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POST-HARVEST LOSSES AMONG SMALLHOLDER FRUITS AND VEGETABLE SMALLHOLDER FARMERS AND THEIR POTENTIAL IMPLICATIONS FOR FOOD AVAILABILITY: EVIDENCE FROM TWO WOREDAS IN THE OROMIA REGION OF ETHIOPIA

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ABSTRACT

This study examined post-harvest losses (PHL) and their implications for food availability among smallholder fruit and vegetable farmers in Ethiopia's Oromia Region. The study was conducted in six kebeles of Adami Tulu Jido Kombolcha and Dugda woredas using a cross-sectional quantitative survey of 359 fruits and vegetable-producing households selected through multistage sampling method. Data were collected using structured questionnaires administered through KoboCollect App from December 2023 to March 2024. We assessed farm-level post-harvest loss (PHL) using the Aggregate Self-Reported Method, in which farmers reported quantities lost during harvesting and handling, transportation, storage, and marketing; we calculated percentage loss relative to the initial harvested quantity. The estimated producer-level losses were 11.84% for tomato, 8.62% for kale, and 13.81% for papaya. Regional-level PHL estimates were extrapolated by applying the farm-level loss rates estimated in this study to Oromia Region's annual fruit and vegetable production data for 2013-2022. A deterministic 25% PHL-reduction scenario was used to estimate the quantity of produce that could theoretically be recovered and converted, using a dietary consumption benchmark into annual fruit-and-vegetable person-year supply equivalents. The analysis estimated cumulative fruit and vegetable PHL of 724,071.91 tons over the 2013-2022 period. Under the 25% PHL-reduction scenario, the estimated quantity of produce that could potentially be recovered varied across the study years. In 2022, the recovered quantity was equivalent to the annual fruit-and-vegetable consumption requirement of 832,444 people for one year (832,444.34 person-year equivalents), representing the highest annual estimate during the study period. When the annual estimates for 2013-2022 are summed, they amounted to approximately 3.31 million person-years. This cumulative estimate represented the aggregate annual food-supply equivalent generated over the ten years, expressed as the number of one-person annual fruit-and-vegetable consumption requirements that could theoretically be met by the recovered produce in each respective year. The findings indicated that reducing producer-level PHL could increase the quantity of fruit and vegetables potentially available for consumption, highlighting the importance of improved harvesting, handling, storage, transportation, and marketing practices among smallholder farmers.

Key words: Post-harvest loss, smallholder farmers, fruit and vegetables, food availability, Ethiopia

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INTRODUCTION

Achieving food and nutrition security remains a critical development challenge in Ethiopia, particularly in regions such as Oromia where rapid population growth, structural inefficiencies in agricultural systems, and recurrent shocks continue to strain food availability and access. Despite considerable efforts to increase agricultural production, a significant proportion of food produced by smallholder farmers is lost after harvest, thereby limiting the effectiveness of production gains. Globally, it is estimated that nearly one-third of food produced for human consumption is lost or wasted, with particularly high losses occurring in perishable commodities such as fruits and vegetables in developing countries [1]. These post-harvest losses (PHL) reduce food availability, lower farm incomes, and undermine efforts to achieve food and nutrition security.

Smallholder vegetable farmers play a crucial role in supplying nutrient-dense foods that are essential for diversified diets and improved health outcomes. However, they face multiple constraints along the post-harvest value chain, including inadequate harvesting techniques, lack of storage infrastructure, poor transportation systems, and weak market integration [2, 3]. These challenges contribute to significant quantitative and qualitative losses, which not only diminish the volume and quality of food reaching consumers but also reduce the economic returns to farmers. In this context, this study assessed post-harvest losses among smallholder farmers producing tomato, kale, and papaya, which are important horticultural crops widely produced and consumed in the study area. Reducing post-harvest losses in these crops represents a cost-effective and sustainable strategy to enhance food availability without expanding production or cultivated land [4].

At the household level, food security is influenced by a complex interaction of demographic, socioeconomic, and institutional factors. Access to land, education, extension services, credit, and market institutions play critical roles in shaping both production outcomes and the ability of households to secure sufficient and nutritious foods [5, 6]. Moreover, post-harvest losses directly affect household welfare by reducing marketable surplus and income, thereby constraining food access and consumption [3]. Understanding the combined effects of these factors is essential for designing integrated interventions that simultaneously improve productivity, income, and food security.

Although a growing body of literature has examined agricultural productivity and food security in Ethiopia, relatively limited attention has been given to the integrated role of post-harvest losses in influencing both household income and food security outcomes. Most existing studies tend to focus either on production constraints or consumption outcomes in isolation, without adequately linking farm-level inefficiencies to broader food system implications [2, 5]. This study addresses this

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gap by providing a comprehensive analysis of post-harvest losses among smallholder vegetable farmers in Oromia and examining the implications at both household and regional levels.

Specifically, the study aimed to estimate the extent of post-harvest losses among smallholder fruits and vegetable growing households and explore their potential implications for food availability and livelihoods in the Oromia Region of Ethiopia. By integrating farm-level evidence on post-harvest losses with regional-level analysis, the study provided insights into the potential contribution of reducing post-harvest losses to improved food availability and agricultural livelihoods.

Overall, the study argues that addressing post-harvest losses is not merely a technical issue but a strategic policy priority. Strengthening post-harvest management systems can significantly improve food availability, enhance farmers' incomes, and contribute to achieving sustainable food and nutrition security in Oromia region.

MATERIALS AND METHODS

Description of the study area

Agriculture is the primary source of livelihood in Ethiopia and remains central to employment, income, and food security. A map of the study area is shown in Figure 1. In the East Shoa Zone of the Oromia Region, the majority of the population depends on smallholder farming, with over 60% of the labour force engaged in agriculture [7]. Nationally, about 64.9% of the employed population works in agriculture, highlighting the sector's continued dominance [8]. However, agricultural productivity is constrained by climatic variability, limited services, and significant post-harvest losses, particularly for perishable crops.

The study was conducted in Adamitulu Jido Kombolcha and Dugda woredas. Adamitulu Jido Kombolcha, located in the Central Rift Valley, lies between 1500 and 2300 meters above sea level and experiences a semi-arid climate with annual rainfall of 600-800 mm [9, 11]. Dugda woreda, situated at 1600-2020 meters above sea level, receives about 750 mm of rainfall annually, mainly between June and September [11].

Mixed crop-livestock farming dominates both woredas, with cereals, pulses, and vegetables forming the main production systems. Irrigated vegetable production, particularly onion and tomato, plays an increasing role in improving household income and food security [12, 13]. Despite these opportunities, post-harvest losses remain a major challenge affecting both income and food availability.

Overall, the study area comprised selected fruits and vegetable-producing kebeles in Adami Tulu Jido Kombolcha and Dugda woredas of East Shewa Zone, Oromia

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Region, and the findings are intended to apply to the sampled smallholder fruits and vegetable-farming households and similar production settings within the study area.

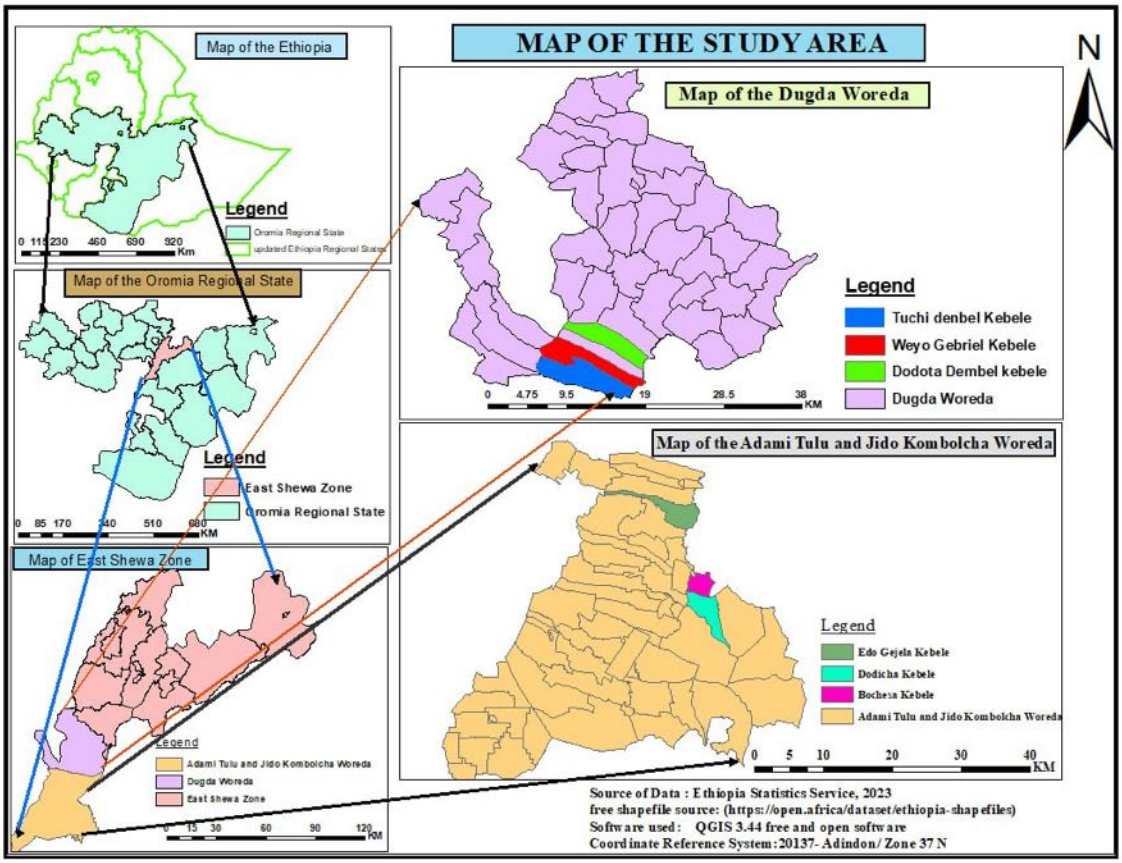


Figure 1: Map of the study area

Crop Selection and Study Scope

The study was supported by the Ethiopian Ministry of Agriculture, whose programmatic priorities included two vegetable crops (tomato and kale) and one fruit crop (papaya). Accordingly, these three crops were purposively included in the study to reflect the institutional priorities and production context under which the research was undertaken. The inclusion of papaya was therefore intentional and formed part of the predefined crop scope. Consequently, the study focuses on post-harvest losses among producers of selected horticultural crops, comprising tomato, kale, and papaya.

Research design

This study employed a quantitative research approach using a survey method within a cross-sectional study design. The design was selected to assess the magnitude of post-harvest losses and examine associations among relevant farm- and household-level variables in relation to the study objectives and research questions. The cross-

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sectional design provided descriptive and associational evidence but does not establish causal relationships.

By adopting a quantitative research approach, the study ensured an objective and systematic assessment of the research problem through the collection of numerical data and the application of statistical techniques for analysis. This approach facilitated the measurement of relationships among variables, enhanced the objectivity of the findings, and supported the generalization and replication of the results, which are key principles of quantitative research [14]. The use of pre-tested structured questionnaires enabled the collection of substantial and standardized data from the sampled population in the study area. This approach was consistent with the study's objectives and ensured a systematic, reliable, and structured investigation of the factors associated with post-harvest losses, market outlet choices, and food and nutrition security among smallholder vegetable farmers.

Data collection methods

Target population of the study area

Research population is defined as those large groups of individuals or objects which have similarity in characteristics on which the research is based [14]. In this study, the target population was the smallholder vegetable farmers in Adamitulu Jido Kombolcha (ATJK) woreda and Dugda woreda.

Sampling techniques and sample size

Sampling involves selecting participants who represent the target population [14,15]. This study employed a multistage sampling technique to ensure representativeness. First, two woredas (Adamitulu Jido Kombolcha and Dugda) were purposively selected from East Shoa Zone based on their high fruits and vegetable production potential and concentration of smallholder farmers. Second, six kebeles were selected based on production similarity, market participation, accessibility, and security conditions. Third, from a sampling frame of 8,730 registered vegetable-producing households, simple random sampling was applied to select 359 respondents (Table 1). Third, from a sampling frame of 8,730 registered vegetable-producing households, a sample of 359 households was determined using the Krejcie and Morgan sample-size table and selected through simple random sampling (Table 1). All 359 selected households provided complete responses. Because the first two sampling stages involved purposive selection, the findings are limited to the sampled households and selected study settings and are not regionally representative. The sample size was determined using the Krejcie and Morgan formula, ensuring reliability and representativeness of the study population [16].

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Krejcie and Morgan formula

The Krejcie and Morgan formula for sample size estimation in research [18] is as follows:

$$S = \frac{X^2 NP(1-P)}{\mathrm{d}^2(N-1) + X^2 P(1-P)}$$

Where,

S = required sample size

X^2 = the table value of chi-square for one degree of freedom at the desired confidence level

N = the population size

P = the population proportion (assumed to be .50 since this would provide the maximum sample size)

d = the degree of accuracy expressed as a proportion (.05)

Based on the Krejcie and Morgan sample-size table, a total of 359 households were selected from the 8,730 eligible fruits and vegetable-producing households as the required sample for the study (Table 1).

Primary and secondary data

Data sources for the research were from single households in the vegetable producing community in the study area. Primary data were collected face to face using a structured questionnaire from the vegetable smallholder farmers (SHFs).

Secondary data were collected from reports, research findings of published sources and relevant institutions including the Ethiopian Public Health Institute (EPHI), Ethiopian Statistical Services (ESS; formerly the Central Statistical Agency [CSA]), FAOSTAT, AdamiTulu Jido Kombolcha, and Dugda Woredas Agriculture Offices [11, 23, 26].

Data collection instrument and questionnaire design

Data were collected using a structured, pre-coded questionnaire aligned with the study objectives The questionnaire covered socio-economic characteristics, production, post-harvest practices, and market participation. It was pre-tested with 5% of the intended sample among vegetable-producing households in the study area. Pretest respondents were excluded from the final survey. Based on the pretest, ambiguous questions, wording, sequencing, and response options were revised. The questionnaire was prepared in English, translated into Afaan Oromo, and back-translated into English to ensure consistency. Enumerators received training on the questionnaire, interviewing procedures, informed consent, and KoboCollect, and were supervised throughout data collection. Completed questionnaires were reviewed daily for completeness and consistency, with electronic validation checks applied in KoboCollect. Data were collected from December 2023 to March 2024.

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Missing or inconsistent responses were checked against the original questionnaire and, where necessary, excluded from the relevant analysis.

Ethical considerations: Ethical approval was obtained from the UNISA-CAES Health Research Ethics Committee on 4 May 2023 (REC Reference No. 2023/CAES_HREC/060; NHREC Registration No. REC-170616-051), with approval valid from 4 May 2023 to 30 April 2028. Informed consent was obtained from all participants before data collection. Participation was voluntary, and confidentiality and privacy were maintained through the protection and de-identification of research data, in accordance with the approved research protocol. Permission to conduct the fieldwork was also obtained from the Oromia Bureau of Agriculture and Natural Resources.

Data analysis

Data were entered into Microsoft Excel, checked for completeness and consistency, cleaned, coded, and subsequently analysed. Descriptive statistics, including means, frequencies, and percentages, were used to summarize the study variables. Percentages were calculated using the number of valid observations for each variable as the denominator, and missing observations were excluded from the respective calculations. Post-harvest losses were calculated and aggregated separately for tomato, kale, and papaya using the respective crop-specific sample sizes. No sampling weights were applied because the analysis was based on the surveyed households. The formulas and operational definitions of the variables were presented in the relevant methodological sections. Data analysis was performed using Microsoft Excel, and SPSS version 24, as applicable. Where appropriate, estimates are reported with 95% confidence intervals to indicate statistical uncertainty.

Estimation of regional fruit and vegetable production volume for post-harvest loss and food security analysis

Estimating the potential regional magnitude of post-harvest losses for the crops under study (tomato, kale, and papaya) involved obtaining annual production data for 2013-2022 from the Ethiopian Statistical Service (ESS). The production data were aggregated over the ten-year period (Eq. 1). Because the PHL rates were estimated from the household survey conducted during December 2023-March 2024, these rates were applied to the 2013-2022 production data as a scenario analysis rather than as estimates of actual annual PHL. Thus, the analysis assumes a constant-rate scenario and does not imply that PHL rates remained unchanged over the decade. Temporal sensitivity analysis was conducted by applying alternative PHL rates to the historical production series to assess the effect of variation in the assumed loss rates on the estimated quantity of PHL.

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The post-harvest loss rates measured in the sampled woredas (Eq. 2) were applied to regional production data using production-weighted averages (Eq. 3) based on ESS statistics. Although the loss estimates were derived from selected woredas, the study areas were purposively selected because they are important production areas for the specific crops under investigation, namely tomato, kale, and papaya. Nevertheless, because the woredas were purposively selected, the resulting regional estimates should not be interpreted as statistically representative of the entire Oromia region. Rather, they provide a bounded illustrative scenario of the potential magnitude of post-harvest losses if the observed crop-specific loss rates were applied to regional production. To assess the sensitivity of the estimates to variation in loss rates, plausible lower and upper PHL rates were applied to the regional production data, providing an indicative range of potential regional losses while acknowledging the geographic limitations of the extrapolation.

These regional loss estimates were further used to estimate the potential number of people whose food security could have been improved if post-harvest losses were reduced, linking crop losses directly to household food availability and nutrition outcomes.

To gain a more informed understanding of production trends, annual production data spanning 2013-2022 were compiled from ESS. By aggregating the annual production figures over the ten-year period, the study produced a reliable estimate of the average volume of crops produced regionally. This approach not only emphasized the importance of precise production assessment in understanding agricultural output but also identified potential areas for improvement in crop management and post-harvest handling. This approach of combining agricultural production statistics with estimated post-harvest loss rates to quantify the economic and food security implications of post-harvest losses is consistent with the approach applied by Teferra [3], thereby providing methodological support for the regional loss estimates.

A primary step involved calculating the total regional production (TP) for tomato, kale, and papaya by summing annual production from 2013 to 2022 (Eq. 1). Missing crop-year observations were treated as missing and excluded from the summation. Thus, Eq. 1 represented the ten-year cumulative production, not the annual average.

$$TP = \sum_{i=1}^{10}(X_i) \qquad \textit{Eq. 1}$$

Where:

TP = Total production over ten years
X_i = Production of fruits or vegetables in year i
i= Year index (i=1,2, 3,…….10)

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Farm-level post-harvest loss estimation: Post-harvest losses were estimated at the farm level using the Aggregate Self-Reported Method, following the procedure described by Creswell and Creswell [20]. Farmers reported the quantities harvested and the quantities lost during harvesting, handling, storage, transportation, and marketing for the 2023/24 production season. Reported quantities were recorded in kilograms (kg) or converted to kg using the applicable local-unit conversion factors. Loss percentage for each crop was calculated as the reported quantity lost divided by the total quantity harvested, expressed as a percentage. The analysis was conducted separately for tomato, kale, and papaya. The method was cited to the original source describing the Aggregate Self-Reported Method rather than the sample-size reference.

The farm-level PHL percentage was calculated using Equation 2:

$$Local\ PHL_i(\%) = \frac{Quantity\ Lost_i}{Total\ Quantity\ Harvested_i} * 100 \quad \text{Eq. 2}$$

Where:

Local PHL_i (%) = Post-harvest loss percentage for crop i at the farm level
Quantity $Lost_i$ = Total weight of crop i lost between harvest and delivery to market
Total Quantity Harvested = Total quantity of crop i harvested at the farm level
i = Index representing each crop included in the post-harvest loss analysis, namely tomato and kale (vegetable crops) and papaya (fruit crop)

Extrapolation to regional post-harvest loss: To derive a regional estimate of PHL, measured farm-level loss rates were aggregated using production-weighted average. Such weighting accounts for the relative contribution of each crop to total regional output, thereby ensuring that crops with higher production volumes influence the regional estimate proportionally. This approach was consistent with methodologies applied in national post-harvest assessments [21, 22] and provided a more representative regional loss estimate than simple arithmetic averaging.

Regional PHL was calculated as follows:

$$\text{Regional PHL} = \sum(\text{PHL}\%_{j\ producers\ level} * \text{Production}_{\text{j regional}})/100 \quad \text{Eq. 3}$$

Where:

Regional PHL = Aggregated post-harvest loss estimates for the region (weight),
PHL%= Post-harvest loss percentage for crop j as measured at producer level,
$\text{Production}_{\text{j}}$ = Total regional production of crop j

This production-weighted approach ensured that the estimated regional PHL reflected the relative production scale of each crop category, improving the representativeness of the overall loss estimate [3]. Weighted extrapolation uses

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production levels to estimate aggregate losses when crop- or region-specific loss data are available for only a subset of the production system [20, 23].

Quantitative estimation of potential food security from recoverable post-harvest losses

Ethiopia's Food-Based Dietary Guidelines (FBDG) recommend an average intake of 150 g of fruits and vegetables combined per person per day for adults, equivalent to 54.75 kg/person/year [24]. This benchmark was used in the present scenario analysis because it is the national, context-specific dietary recommendation and provides a consistent basis for estimating the number of people whose annual fruit and vegetable requirements could potentially be met through recoverable post-harvest losses. Although the WHO recommends at least 400 g/day of fruits and vegetables combined for adults, this higher international benchmark was not used because the analysis specifically adopted the Ethiopian national guideline [26].

Addressing post-harvest losses is critical to improving food availability and dietary quality. To quantify the potential contribution of recoverable losses to food security, this study implemented a systematic, stepwise approach grounded in the empirical farm-level and regional loss estimates described in Eq.2 and Eq.3.

First, the total regional post-harvest losses for fruits and vegetables (in tons) were converted into a potential supply of food for individuals using Equation 4:

$$\mathbf{FVPSE} = \frac{Recoverable\ PHL\ (kg)}{54.75\ kg/person/year} \qquad \text{Eq. 4}$$

Where:

FVPSE = Fruit-and-vegetable person-year supply equivalents, representing the number of persons whose annual recommended fruit-and-vegetable consumption could theoretically be supplied by the recoverable post-harvest losses.

Recoverable PHL: The quantity of post-harvest losses that could theoretically be recovered and made available for human consumption, assuming complete recovery, acceptable quality, and effective distribution without further losses.

PHL = Total regional post-harvest loss (tons), derived from Equation 3

Equation 4 provided a theoretical estimate assuming 100% recovery of post-harvest losses, illustrating the maximum potential contribution of recovered produce to meeting dietary requirements. This approach aligned with methodologies used in previous studies to assess the population-level nutritional impact of post-harvest interventions [3,5].

Recognizing that 100% recovery is unlikely in practice, the analysis incorporated scenario-based adjustments to reflect achievable improvements in post-harvest management. Drawing on evidence of ongoing initiatives in Oromia region to

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improve storage, handling, and market access, the study estimated the impact of reducing 25% of total post-harvest losses on food security using Equation 5:

$$\text{PFS}\ (person) = \frac{Total\ PHLs\ in\ tons * 25\%/100 * 1000}{PCFVC(kg\ per\ person\ per\ year)} \quad \text{Eq. 5}$$

The 25% reduction was adopted as a conservative and contextually realistic scenario, informed by previous studies that have considered higher PHL reduction levels, such as 50% [3]. A 25% reduction was considered more attainable under the prevailing conditions in Ethiopia, including farmers' limited post-harvest knowledge, inadequate storage and transport infrastructure, limited access to appropriate technologies, and economic constraints. To examine how the estimated benefits change under different assumptions, 10%, 25%, and 50% PHL reduction scenarios were considered, with 25% used as the main scenario. These scenarios represent hypothetical reductions rather than observed intervention effects.

This scenario-based calculation provided a realistic and policy-relevant estimate of the potential number of individuals whose dietary needs could be met if post-harvest losses were partially mitigated. It also highlighted the direct linkage between improved post-harvest handling and enhanced household food and nutrition security, reinforcing the importance of interventions aimed at reducing losses along the supply chain.

The methodology first measured PHL at the farm level, then extrapolated these results to the regional level using production weights, and finally applied scenario-based analysis to assess both the magnitude of losses and the potential food security benefits of reducing them. Consequently, the estimates generated serve as evidence to inform policy decisions, prioritize investment in post-harvest management, and design interventions that can tangibly improve dietary outcomes for smallholder vegetable-producing households in Oromia region.

RESULTS AND DISCUSSION

Fruit and vegetable post-harvest losses and food security

Oromia's population increased from 31.95 million in 2013 to 39.98 million in 2022, indicating increased food demand over the period (Table 2). Food-insecurity estimates available for selected years showed substantial variation, with 8.66 million people (26.4%) in 2014, 10.17 million (29.4%) in 2016, 7.56 million (20.8%) in 2018, and 19.99 million (50.0%) in 2022. Thus, only the 2022 estimate exceeded one-third of the regional population. Given that these observations were nonconsecutive and may not be directly comparable across years, they do not establish a persistent or widening trend in food insecurity. Nevertheless, the 2022 estimate indicated a substantial food-insecurity burden that, alongside estimated recoverable post-

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harvest losses, highlighted the potential importance of reducing such losses to improve food availability.

It should be noted that the post-harvest loss estimates presented in Table 2 do not represent losses for all food commodities produced in Oromia. Rather, they represent the estimated post-harvest losses for the three crops included in this study, namely tomato, kale, and papaya. Therefore, these estimates should be interpreted as an indication of the potential contribution of reducing losses in these crops rather than as a measure of the total food loss burden in the region.

The survey results provided the farm-level basis for estimating the implications of post-harvest losses (PHL) for food availability in the Oromia region. The study covered 359 vegetable-producing households in Adami Tulu Jido Kombolcha and Dugda woredas, producing tomato, kale, and papaya. The estimated average PHL rates were 11.84% for tomato, 8.62% for kale, and 13.81% for papaya, based on farmers' reported harvested and lost quantities. These crop-specific loss estimates were subsequently applied to regional production data obtained from the Ethiopian Statistical Service (ESS) to estimate regional PHL and the potential fruit-and-vegetable person-year supply equivalents under different PHL-reduction scenarios.

The result of this study in Table 2 further presented the implications of post-harvest losses (PHL) for food security in the Oromia region by estimating the number of people who could potentially achieve food security if PHL were reduced by 25%. This analysis is important for understanding the magnitude of food insecurity in the region and for highlighting the potential benefits of improved post-harvest management practices.

The substantial food-insecurity burden observed in 2022 indicated that reducing post-harvest losses from these three crops could potentially improve food availability. However, the nonconsecutive and potentially non-comparable food-insecurity observations do not support conclusions about a persistent or widening trend over the period.

Given the post-harvest loss levels observed in this study 11.84% for tomato, 8.62% for kale, and 13.81% for papaya the complete elimination of post-harvest losses is not a realistic expectation. These losses occured at different stages of the post-harvest period at producrs level and were influenced by multiple factors, including harvesting practices, handling methods, storage limitations, transportation conditions, and market-related constraints. The findings therefore suggested that, although post-harvest losses can be reduced through appropriate interventions, some level of loss is likely to remain because of the perishable and biological nature of the crops and existing limitations in post-harvest infrastructure and technologies [3, 26]. Consequently, the scenario analysis in this study adopted a 25% reduction

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in post-harvest losses as a more realistic and achievable improvement target rather than assuming their complete elimination. Even this level of reduction would require improvements in harvesting, handling, storage, transportation, and market access, consistent with the challenges reported in previous studies [27].

Based on these considerations, this study used a 25% reduction in post-harvest losses as a scenario for estimating the potential improvement in food availability and its possible contribution to food security. The scenario was applied to the post-harvest loss rates measured in this study, which were 11.84% for tomato, 8.62% for kale, and 13.81% for papaya. Under this scenario, 25% of the estimated losses for each of the three crops was considered potentially recoverable and was subsequently used to estimate the quantity of produce that could be saved at the regional level. Although this scenario does not assume the complete elimination of post-harvest losses, achieving such a reduction would require improvements in harvesting and post-harvest handling practices, storage infrastructure, transportation, and supply chain management.

Focusing on the years with available food-insecurity data (2014, 2016, 2018, and 2022), the findings in Table 2 indicated the potential contribution of a 25% reduction in post-harvest losses (PHL) to food availability. In 2014, with a population of 32.82 million and 8.66 million food-insecure people, a 25% reduction in PHL could theoretically provide a fruit-and-vegetable supply equivalent to 243,187 person-years, representing 2.81% of the reported food-insecure population. In 2016, the estimated supply equivalent was 256,949 person-years, equivalent to 2.53% of the 10.17 million food-insecure population. In 2018, the estimated supply equivalent was 234,533 person-years, equivalent to 3.10% of the 7.56 million food-insecure population. These percentages are arithmetic scenario ratios and do not represent measured improvements in food security. The estimates assumed that the recoverable produce remained suitable for consumption and can be fully recovered and distributed, while distribution, affordability, spoilage, substitution, and household access are not modeled.

A much larger impact was observed in 2022, when food insecurity increased sharply to 19.99 million, while a 25% reduction in PHL could generate food availability equivalent to 832,444 person-years, representing the highest potential contribution of 4.16%. This result was associated with the substantial increase in estimated PHL of fruits and vegetables, from approximately 91,329 tonnes in 2021 to 182,305 tonnes in 2022, largely due to higher total production, which reached approximately 1.4 million tonnes. Thus, a 25% reduction in PHL could make a substantially larger quantity of fruits and vegetables available for potential consumption.

This analytical approach was built on established food security assessments in the Oromia region and similar contexts, where the potential effects of reducing post-

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harvest losses on food availability have been modeled. By applying farm-level PHL percentages derived from this study to regional production data, annual loss volumes were estimated and subsequently translated into potential food security gains. A similar methodology was employed by Tefera [3], who combined production and food security data to estimate the number of people who could be fed if post-harvest losses were reduced. Evidence from national surveys further highlighted the significant contribution of fruits and vegetables to overall crop losses, supporting the relevance of extrapolating farm-level findings to broader regional or national analyses.

Overall, the results presented in Table 2 illustrated the relationship between population growth, food insecurity, production, and post-harvest losses (PHL) of fruits and vegetables in the Oromia Region during 2013-2022. Over this period, total PHL of fruits and vegetables was estimated at 724,071.90 tonnes. To assess the potential contribution of reducing these losses to food availability, the methodology described in the Methods section was applied using the recommended per capita fruit and vegetable consumption level of 54.75 kg per person per year from the Ethiopian Food-Based Dietary Guidelines. Based on this approach, preventing 25% of PHL would have generated a cumulative food supply equivalent to approximately 3.31 million person-years over the ten-year period, corresponding to an average of approximately 0.331 million person-year supply equivalents per year. This estimate represented the potential quantity of fruits and vegetables that could have been available for human consumption under the assumed loss-reduction scenario.

The results therefore demonstrated the potential role of PHL reduction in increasing the quantity of food available within the food system. However, increased food availability does not necessarily translate into improved food security because actual benefits depend on whether the recovered produce can be accessed, allocated, and utilized by food-insecure households. Physical and economic access, purchasing power, distribution systems, household food preferences and utilization, perishability and storage conditions, and the stability of food supplies across seasons and years may all influence the extent to which recovered produce contributes to food security. Similarly, the analysis does not model how the potentially recovered food would be allocated among households or whether it would reach those experiencing food insecurity. The estimates also assume that the recoverable produce remains suitable for human consumption and can be effectively recovered and distributed. Therefore, the findings should be interpreted as an availability-based scenario that quantifies the potential food supply recoverable through a 25% reduction in PHL, rather than as a direct estimate of food-security gains or the number of people who would become food secure. This approach provides a useful indication of the

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magnitude of food resources that could potentially be retained within the food system through improved post-harvest management.

Figure 2 presented the trends in population growth and potential food availability from a 25% reduction in post-harvest losses (PHL) of fruits and vegetables in the Oromia Region during 2013-2022. The population increased steadily from approximately 31.9 million in 2013 to nearly 40 million in 2022, reflecting increasing pressure on food demand. In contrast, potential food availability, expressed as person-year supply equivalents, fluctuated through 2020 before increasing sharply, reaching approximately 832,444 person-year supply equivalents in 2022. This pattern reflected annual variations in fruit and vegetable production and estimated PHL. The figure distinguished population in million persons from potential food availability in person-year supply equivalents based on population and production data for the Oromia Region and PHL estimates calculated using the methodology described in the methodology section. These results are scenario estimates, and no statistical confidence intervals were calculated.

These results not only highlighted the significant impact that post-harvest losses have on food security, but also emphasized the urgent need for effective interventions aimed at reducing these losses. By addressing the challenges associated with post-harvest management, it is possible to improve access to food for vulnerable populations and work towards ensuring that more individuals achieve food security. The findings serve as a critical reminder of the interconnectedness of agricultural practices, food availability, and the well-being of communities, underscoring the importance of implementing strategies that can mitigate food insecurity and improve overall food systems.

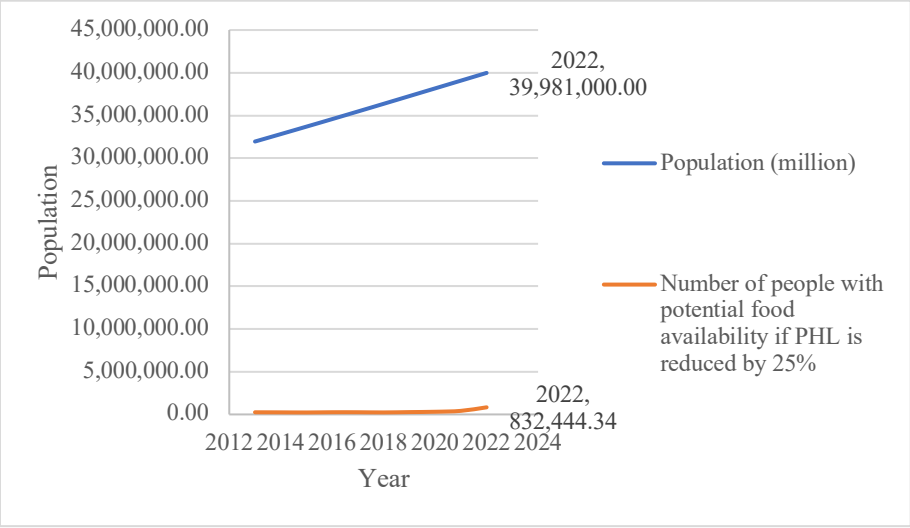


Figure 2: Potential food availability from a 25% reduction in PHL(2013–2022)

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Figure 2 presented the estimated PHL of fruits and vegetables, calculated using the PHL rates obtained from this study and extrapolated to the regional fruit and vegetable production data. The estimates highlighted the potential magnitude of losses and the importance of reducing PHL through improved harvesting, handling, storage, transportation, and marketing practices to enhance food availability and nutrition.

Addressing post-harvest losses presents a significant opportunity to improve food security, nutrition, and public health in Oromia. The proposed 25% reduction could be achieved through practical interventions identified among vegetable farmers, including improved harvesting and handling, appropriate packaging, timely marketing, better transportation and storage, and strengthened extension and training services. Scaling up these practices could substantially reduce vegetable PHL and increase food availability.

Beyond improving food availability, reducing post-harvest losses supports farmers' livelihoods by increasing the quantity of produce available for sale and consumption, thereby improving household income and nutrition. It contributes to economic stability by reducing resource and income losses and aligns with the UN Sustainable Development Goals, particularly Goal 2, which aims to end hunger and improve nutrition by 2030 [28]. Taken together, the results highlighted post-harvest loss reduction as a strategic, multifaceted intervention for strengthening regional food and nutrition security, promoting sustainable agriculture, and improving the quality of life for millions of individuals.

Limitations

This study had several limitations. The cross-sectional, self-reported survey may be affected by recall and measurement errors and cannot fully capture seasonal or temporal variation in post-harvest losses and food security. The purposive selection of two woredas in East Showa limited the generalizability of findings to other production areas. National and decade-wide estimates were extrapolated from study-area loss rates using secondary production data; differences in regional conditions and comparability of secondary data series across years may affect their precision. The 25% loss-reduction scenario and conversion to food-supply equivalents were deterministic assumptions. Finally, the study focused on producers and did not directly measure household food- or nutrition-security outcomes.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The study found measurable post-harvest losses among smallholder fruits and vegetable producers surveyed in Adami Tulu Jido Kombolcha (ATJK) and Dugda woredas of the East Showa Zone. Based on the producer-level survey, the estimated PHL rates were 11.84% for tomato (n = 119), 8.62% for kale (n = 204), and 13.81%

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for papaya (n = 36). These estimates were derived from farmer-reported quantities of harvested and lost produce using the Aggregate Self-Reported Method and therefore reflect conditions among the surveyed producers rather than direct measurements for the entire Oromia Region. Descriptive and regression analyses indicated that PHL was associated with multiple crop-specific factors, including mechanical damage, pests and diseases, weather conditions, labour availability, transportation and other post-harvest management constraints. For the broader scenario analysis, the study-derived PHL rates were applied to Oromia regional production data for 2013-2022. The resulting 724.1 thousand tons represents a model-based estimate of potential regional PHL under the assumptions of the extrapolation, rather than a directly measured regional loss. Similarly, the estimated benefit of a 25% reduction should be interpreted as a potential food-supply equivalent rather than the number of people actually becoming food secure. The study also concluded that persistent post-harvest losses represent an important constraint to improving food availability and farmers' economic benefits. Reducing these losses could increase the proportion of harvested produce available for consumption and sale.

It is recommended that relevant government institutions strengthen existing post-harvest research, extension, and capacity-building systems to support the adoption of improved practices for reducing post-harvest losses. The institute should operate through a central hub and regional centers, training stakeholders and generating scalable technologies. In parallel, the government should promote AI-driven solutions such as smart storage, predictive analytics, and automated grading to modernize post-harvest systems and reduce losses by up to 25%. Priority should be given to strengthening post-harvest infrastructure and services for smallholder farmers, including aggregation centers, appropriate storage facilities, improved transportation systems, and accessible mobile-based advisory services. Where appropriate, AI-enabled technologies may be integrated into these systems to improve market information, storage management, early warning, and post-harvest decision-making. Further empirical research is needed to quantify the effectiveness of AI-enabled interventions in reducing post-harvest losses among smallholder vegetable farmers in Ethiopia. Strengthening coordination among relevant government institutions and stakeholders should be considered to support value addition, post-harvest management, and supply-chain efficiency. Finally, strengthening policy and investment frameworks through increased funding, incentives, and innovation support will create an enabling environment for sustainable, technology-driven transformation of Ethiopia’s post-harvest sector.

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AUTHORS' CONTRIBUTIONS

Michael Tarekegn: Conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, visualization, writing-original draft.

Sibongile Tekana: Supervision, validation, data verification.

Michael Antwi: Supervision, writing-review and editing.

Shimelis Admassu: Supervision, validation.

CONSENT FOR PUBLICATION

All authors have reviewed and approved the final version of the manuscript and consent to its submission and publication in the *African Journal of Food, Agriculture, Nutrition and Development (AJFAND)*.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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Table 1: Sample size of the study

SN	Woreda	Kebele	Population of smallholder farmers	Number of smallholder farmers (Sample size at 5% margin of error)
1	AdamiTulu Jido kombolcha (ATJK)	Bochesa	85	69
		Dodicha	67	57
		Edo Gejela	67	57
		Subtotal	**219**	**183**
2	Dugda	Dodota Denbel	65	55
		Tuchi Denbel	71	60
		Woyo Gebriel	73	61
		Subtotal	**209**	**176**
		Total	**428**	**359**

Table 2: Potential implications of Post-Harvest Losses (PHL) of fruits and vegetables on regional food insecurity (2013-2022)

Year	Population (million)	Food insecurity (million)	Fruits and veg. production (ton)	Total PHL (ton)	Number of people with potential food availability if PHL is reduced by 25%
2013	31.948		492,987.94	55,127.31	251,723
2014	32.816	8.663	469,710.07	53,257.95	243,187
2015	33.692		427,262.34	50,248.60	229,446
2016	34.575	10.165	483,393.76	56,271.84	256,949
2017	35.467		485,876.50	56,037.56	255,879
2018	36.364	7.56	442,810.15	51,362.80	234,533
2019	37.267		505,801.13	59,881.57	273,432
2020	38.17		592,671.36	68,249.80	311,643
2021	39.075		758,249.49	91,329.16	417,028
2022	39.981	19.991	1,421,656.89	182,305.31	832,444

Source: own compilation and CSA (2022)

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