) to suggest appropriate scale innovative interventions for potato loss reduction in the area.

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METHODOLOGY

Description of the study area

The baseline survey was conducted in *Tiyo* district of Arsi Zone, Oromia region, Ethiopia for potato crops (Figure 1). Assela is the zonal capital, located 175 km South-East of Addis Ababa.

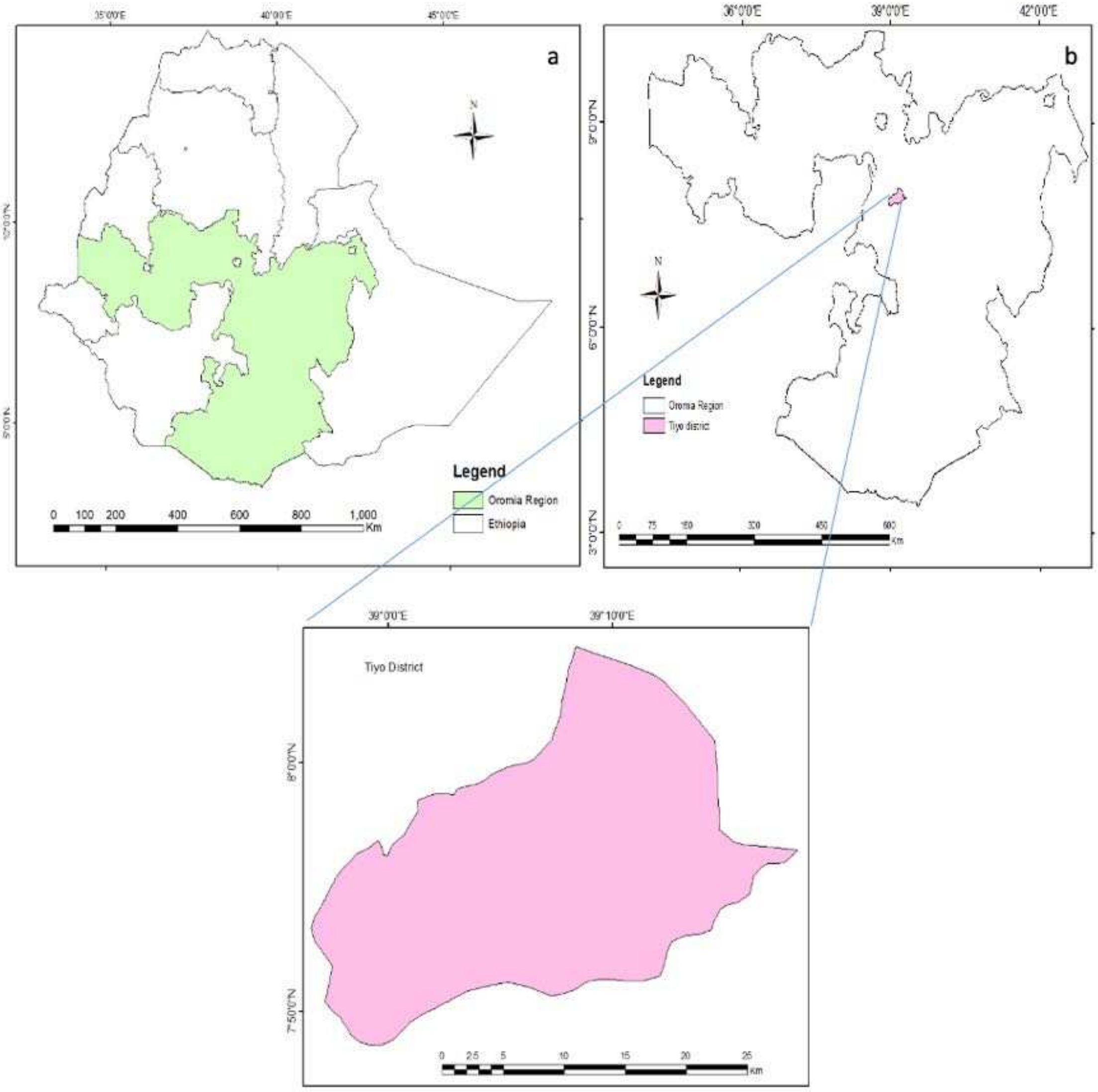

Figure 1: (a) Regional map of Oromia (b) location of the *Tiyo* district within the region

Tiyo is one of the 24 districts of Arsi zone. It is located at 6° 59' to 8° 49' N latitudes and 38° 41' to 40° 44' E longitudes. Its altitude ranges from 1850 to 4050 m.a.s.l. Crop-livestock mixed farming system characterizes the zone. Crop production is carried out in both meher and belg seasons although the main cropping season is meher. Malt barley, wheat, teff, maize, sorghum, fava bean, field peas, lentil, linseed, onion, and potato are the major annual crops grown in the district [17]. The total land allocated for cultivation of potato in *Tiyo* district by respondents during 2020/21 cropping season ranged from 0.25 to 6 ha (survey result, 2022).

Approaches and methods

The quantitative survey approach was purposively selected to help collect quantitative data needed to set appropriate indicator targets. Both primary and secondary data were used [18]. The primary data collection was carried out online using Computer-Assisted Personal Interviewing (CAPI) data collection platform, as it is a better alternative to the traditional pen-and-paper interviewing method [19], by programming a semi-structured questionnaire in KoboCollect software for tablets in 2022. The data collected included information on socio-economic status, demographic, postharvest practices, and farmers' self-reported perception of their quantitative postharvest losses experienced in the previous season (2020/21). The topics covered in the questionnaire included personal information like, age, family size, potato farm size, level of education and years of experience, active working persons, postharvest training received, stage and time of harvest of produce, percentage loss of produce during harvesting, storage and transportation, storage awareness, on-farm storage facilities utilized and for how long, mode of transportation and packaging materials utilized by the respondents were investigated.

The study has also taken some personal observations to get salient information that helped to identify problems faced by the farmers. The postharvest loss was estimated and quantified as a percentage based on the total harvested quantity as perceived by the respondents. The questionnaire was carefully designed and elicited categorical farmers' perception of postharvest losses at each stage of farm level potato value chain (that is harvest handling, storage and transport to storage/market) were collected by trained enumerators proficient with local language.

Sampling techniques

Producers of potatoes were selected using a multi-stage sampling method. The first stage was a purposive selection of potato crop-growing district and major potato-producing *kebeles* in the district based on the intensity of potato production in Arsi zone. The second stage involved a random selection of five potato-producing *kebeles* (*Dosha, Oda_Dawata, Burka_Chilalo, Denkaka_Konicha, and Hora_Bilalo*) from a list of the potato producer *kebeles* in the district. The Kebele identification was made by reviewing secondary data on production and area coverage of the crop [17].

In the third stage, a simple random sampling technique was used in selecting the respondents for the survey from each target *kebeles*. Sample producer households were randomly selected from the total potato crop producer households after being determined by using the sample size determination formula [20].

$$n = N/ (1 + N (e)^2) \qquad (1)$$

Where: n is the sample size of potato producer households, N is the total potato producer households in the district (N = 182193 and e = 0.069 is the precision level used to determine the required sample size.

After preparing a fresh list of sampling frames, a total sample size of 209 households was determined based on probability proportional to the size of total potato-growing farmers in each Kebele as described by Franklin and Walker [21]. Survey respondents were provided a detailed explanation of the overall objective of the study ahead of time. All household heads (survey participants) provided written informed consent to participate after the purpose of the study was described in their local language. The participants were also informed that they have full right to withdraw from the study participants and ask for anything unclear to them at any time. To assure the confidentiality of the participants, a unique code was written on the questionnaire.

The conceptual and analytical framework

After the completion of data collection, data stored in tablets was transferred to a computer properly for data processing and analysis. The collected data were coded and analyzed using IBM Statistics SPSS version 22 for Windows package [22] software tool. Data were analyzed by descriptive statistics and ordinal *probit* regression model analysis.

The primary data were then organized in tables. Descriptive statistics such as frequency distribution, percentages, and mean were used in analyzing the socio-demographic characteristics of respondents, previous training on postharvest loss reduction, postharvest handling practices, causes of losses and farmer perceived quantity of potato lost at harvest and postharvest stages.

In addition, the categorical potato loss data collected at harvest, storage, and transport stages were ordinal, and *probit* or logit models are the most appropriate for conducting regression analysis on it [16]. The *probit* model assumes that random errors have a multivariate normal distribution and it's used for modelling the relationship between one or more numerical or categorical predictor variables and a categorical outcome [23]. Researchers used an ordered *probit* regression model for analyzing farm-level loss percentage data collected in their respective study surveys; which were organized into four loss categories [16, 24]. Ordinal

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probit regression models were used to investigate the relationship between postharvest loss of potatoes and its explanatory variables as briefly described by Dooga *et al.* [25]. Farmer-level postharvest loss categories at harvest, storage, and transport stages were reported based on the loss percentages the producer perceived. The general ordinal regression model is given as:

$$\text{link}(\gamma_{ij}) = \theta_j - [\beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_p x_{ij}] \quad (2)$$

Where: link (γ_{ij}) is the link function
γ_{ij} is the cumulative probability of the jth category for the ith case
γ is the outcome variable for the loss percentages the producer perceived
θ_j is the threshold for the jth category
p is the number of the regression coefficient
$x_{i1} \ldots x_{ij}$ are the values of the predictors for the jth case
$\beta_1 \ldots \beta_p$ are regression coefficients.

The selection of the predictor variables was based on past research reports by Rühl *et al.* [15]. They reported that the experience in farming and training, the time or days of harvesting, and the type and use of storage facilities were those most commonly used and which showed to be significant for losses. In the current study, the predictors were sub-divided into factors (gender, postharvest training received by farmers, harvest stage, harvest time, storage facility type, storage before market, and mode of transport to market) and covariates (age, active family members, years of schooling, total potato land, and potato farming experience). Testing for the overall significance of the regression models was done using model fitting information, chi-square statistic, and test of parallel lines as detailed in Dooga *et al.* [25].

RESULTS AND DISCUSSION

Demographic and socio-economic characteristics of sample households

Descriptive results on the present study sample households included in the baseline survey revealed that male respondent households represent about 73.7%, whereas female respondent households represent about 26.3%. The survey result showed that 92.34% and 7.7% of them were literate and illiterate, respectively. The average experience of the potato producer respondents in *Tiyo* district was 13.95 years. They are relatively more experienced as compared with the 7.04 years of experience in potato production in Sheka Zone, South-West Ethiopia [27]. This suggests that there is a gap in appropriate postharvest technologies in the area.

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The average family size and economically active respondents' household members were 3.54 and 5.84, respectively. The average age of respondents was 43.41 years.

The household head's education level in mean years of schooling was 8.16. About 7.7% of the households had no formal education or were illiterate with the remaining having either primary, secondary, or tertiary education (Figure 2). This was relatively smaller than the 11% illiteracy level reported by Urge *et al.* [26] for other districts in Ethiopia. Farmers with some level of formal education may better understand the causes of postharvest loss and the benefit of proper handling than those with no formal education. The average area allocated by sample farmers for potato production in the 2020/21 cropping season was about 0.74 ha.

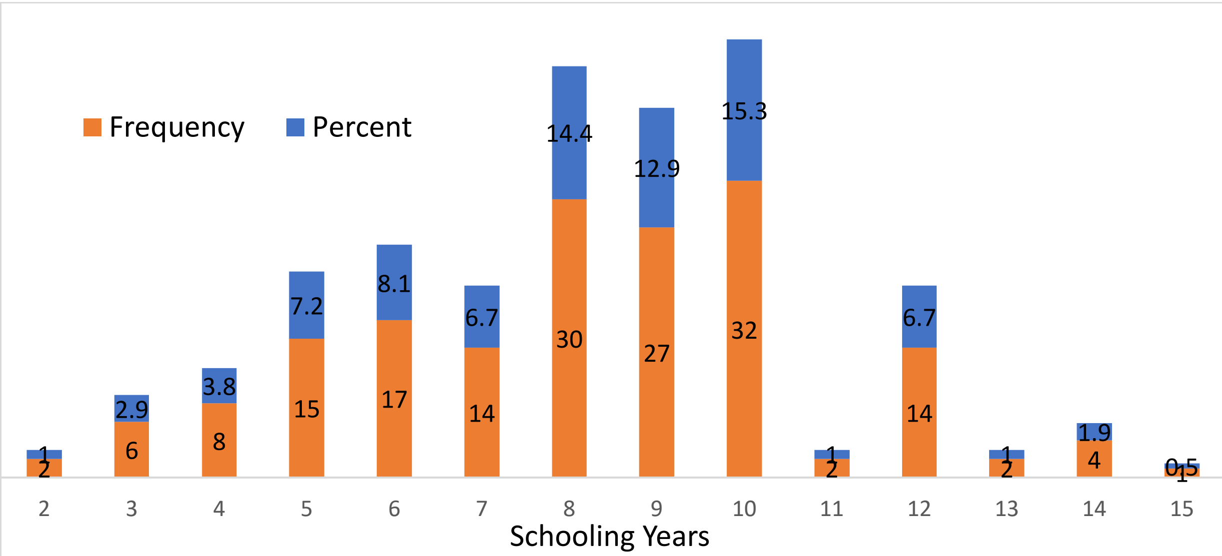

Figure 2: Level of education of household head, who get formal Education, in years of schooling (survey result, 2022)

Potato handling practices during different levels of postharvest activities

Harvest and field handling

The criteria used for determining maturity or stage of harvest by respondents were shown in Table 1 where 47.8%, 15.3%, and 10.5% of respondents harvest their potato produce based on observing color change in potato leaves, color change in potato leaves and tuber size, color change in potato leaves and market price, respectively. With regards to harvesting time, the majority of respondents (69.9%) harvest their produce in the mornings whereas 19.6% of respondents harvest at midday.

The maximum percentage of farmers harvested based on the color change in potato leaves and by observing tomato leaf and/or fruit color change. The produce harvesting stage needs to be based on the intended market that is the preference

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of the local consumers, farmer nearby market, distant market, or long-term storage plan.

Figure 3: Farmers' potato maturity determination (a) and harvest practices (b) in the survey area (2022)

The use of plastic crates in the *Tiyo* district is limited and only 2.4% of respondents reported its use during harvesting. The majority of respondents used traditional baskets (46.6%), pliable plastics (22%), and timber crates (18.2%). Potato produce in the area was also packed by using local sacks, cardboard boxes, and rigid plastic materials during harvesting.

Storage methods

Maintaining appropriate storage conditions for potato tubers can slow down respiration rate, reduce re-growth or sprouting, prolong shelf-life, and inhibit the development of decay-causing pathogens. Lack of storage facilities can force farmers to sell their produce even if the prices are low.

Almost a third (58.9%) of smallholder potato farmers in *Tiyo* district did not practice storage at all. The remaining potato producers maintained their produce before marketing by using storage rooms for spreading potatoes on flour, bulk storage in piles, stacking bags on one another, stacking wooden crates, and using traditional storage structures. They also employ delayed harvest for extending shelf life. There is no use of cold storage in the area.

The majority of farmers (40.7%) used a combination of storage methods: spreading on flour, traditional storage, and delayed harvest. Among respondents, only 5.8% of farmers had traditional storage structures. Delayed harvest (5.8%) is one of the on-farm storage methods employed by farmers in the district. The most common one, however, is storing harvested potatoes by spreading them on the floor of the storage room before transportation with a response rate of 40.1% (Table 2). Storage times vary from less than a week to more than four weeks in the

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district as reported by the farmers. Farmers in the district mostly, with a 43% response rate, store their potato produce for longer than 4 weeks before the sale.

Transportation of produce
As shown in Table 3, about 78% the respondents have practiced transport of potatoes from farm to storage or market using pack animals, handy/animal-pulled carts, vehicles, and human back/labor as a mode of transportation. The primary mode of transportation of potatoes in the study area to the markets was by loading them on pack animals like horses and donkeys with a 45.4% response rate. Whereas only 10.4% of the respondents have transported potatoes from the field to the marketing area using vehicles.

Loss during different levels of postharvest potato handling practices
From the survey, it was found that every farmer has a different percentage of loss during postharvest activities from harvesting to marketing. The producer-level postharvest potato value chain comprises numerous unit operations such as harvesting, sorting, cleaning, packaging, transport to storage, storage, transport to market, and marketing. Farmer perception of postharvest losses along the on-farm postharvest handling chain is presented in Table 4 for percent loss at the farm during harvesting, sorting, cleaning, packaging, field to storage transport, storage, and transport to market. Considerable potato losses in both quantity and quality were experienced at each postharvest operation. The highest (58.9%) and the second highest (20.1%) losses were recorded at harvesting and storage operations, respectively, compared to all other producer-level postharvest operations of the potato value chain (Table 4) assessed in the target area. These higher percent of losses during harvesting and storage operations might be a result of untimely harvesting, improper harvesting method, and storage disease infestation. Moreover, it can also be due to loss that is further exacerbated during extended storage as a result of sustained physical injury from improper harvest, field handling, and transportation activities [9].

The majority of respondents (34.4%) lost their produce due to the harvesting method used followed by improper handling, unfavorable environmental conditions (rain, hail, wind), and pests as reported by 6.2%, 4.8%, and 2.4% of respondents, respectively. About 19.1% of respondents put all possible causes combined as reasons for potato loss at the harvest stage. This is due to the harvesting methods commonly practiced in the study area, harvesting manually using digging tools, in which the commodity may be subjected to mechanical damage. Similar cases were reported by Urge *et al.* [26] that harvesting loss comprised of insect damage (3.13% and 2.15%), rotten loss (2.63% and 2.41%), cutting loss (3.05% and 2.02%), potato remained under the soil during harvesting (1.87% and 2.74%), and other losses (3.13% and 1.45%) at Chelia and Jeldu districts, respectively.

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The aggregate farm level postharvest potato crop loss in the study area was 15-46% (Table 5). Elevated loss during harvesting and on-farm storage (collectively with an 80% response rate) in the target area is likely to reflect poor harvesting practices and temperature management (Table 4). This (15-46% of total losses) is comparable with but less than the result of postharvest loss assessment by Degebasa [27] using descriptive results indicating that the mean value of the amount of potato postharvest loss at the producer level was 21.72%. Similar results were also reported that estimated average harvest and transportation-related potato losses were 12.45 and 11.7% in Dedo and Seka districts, respectively, in Ethiopia [9]. Table 5 presents the percentage of respondents reporting five loss categories. All potato farmers experienced categorical percent losses during harvesting, storage, and transport stages. In the target study area, 59.3%, 25.4%, and 4.8% of the respondents experienced less than 5%, between 6% and 10%, and more than 21% loss, respectively, at the harvesting stage.

All respondents practicing storage have experienced potato loss in the last cropping season. At the storage stage, 84.1%, 12.5%, and 3.4% of the respondents experienced less than 5%, between 6 and 10%, and between 11% and 15% losses, respectively. Usually in the study area, producers place the produce directly onto the floor which can subject potatoes to microbial contamination and result in decay. Potato tubers stored in such condition sprout within a short time and involves high postharvest loss [28]. Hence, appropriate storage facilities specific to potatoes need to be introduced in the respective target area to reduce the existing losses.

Similarly, all respondents experienced potato loss during transport to market in the last cropping season. About 96.6% and 3.4% of the respondents experienced less than 5%, and between 5% and 10% losses, respectively, at the transport stage. Minimal losses were encountered during transport, as compared to harvesting and storage stages, with all respondents reporting losses of less than 10% (Table 5).

Causes and severity of potato losses during different levels of postharvest activities

Causes attributed to producer-level potato loss were many and varied in their severity level. Potato loss during postharvest operations occurred due to improper and lack of storing structure, insects, and worms as well poor handling techniques. Generally, losses due to biotic factors were more pronounced compared to losses from poor handling practices of potato produce. Bad weather (rainfall, wind) (35.4%), molds in the field (26.3%), insects in the field (23%), and harvesting methods used (15.8%) were major factors for producer-level potato losses. Similarly, the highest moderately severe threats that contributed to producer-level

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potato loss in the target area were from the harvesting method used (34.4%) and other domesticated animals (34%). These results corroborate with research results of Tadesse *et al.* [10] and Urge *et al.* [26] who reported that paramount potato postharvest loss occurred due to lack of storing area, insects, and worms as well as improper harvesting, poor handling, and improper storage management techniques.

Postharvest Treatments Adopted by Respondents during Different Levels of Handling Activities

From the survey, it was found that most farmers in the respective target districts didn't apply appropriate postharvest treatments for potatoes (84.7%). Based on survey findings, about 6.3%, 12.5%, 18.8%, 18.8%, and 59.4% of farmer respondents applied the chemical spray, cleaning (washing), cooling, and sorting. Potato curing practice was limited to 3.1% of respondents.

Other postharvest treatments used by respondents for the preservation of potatoes such as application of chemicals (pesticides) in the field before harvest, moisture content measurement, and produce quality inspection during storage were limited with a response rate of 38.8%, 9.6%, and 53.6% for potatoes. Almost all the respondents used the observation method (95.5%) for storage inspection. Whereas, very few (4.8%) were concerned about cooling for reducing storage losses of produce. The respondents also affirmed the need for technology that can help them preserve their potato produces for longer periods as their response rates were above 91.4% concerning willingness to pay for technologies.

Ordinal *Probit* Regression Analysis of Producer-Level Postharvest Potato Loss Determinants

The results of postharvest potato loss determinants analysis at each stage of farm level potato value chain are presented in Table 6. Potato quantity loss was assessed at harvest, storage, and transport stages using categories of losses. Signs of parameter estimates and statistical significance of the coefficients from the ordinal *probit* regression model estimation indicate the direction of the response associated with the presence of a particular variable. For example, a positive parameter estimates of a given variable indicates that the probability of farm-level potato loss in the study area increases with the presence or level of that variable while a negative parameter estimate shows a decreasing effect.

The stage of harvest or maturity determination method, working family members, and formal years of schooling of the household head were significant determinants of potato harvesting loss. Working family members significantly ($p<0.01$) increased loss while years of schooling ($p<0.05$) significantly reduced loss. But the sign of working persons in the household was positive, which is unexpected as it indicate

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that higher number of working persons in a family are more likely to experience higher loss. Although training received on the postharvest loss reduction was not significant, its sign is positive indicating that those respondents who didn't take postharvest training were more likely to perceive they experience higher categories of losses during the harvesting stage. These results are consistent with Raghuvanshi *et al.* [29] who reported that the level of education has a positive influence on the proportion of produce loss. In addition, harvesting using leaf color change observation as a criterion had significantly (p<0.01) mitigated potato loss.

Female respondents, total potato land, and lack of postharvest training were significant factors that affected lower categories of losses during potato storage. Female respondents (p<0.05), land size (p<0.05), and lack of training (p<0.1) had accentuated loss. This justifies the need for postharvest potato storage management interventions in the area. This is in line with the report of Akello *et al.* [28] that access to storage management training is one of the significant factors in reducing potato loss. Farmers who had stored potatoes for less than a week were less likely to face significant losses at the postharvest potato storage stage. Storage facilities used in the study area were positively related to potato loss and their effects were not significant. This contradicts the results of Raghuvanshi *et al.* [29] who reported that storage facility was found significant factor affecting postharvest losses at the farm level negatively. This indicates the absence of appropriate storage structures for potatoes in the target study area. This is in line with the report of Wongnaa *et al.* [30] that provision of adequate storage facilities to the farmers may reduce postharvest losses in potatoes considerably.

Age and potato farming experience were significant variables that affect transport level postharvest loss of potatoes. Age of household reduced (p<0.1) loss whereas farming experience promoted (p<0.1) it. But the positive sign for farming experience was not expected. All the other variables were found non-significant.

At all three farm-level postharvest stages of the potato value chain, lack of postharvest training had a positive sign that potato loss in the study area increases with its levels. Similar was reported by Abera *et al.* [14] that produce losses were exacerbated by a lack of awareness of postharvest handling practices and less consideration of the cumulative effect of every single cause of loss.

The model fitting test resulted in p-values for the harvest and storage models of 0.02 and 0.00 ($p < 0.05$), respectively, which implies at least one of the regression coefficients in the respective models was not equal to zero (Table 6). Hence, the final models were statistically significant and predicted their corresponding dependent variables better than the intercept-only models. While the p-value for the transport stage model fitting test was 0.08 indicating that it is significant only at the p = 0.1 level. This might be due to the relatively less level of potato loss perceived by respondents at the transport stage in the area.

Moreover, the Pearson's and deviance chi-square statistic values obtained from goodness-of-fit analysis for the harvest, storage, and transport stages' models were presented in Table 6. The significant values were large ($p > 0.05$), indicating that the data and the model predictions are similar. This is an indicator that the models were good as the lack of significance is interpreted as indicating a good fit [25].

In addition, the results of the parallel line test for all producer-level postharvest stages show that *probit* link functions make the assumptions for the null hypothesis valid for ordinal regression analysis of the data ($p > 0.05$). This means that we can use the same set of regression parameters (that is $\beta 1$s … βps) in modeling each loss level of postharvest potato losses at harvest and storage stages in the target study area.

CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

The survey provided factual baseline information on the aspects and impacts surrounding the producer-level postharvest operations such as harvesting, field handling, packaging, postharvest storage management, transport, and marketing activities. The research has provided practical insights, which will inform stakeholders on the actual issues on the ground to appropriately strategize for the identification, selection, and analysis of the best harvest and postharvest potato management options for interventions in the target area.

Harvesting potatoes at an appropriate stage of maturity and time of day is important for long-term storage and transport to the distant market. Postharvest potato management in the target area lacks proper storage methods such as cold storage and proper packaging materials such as plastic crates. Considerable potato losses in both quantity and quality, based on farmers' perceptions, were experienced at each harvest and postharvest operation. Elevated loss during harvesting and on-farm storage (collectively with an 80% response rate) in the target area is likely to reflect poor harvesting practice, poor field handling, improper packaging and transport, and lack of appropriate storage and temperature management. Hence, appropriate harvest handling, postharvest treatments, storage facilities, packaging materials, and transport modes specific to potatoes need to be introduced in the target area to reduce the existing potato loss.

The stage of harvest or maturity determination method, working family members, and formal years of schooling of the household head were significant determinants of potato harvesting loss. Female respondents, total potato land, and lack of postharvest training were factors that significantly affect lower categories of losses

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during potato storage. Age and potato farming experience were significant variables that affect transport level postharvest loss of potatoes. At all three farm-level postharvest stages of the potato value chain, lack of postharvest training had a positive sign that potato loss in the study area increases with its levels.

Farmers could minimize the existing losses and improve the efficiency of the potato value chain stages through changes in postharvest practices. These changes could be attained through postharvest interventions (focusing on operations such as harvesting, field handling, storage treatments for controlling pests and microorganisms, storage temperature management techniques, and packaging containers) including the following:

- Potato-specific harvest handling knowledge and skill capacity-building interventions need to be given to producers and development agents.
- Simple potato produce-specific cooling methods and storage facilities should be built in the target areas using locally available materials to offer prolonged periods for produce before spoilage as the product awaits transportation to markets.
- Provision of training on construction of improved small-scale farm structures and ventilated storage facilities to avoid market glut and make potatoes available off-season.
- Introduction of improved/appropriate size packaging materials (such as reusable plastic crates) and transport methods specific to potatoes is needed.
- Introduction of potato curing technology is needed.
- Simple value-addition methods, such as potato drying using indirect solar dryers and potato flour processing for fortifying local cereals, need to be introduced.

The output information from the survey can be employed by policymakers and other developmental stakeholders to design appropriate postharvest farm-level interventions specific to potato produce in the survey area. Nevertheless, as the present study depends on cross-sectional data, research implementing spatial and temporal data covering the whole potato value chain in Ethiopia might be required to draw a sound conclusion for broader scope interventions.

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Conflict of Interest

The authors report there are no competing interests to declare.

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Table 1: Potato harvest and field handling methods practiced by respondents (N=209)

Variable		No of Respondent	% respondents
Time of harvest	Mornings	146	69.9
	Midday	41	19.6
	Afternoon	22	10.5
Maturity determination criteria/Stage of harvest	observing color change in potato leaves	100	47.8
	observing color change in potato leaves and tuber size	32	15.3
	observing color change in potato leaves and market price	22	10.5
	observing color change in potato leaves, tuber size and market price	37	17.7
	observing color change in potato leaves and market demand	14	6.7
	observing color change in potato leaves, tuber size, and market price/demand	4	1.9
Plastic crate use during harvesting	Yes	5	2.4
	No	204	97.6
Type of harvest container	Traditional baskets	97	46.4
	Sacks	2	1.0
	Timber crates	38	18.2
	Plastic crates	5	2.4
	Cardboard boxes	13	6.2
	Pliable plastics	46	22.0
	Rigid Plastics	8	3.8

Source: Survey data, 2022

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Table 2: Storage facilities utilized and storage before market by respondents (N = 209)

Variable		No of Respondent	% respondents
Storage after harvest	Yes	86	41.1
	No	123	58.9
Storage type used	Spreading on flour	36	41.9
	Bulk storage in piles	2	2.3
	Stacking bags on one another	1	1.2
	Stacking wooden crates	1	1.2
	Stacking plastic crates	1	1.2
	Cold storage	0	0.0
	Traditional storages	5	5.8
	Delayed harvest	5	5.8
	Traditional storage, delayed harvest	12	14.0
	Spreading on flour/delayed harvest	23	26.7
Storage before market	Less than a week	22	25.6
	Two to 3 weeks	12	14.0
	Three to 4 weeks	15	17.4
	Longer than 4 weeks	37	43.0

Source: Survey data, 2022

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Table 3: Mode of transportation utilized for potatoes by respondents (N = 209)

Variable		No of Respondent	% respondents
Transport from farm to storage/market	Yes	163	78.0
	No	46	22.0
Transport mode/type	Pack animals	74	45.4
	Pack animals, handy carts	24	14.7
	Pack animals, animal pulled carts	42	25.8
	Vehicles	17	10.4
	Labor force	6	3.7

Source: Survey data, 2022

Table 4: Postharvest operations at which potato loss was experienced in the 2020/21 cropping season by respondents (N = 209)

Postharvest operation	No of respondent	% loss
Harvesting	123	58.9
Sorting	13	6.2
Cleaning	6	2.9
Packaging (bagging)	5	2.4
Transportation (field to storage)	8	3.8
Storage	42	20.1
Transportation (storage to market)	12	5.7

Source: Survey data, 2022

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Table 5: Percent of respondents indicating potato loss category

Loss category	Harvest Handling	Storage	Transportation
More than 21% (Loss category 5)	0.8		
Between 16 and 20% (Loss category 4)	1.7		
Between 11 and 15% (Loss category 3)	3.3	3.4	
Between 6 and 10% (Loss category 2)	26.4	12.5	3.4
Less than 5% (Loss category 1)	67.8	84.1	96.6
Number of observations	121	88	116

Source: Survey data, 2022

Table 6: Determinants of postharvest losses along the producer-level potato value chain

Variables	Harvest	Storage	Transport
Loss category 1	-.39(.78)	3.97(1.29)***	-5.48(4.33)
Loss category 2	.90(.79)	5.15(1.36)***	-
Loss category 3	1.34(.81)*	-	-
Loss category 4	1.89(.86)***	-	-
Age (N)	-.01(.01)	.02(.02)	-.28(.15)*
Education (years of schooling)	-.09(.04)**	.05(.07)	-.02(.24)
Gender (0 = female, 1 = male)	.01(.28)	.94(.43)**	1.12(1.32)
Potato land size (ha)	.25(.23)	.75(.37)**	-.25(1.10)
Farming experience (N)	-.01(.01)	-.01(.02)	.24(.14)*
Working persons (N)	.17(.07)***	.09(.11)	-.15(.34)
Training received (0 = no, 1 = yes)	.13(.25)	.72(.42) *	1.90(1.39)
Harvest stage			
1 = Observing leaf color change	-1.49(.42) ***		
2 = color change/size	-1.12(.50) **		
3 = color change/market price	-.40(.42)		
4 = color change/market demand	-.53(.47)		
Harvesting time			
1= morning	.54(.40)		
2= midday	.23(.47)		
3= afternoon	0[a]		
Storage facility type			
1= spreading on flour/bulk storage in piles/stacking bags on one another/delayed harvest		3.71(10.43)	
2= traditional storages		4.66(8.74)	
3= cold storage		2.24(8.73)	
Storage before market			
1= less than a week		-4.83(7.57)	
2= two to 3 weeks		.59(.58)	

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3= three to 4 weeks 4= longer than 4 weeks		.50(.46) 0[a]	
Transport mode/type 1= pack animals 2= animal pulled carts 3= labor force 4= vehicles			 -8.30(.00) -2.30(1.54) -1.96(1.45) -.25(1.37)
Model Fitting Information	P = 0.02	P = 0.00	P = 0.08
Goodness-of-Fit (chi-Square) Pearson Deviance	 P = 0.14 P = 1.00	 P = 0 .99 P = 1.00	 P = 1.00 P = 1.00
Test of parallel lines	P = 1.00	P = 1.00	P = 1.00

Source: Survey data, 2022

Note
= no respondent indicating the loss category;
0[a] = this parameter is set to zero because it is redundant;
Standard errors in parentheses;
Regression coefficient *, **, *** = significant at 10%, 5%, and 1%, respectively;
p is statistical significance level

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