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Original research

Determinants of Post-Harvest Losses Among Smallholder Tomato, Kale, and Papaya Producers in East Showa Zone, Oromia Region, Ethiopia

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ABSTRACT

INTRODUCTION. Post-harvest losses (PHL) are a major constraint for smallholder vegetable farmers, reducing income, food availability, and household resilience. Understanding the extent and determinants of these losses is vital for designing effective interventions.

AIM. To analyze the demographic, socioeconomic, cultural, and institutional factors influencing post-harvest economic losses in the vegetable value chain of the Oromia region, Ethiopia.

MATERIALS AND METHODS. Primary data were collected using KoboCollect from 359 randomly selected vegetable-producing households using a semi-structured questionnaire administered through face-to-face interviews. Data were analyzed using descriptive statistics (mean, standard deviation, and frequency) in SPSS version 24.0, and a Multiple Linear Regression Model was applied to identify factors influencing post-harvest losses.

RESULTS. Households cultivated an average of 0.475 hectares of land, with vegetables contributing 70.95 % of total income and livestock 26.17 %. Tomato, kale, and papaya recorded post-harvest losses of 11.84 %, 8.62 %, and 13.81 % at producer level, respectively. Regression results identified yield, cultivated area, production experience, age, weather, transport, labor, and education as significant determinants of PHL.

CONCLUSIONS. Post-harvest losses significantly undermine the livelihoods of smallholder vegetable farmers. The findings highlight the need for training, affordable storage facilities, integrated pest management, and strategic investments in infrastructure, irrigation, and marketing. This study contributes to existing literature by integrating socioeconomic, biophysical, and market factors, offering practical insights for enhancing food security and farmer resilience in the region.

KEYWORD: tomato, kale, papaya, post-harvest loss, smallholders, food security, Multiple Linear Regression Model, Oromia https://doi.org/10.31279/2782-6414-2025-3-4 Исследовательская статья

Детерминанты послеуборочных потерь в малом производстве томатов, капусты кале и папайи в Восточной зоне Сева, регион Оромия, Эфиопия

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КОНФЛИКТ ИНТЕРЕСОВ:
авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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АННОТАЦИЯ

ВВЕДЕНИЕ. Послеуборочные потери (ПУП) являются серьезным ограничением для мелких фермеров, выращивающих овощи, поскольку они снижают доходы, доступность продовольствия и устойчивость домохозяйств. Понимание масштабов и определяющих факторов этих потерь крайне важно для разработки эффективных мер поддержки.

ЦЕЛЬ. Проанализировать демографические, социально-экономические, культурные и институциональные факторы, влияющие на экономические потери после сбора урожая в овощной цепочке создания стоимости в регионе Оромия, Эфиопия.

МАТЕРИАЛЫ И МЕТОДЫ. Первичные данные были собраны с помощью приложения KoboCollect от 359 случайно выбранных домохозяйств, выращивающих овощи, с использованием полуструктурированного вопросника в ходе личных интервью. Данные были проанализированы с помощью описательной статистики (среднее значение, стандартное отклонение и частота) в SPSS версии 24.0, а для выявления факторов, влияющих на послеуборочные потери, была применена модель множественной линейной регрессии.

РЕЗУЛЬТАТЫ. В среднем домохозяйства обрабатывали 0,475 гектара земли. При этом на овощи приходилось 70,95 % общего дохода, а на животноводство – 26,17 %. Уровень послеуборочных потерь на уровне производителя для томатов, капусты кале и папайи составил 11,84, 8,62 и 13,81 % соответственно. Результаты регрессионного анализа показали, что значимыми детерминантами ПУП являются урожайность, площадь возделывания, опыт производства, возраст фермера, погодные условия, транспортировка, рабочая сила и уровень образования.

ЗАКЛЮЧЕНИЕ. Послеуборочные потери существенно подрывают средства к существованию мелких фермеров, выращивающих овощи. Результаты исследования подчеркивают необходимость в обучении, доступных хранилищах, интегрированной системе защиты растений, а также стратегических инвестициях в инфраструктуру, орошение и маркетинг. Данное исследование вносит вклад в существующую литературу за счет интеграции социально-экономических, биогеофизических и рыночных факторов, предлагая практические рекомендации для повышения продовольственной безопасности и устойчивости фермеров в регионе.

КЛЮЧЕВЫЕ СЛОВА: томат, капуста кале, папайя, послеуборочные потери, мелкие землевладельцы, продовольственная безопасность, модель множественной линейной регрессии, Оромия

1. INTRODUCTION

Agriculture plays a crucial role in the livelihoods of many households, particularly in rural areas where farming is often the primary source of income [1]. The Oromia region in Ethiopia is characterized by a large population engaged in subsistence farming, particularly in vegetable production, which plays a crucial role in the local economy and food security. However, smallholder vegetable farmers in the Eastern Showa zone of Oromia region face numerous challenges that impact their livelihoods, including postharvest losses, lack of access to markets, inadequate storage facilities, limited processing opportunities, and unreliable transportation infrastructure [2]. These challenges contribute to reduced incomes, limited access to nutritious food, and compromised food security among farming communities.

Postharvest economic losses refer to a wide range of challenges and inefficiencies that occur after crops are harvested, including physical losses, poor handling practices, improper storage, inadequate transportation, and difficulties in accessing markets [3]. These losses not only reduce farmers' incomes but also have broader consequences on food availability, affordability, and nutritional security within the community [4]. Understanding the causes and implications of these losses is crucial for designing targeted interventions aimed at mitigating the impacts and supporting smallholder farmers in enhancing their economic and food security status.

Food and nutritional security encompasses both the availability and affordability of diverse, safe, and nutritious food for individuals and communities [5]. Achieving food and nutritional security is particularly critical for vulnerable populations, including smallholder farmers in the East Showa zone of Oromia region. Insufficient access to food and inadequate dietary diversity can lead to malnutrition, stunted growth, and other health issues, contributing to a cycle of poverty and underdevelopment [6].

Thus, the main aim of the study was to analyze the demographic and socioeconomic factors, cultural dynamics, and institutional arrangements that influence post-harvest economic losses within the value chain of vegetable production in the study area.

2. MATERIALS AND METHODS

2.1. Description of the study area

The study was conducted in Adami Tulu Jido Kombolcha (ATJK) woreda and Dugda woreda of the East Showa Zone in the Oromia Region of Ethiopia. Adami Tulu Jido Kombolcha woreda is located at the center of the region in the Great Rift Valley area that lies between the Ethiopian plateau to the north and the Somalia plateau to the south [7]. Geographically the area is located between 38°25'E and 38° 55'E longitude and 7°35'N and 8°05'N latitude [7]. The altitude ranges from 1500 m to 2300 m above sea level [8]. The average annual rainfall of the area ranges from 650 to 750 mm with a higher erratic in nature [9].

Dugda woreda on the other hand is bordered by Bora Woreda in the North and North West, Arsi zone in the East, Adami Tulu Jido Kombolcha Woreda in the South and Gurage zone of SNNPR in the West [10]. It is found between 8^{0}01'N to 8^{0}10'North latitude and 38^{0}31'E to 38^{0}57'E longitude. The Woreda has a total of 40 kebeles where 36 kebeles are under rural administrations and the remaining four are urban kebeles [11]. The altitude of the woreda ranges from 1600 to 2020 masl [10]. According to [12] the woreda receives a mean annual rainfall of 750 mm with a mono-modal pattern, which falls much between October and November. These climatic conditions of the study woredas contribute to the agricultural practices in the woreda, particularly vegetable cultivation.

The map presented in Figure 1 delineates the geographic context of the study area in Ethiopia. Centrally located within the country, the Oromia Region houses the East Showa Zone, which is situated in the southernmost part of Oromia region. For this research, two specific woredas (districts) were selected from the East Showa Zone: Adami Tulu Jido Kombolcha (ATJK) Woreda and Dugda Woreda.

Within these woredas, the study identified three kebeles (the smallest administrative divisions) for detailed examination, as illustrated in Figure 1. From ATJK Woreda, the chosen kebeles are Bochesa, Dodicha, and Edo Gejela. In Dugda Woreda, the selected kebeles include Dodota Denbel, Tuchi Denbel, and Woyo Gebriel.

The map effectively visualizes this hierarchical spatial framework, progressing from the national level of Ethiopia to the regional context of Oromia, down to the zonal specification of East Showa, and subsequently to the woreda and kebele levels where the research was implemented. This structured approach ensures a comprehensive understanding of the study's geographical setting.

2.2. Demographic and socio-economic setup

The selected woredas for this study are characterized by their strong reputation for vegetable production, particularly among smallholder farmers (SHFs), as noted by [13]. These areas possess favorable agro-ecological conditions that support vegetable cultivation and are strategically located in peri-urban settings, which include communal rural areas.

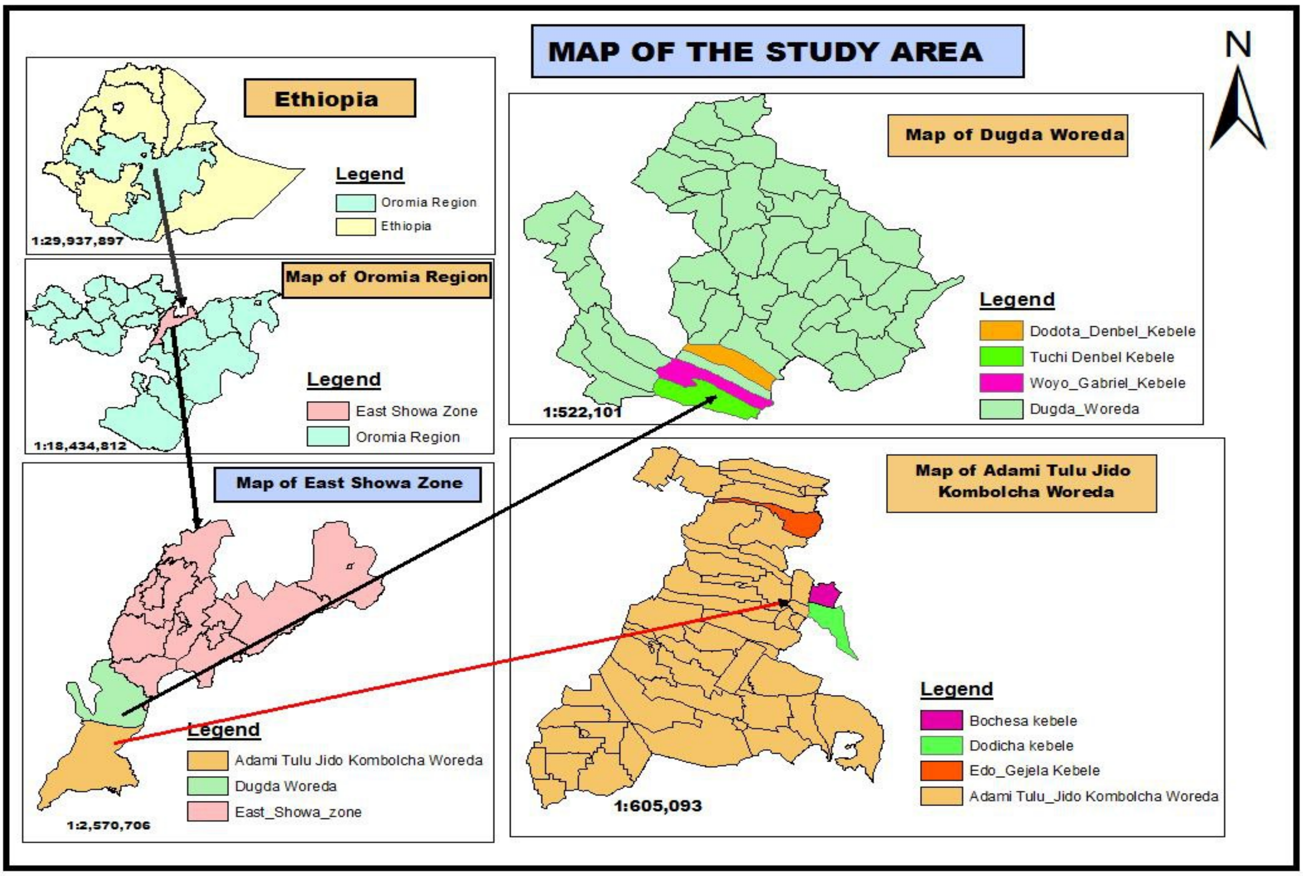

Figure 1
Map of the study area

Their proximity to major markets, especially in the capital city of Addis Ababa and Eastern Ethiopia, provides smallholder vegetable farmers with significant opportunities to supply urban markets. With a combined non-farming population exceeding 5.96 million, as reported by the Ethiopian Government in 2022, there is a robust demand for vegetable produce in Addis Ababa [14]. Additionally, all key vegetable producers and marketing actors are actively engaged in distributing products primarily to the eastern and central markets of the country. Furthermore, these woredas face challenges related to food and nutritional insecurity.

2.3. Sampling procedure

The study adopted a multistage sampling technique for the selection of specific locations as well as target hosuseholds engaged in the production and selling of vegetables. This sampling technique helped to select the study areas and target populations moving down from the woreda level to kebele and finally household level.

Accordingly, three stage sampling techniques were employed. In the first stage two woredas namely ATJK and Dugda woredas out of the the twelve woredas of the East Showa zone of Oromia region were purposively selected. The second stage where the study employed was the random selection of fruits and vegetables producing kebeles from each woreda to have a total of 6kebeles. In the third stage, farming households at the kebele level were randomly sampled from the list of smallholder farmers provided by the Woreda Agricultural Office. Finally, total samples of 359 smallholder vegetable farmers out of the 8730 total smallholder farmers were ultimately interviewed in the six kebeles.

The sample size of respondents was determined using the formula by [15]. The Krejcie and Morgan formula specified below is often chosen for sample size determination due to its simplicity and ease of use, particularly for researchers working with large populations. The Krejcie and Morgan table is well-suited for estimating sample sizes, particularly when studying proportions like vegetable producing households, and is readily adaptable to finite populations for ensuring representativeness. It provides a straightforward way to determine the required sample size for a given population, making it a valuable tool for researchers.

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

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 (8730)
- 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)

The sample size was calculated using the [15] formula above. The total population of smallholder vegetable farmers in the study kebeles were 8730 (Table 1). Accordingly, the sample size of the study was 359 smallholder vegetable farmers. Table 1 presents the distribution of smallholder farmers across selected woredas and kebeles involved in the study. It highlights two main woredas: Adami Tulu Jido Kombolcha (ATJK) and Dugda. In ATJK Woreda, there are three kebeles – Bochesa, Dodicha, and Edo Gejela – totaling 183 smallholder farmers. In Dugda Woreda, the study covers three kebeles as well: Dodota Denbel, Tuchi Denbel, and Woyo Gebriel, with a combined total of 176 smallholder farmers. Overall, the total number of smallholder farmers represented in the study is 359. This table effectively summarizes the population of smallholder farmers within the chosen geographical areas, facilitating a clearer understanding of the research context.

Table 1
Sample size of each study kebele

SN	Woreda	Kebele	Number of smallholder farmers
1	ATJK	Bochesa	69
		Dodicha	57
		Edo Gejela	57
Subtotal			183
2	Dugda	Dodota Denbel	55
		Tuchi Denbel	60
		Weyo Gebriel	61
Subtotal			176
Total			359

ATJK: Adami Tulu Jido Kombolcha

2.4. Method of data collection and analysis

This study employed positivism philosophy, deductive approach, quantitative research method, utilizing a survey research strategy within a cross-sectional study design. The choice of this method was to effectively achieve the study's objective, elucidate causal relationships among variables through deductive reasoning, and address the research inquiries [16].

According to [16] a research population is defined as those large groups of individuals or objects which have similarity in characteristics in which the research is relied on. In this study, the target population were the smallholder vegetable farmers in Adamitulu Jido Komblocha woreda and Dugda woreda.

The primary data for the research was collected from individual households in the vegetable-producing community within the specified study areas. Furthermore, secondary data was gathered from an array of reports, published research outcomes, and relevant institutional sources.

This combination of sources provided a comprehensive understanding of the community's agricultural practices. This primary data collection was conducted through direct, face-to-face interactions utilizing a semi-structured questionnaire aimed at vegetable smallholder farmers (SHFs). The questionnaire was carefully designed to collect quantitative data using the koboCollect application. Before launching the official survey, the questionnaire was assessed for reliability and tested with 20 smallholder farmers who were not part of the main survey population. This initial testing played a critical role in ensuring that the questionnaire accurately addressed the research questions and objectives while also helping to eliminate any unnecessary questions. The data collection process is fundamental to the execution of the research project; thus, both primary and secondary data were employed in this investigation, with the koboCollect platform facilitating the data acquisition.

2.5. Data analysis

Microsoft Excel program and Statistical Package for Social Sciences (SPSS) version 29.0 were used for primary data entry and data analysis respectively. Descriptive statistics such as mean, standard deviation and frequencies were used to examine the demographic and socio-economic characteristics of the smallholder farmers. The Multiple Linear Regression Model /MLR/ was employed to examine factors associated with the postharvest losses of the crops under study.

2.6. Methods for measuring food losses

The four methodologies for assessing postharvest losses, as developed by [17], include the Aggregate Self-Reported Method, the Category Method, the Attribute Method, and the Price Method. For the purposes of this particular study, the Aggregate Self-Reported Method was selected for implementation. This specific method relies on the information provided directly by the producers, which, in this context, refers to smallholder vegetable farmers operating within the study area.

2.7. Calculation of weight loss data at producers' level

For the assessment of weight loss, only one specific value chain was analyzed for each of the crop: tomato, kale, and papaya. The calculation of weight loss for these crops was conducted immediately after they were freshly harvested from the smallholder vegetable farmers' fields. Following the initial harvest, the subsequent losses that occurred during harvesting, transportation of the produce from the field to market, as well as during storage and marketing processes, were also recorded as per the information gathered from the producers. Notably, these subsequent losses were tracked while the farmers themselves managed these stages of the value chain. This approach ensured that the assessment captured the complete picture of weight loss from the moment of harvest through to the point of sale.

2.8. Multiple Linear Regression model to examine the factors associated with postharvest losses

Multiple Linear Regression/MLR is a convenient model for dependent variables of interest, such as post-harvest economic losses indices which are continuous in nature rather than categorical [18]. This makes MLR more suitable than logistic regression, which is designed for binary or multinomial outcomes. Furthermore, MLR allows simultaneous examination of the effect of several predictor variables – including demographic, socioeconomic, and market-related factors – on the magnitude of losses and food security outcomes [19]. Compared to alternative models, MLR provides not only the direction and significance of relationships but also the magnitude of changes in the dependent variable for unit changes in explanatory factors, which is crucial for generating policy-relevant insights [20].

Therefore, to achieve the research objectives, a Multiple Linear Regression (MLR) model was employed, drawing on methodologies similar to those utilized in previous studies conducted by [21]; as well as [22]. This comprehensive model allowed for a thorough examination of the determinants affecting postharvest losses in the selected crops.

Additionally, functional analysis was performed to explore the factors contributing to postharvest economic losses at the farm level, drawing parallels to methodologies employed in earlier research on food grains by [21]; as well as studies on chickpeas by [23] and vegetables by [24]. This multifaceted approach not only provided insights into the extent of postharvest losses but also highlighted the critical factors that farmers must consider to mitigate these losses effectively. The general form of the estimated multiple regression equation is as follows:

$$\hat{y} = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + \ldots b_k X_k,$$

and the population model

$$\mu_y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots \beta_k X_k,$$

where

k = the number of independent variables (also called predictor variables)

$\hat{y}$ = the predicted value of the dependent variable (computed by using the multiple regression equation)

$x_1, x_2, \ldots, x_k$ = the independent variables

β_0 is the y-intercept (the value of y when all the predictor variables equal 0)

b_0 is the estimate of β_0 based on that sample data

$\beta_1, \beta_2, \beta_3, \ldots \beta_k$ are the coefficients of the independent variables $x_1, x_2 \ldots x_k$

$B_1, b_2, b_3, \ldots, b_k$ are the sample estimates of the coefficients $\beta_1, \beta_2, \beta_3, \ldots \beta_k$

Hence the following multiple linear regression function was adopted in the present study:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + \ldots a_9 X_9 + e,$$

where

Y = Post-harvest losses of vegetables/fruits at farm level in quintals

X_1 = Total yield of vegetables/fruits in quintals

X_2 = Area under vegetables/fruits (ha)

X_3 = Age of the household head (hhh) in years

X_4 = Vegetable/fruits production experience of the hhh

X_5 = Education status of the hhh

X_6 = Storage dummy which takes the value '0' if the storage facility is adequate and value '1' otherwise

X_7 = Weather dummy which takes the value '0' if the weather during harvesting is favorable and value '1', otherwise

X_8 = Transportation dummy which takes the value '0' if transport facility is adequate and value '1' otherwise

X_9 = Labour dummy which takes the value '0' if the labour availability during harvesting is adequate and value '1', otherwise.

e = Random-error

3. RESULTS AND DISCUSSION

3.1. Descriptive results of the demographic and socio-economic characteristic of the respondents

The demographic and the socioeconomic characteristics of the vegetable producing households surveyed in the study areas are shown in Table 2 below. Age of the head of the household, size of the household, experience in the production of vegetables of the household and the size of the farm were the components used to evaluate the demographic and socio-economic characteristic of the households surveyed (Table 2). The One-way-ANOVA showed that in the sampled kebeles of the study area, the average age of farmers varied significantly at p<1 % probability level among the respondents. The average age of households ranged from 34.5 years in the Bochesa kebele to 43.3 years in the Tuchi Denbel kebele. Bochesa kebele stands out with the youngest vegetable-producing households, while Tuchi Denbel has the oldest. The presence of young smallholder farmers in Bochesa kebele can be attributed to the availability of an irrigation scheme, which encourages young farmers to engage in vegetable production using irrigated water and achieve two to three harvests per year.

The study is consistent with the findings of various researchers. A study conducted in Dugda and Mieso woredas by [25] in the year 2010 over 161 respondents indicated that the average age of the respondents in Dugda and Mieso woredas were 41 and 38years respectively. In Dugda woreda according to [25], the mean age of the sampled households was slightly above the overall average age of 38.83 years of this study finding. Likewise, the average age of respondents from Mieso, as reported in their findings, is 38 years, which is slightly lower than the average of 38.83 years found in this study. [26] also reported that the average age of the sampled households in ATJK and Dugda woredas was 34.4 years which is much lower than the finding of this study. [27] conducted a study in Illuababora zone of Oromia region over 117 smallholder farmers. As a result, the average age of the surveyed smallholder farmers was 43.62 years.

As such, the average household size of the sample respondents from both woredas is 4.95 and the mean household size varied significantly at p<1 % among the surveyed kebeles based on the One-way ANOVA result. Woyo Gebriel has the lowest household size of 3.9 and Dodota Denbel has the highest average household size of 6.73 (apprx 7). The availability of larger househld size impacts the shortage of labour at various stages of vegetable production [28]. According to [29], in Ethiopia, as of the 2016 survey data the typical household consists of approximately 4.8 (5) individuals which is slightly lower than the finding of this study. The average household size tends to be larger in rural areas, where it reaches about 5.2 individuals per household. In contrast, smaller towns report a lower average household size of 4.3 individuals, while larger towns have even smaller average, with only 3.7 individuals per household. Specifically, within the Oromiya region, the average household size mirrors the national rural trend; also standing at 5.2 individuals per household. This is a little bit higher than the finding of this study. The average household size according to the finding of [26] which was conducted in both woredas of ATJK and Dugda was 5.5persons which is slightly higher than the result of this study 4.95 (5) persons. However, the average household size (10 persons) which was reported by [30] was extremely high when compared to the finding of this study.

Table 2
Socio-economic characteristics of the respondents

Variables	Woreda												Over all	
	ATJK						Dugda							
	Kebele						Kebele							
	Bochesa		Dodicha		Edo Gojela		Dodota Denbel		Tuchi Denbel		Weyo Gebriel			
Sample size	69		57		57		55		60		61		359	
Farmers characteristics														
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age	34.6	4.10	39.9	5.74	40.7	8.46	36.3	4.25	43.4	7.69	38.1	6.278	38.83	6.09
Household size	4.7	1.58	5.7	2.22	4.51	2.6	6.73	2.313	4.18	1.73	3.90	2.119	4.95	2.09
Vegetable production experience	10.5	3.19	12.63	3.60	10.53	4.63	6.96	2.70	9.52	4.49	9.56	3.892	9.96	3.75
Farm size	0.95	0.18	0.88	0.19	1.59	0.61	1.61	0.62	1.37	0.39	1.02	0.26	1.22	.50

SD = Standard Deviation

Source: Survey data

The respondents also have substantial experience in vegetable production, averaging around 9.96 years, which enhances their expertise and knowledge of crop management and market dynamics. Farmers at Dodota Denbel have the lowest average of 6.96 years and farmers at Dodicha have the highest of 12.63 years of vegetable production experience, respectively. Such substantial experience in vegetable production potentially helps to practice the postharvest management activitities and enhance food availability for families, local community and reduce the prices of foods. The average vegetable production experience of the farmers in the study areas was greater than the average vegetable experiences reported in ATJK (6.6 years) and Dugda woredas (4.8 years) in a study conducted by by [26].

The study considers the size of the farm owned by the vegetable producing households, along with other socioeconomic characteristics of the respondents. Among smallholder farmers considered for the study, the average farm size for vegetable production ranges from 0.88 hectares in Dodicha kebele to 1.61 hectares in Dodota Denbel kebele. Similarly, the average farm size of respondents from Edo Gejela kebele have an average farm size of 1.59 hectares. Across both study areas (ATJK and Dugda woredas), the average farm size for vegetable production among sampled households is 1.22 hectares. Specifically, of the 359 respondents, 117 households have land holdings less than 1 hectare, while the remaining 242 households have an average land size of between 1.02 and 1.61 hectares. The One-way ANOVA and descriptive findings indicate a significant variation at p<1 % probability level in the land sizes allocated to vegetable production among the studied kebeles.

As revealed during data collection, this variation in land holding by the sampled respondents is attributed to some farmers in Dodota Denbel kebele who rented additional land for vegetable production. The average landholding of the respondents in the study kebeles is nearly consistent with the results reported by [30], which indicated that farmers have 1.2 hectares per household. However, the average land holding of the respondents in this study is inconsistent with finding of [31] where the high average land holding of the farmers is 3.2 ha.

3.2. Main sources of income

Table 3 provides information on various variables related to sources of incomes of the farmers in ATJK and Dugda woredas. The variables include sample size and the source of household income and amount. The study areas as listed in the table are Bochesa, Dodicha, Edo Gojela, Dodota Denbel, Tuchi Denbel and Woyo Gebriel kebeles. The sample size shows the number of farmers surveyed in each kebele. The source of household income and amount section shows the mean and standard deviation for different sources of income for the farmers. The sources of income listed include vegetables, livestock, salary, pension, and safetynet. The mean represents the average amount of income from each source, while the standard deviation indicates the variation or spread of the income data. Overall, the table provides a comprehensive overview of the sources of income in different kebeles of the study households.

Table 3
Sources of incomes of the respondents

Variables	Woreda												Over all	
	ATJK						Dugda							
	Kebele						Kebele							
	Bochesa		Dodicha		Edo Gojela		Dodota Denbel		Tuchi Denbel		Woyo Gebriel			
Sample size	69		57		57		55		60		61		359	
Source of household income and amount														
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Vegetable	170,217	105,084.2	108,776	44,386.4	570,152	379,109.6	882,462	781,090.4	286,766	12,118.6	377,374	345,093.5	399,291	311,147.1
Livestock	27,939	12,220.1	21,998	15,299.4	14,266	21,455.7	31,754	11,238.6	27,487	16,586.5	41,108	16,893.2	27,425	15,615.6
Safetynet Program	1,341	3,739.5	510	1,878.2	265	2,004.5	95	710.3	571	2,522.2	505	2,003.2	548	2,143.0
Salary/ Wages	1,103	5,219.1	446	1,472.9	1,108	4,079.3	–	–	–	–	620	2,010.3	546	2,130
Pension	175	1,457.5	–	–	1,216	1,667.6	–	–	732	2,253.7	–	–	354	896.4

Source: Survey data

In the study areas, smallholder vegetable farmers have multiple sources of income to support their livelihoods. These include income from vegetable production, livestock, the Safetynet program, salary, and pension. The study analyzed data from 359 respondents and found that revenue from vegetable production is the main source of income among all study areas. The presence of different sources of irrigation water could explain the dominance of the revenue generated from vegetables in the study areas. According to the study condcuted by [32] and visual observation during the data collection period, farmers in the study areas primarily rely on water from the Meki river, Bulbula river and Lake Ziway for irrigation. Others also involve the extraction of groundwater. Farmers in both woredas have the option of participating in a joint irrigation scheme or irrigate their fields individually. In ATJK woreda, the predominant irrigation system is the joint scheme, while in Meki individual irrigation systems that utilize water from boreholes and the Meki River are more prevalent [32].

The results of this study indicate that the average annual income from vegetable production in the surveyed areas is Birr 399,291.34. Additionally, the One-way ANOVA analysis revealed significant differences at p<1 % probability level in the mean income of farmers from vegetable production across the sampled kebeles. The average household income from vegetables and fruits farming in ATJK and Dugda woredas, based on the sampled households, was extremely higher than the Birr 13,714 ($686) per year reported by [33] for the year 2016. This indicates the exponential rise in the share of vegetable on household income and the potential of vegetable farming to enhance household income, especially in the sampled woredas, as it is one of the primary agricultural activities in those areas. The increase in the proportion of income derived from vegetables can be attributed to several factors, including the expansion of irrigation systems, the use of inputs such as seeds, fertilizers, and chemicals, enhanced market access, and improvements in postharvest management practices.

At kebele level, Dodota Denbel has generated an annual income of Birr 882,462.00 which is the highest out of the studied kebeles followed by Edo Gejela stands at Birr 570,152.09 and Woyo Gebriel Birr 377,373.90 from vegetable, respectively. Among the sampled households, Bochesa kebele had the least amount of income from vegetables, which is equivalent to Birr 170,217.30 per season.

As the findings of the study indicated, revenue generated from livestock stood the second source of income next to vegetable. As a result, the annual average revenue generated from livestock is Birr 27,425.69. Among the studied kebeles, Woyo Gebriel kebele had the highest annual income of Bir 41,108.52 from livestock. On the contrary, Edo Gejela had the lowest income from livestock among the six studied kebeles, which is equivalent to Bir 14,108.52. Likewise, the average annual income the farmers received from safetynet program, salary, and pension is Birr 548.42, 546.60, and 354.13 respectively.

3.3. Income generated from each crop

Table 4 from the survey showed the quantity sold and average income generated from two vegetable crops and a fruit crop in ATJK Woreda and Dugda Woreda. The results provided insights into the sales and income patterns specific to these two woredas. As the table displayed, out of the surveyed respondents in ATJK woreda, we found no tomato and papaya producers in Dodicha kebele and no papaya producers in Dodota Denbel and Tuchi Denbel kebeles in Dugda woreda. Based on the results of the survey, it was found that tomato was the most profitable crop, generating the highest average annual income. In Dodota Denbel, the average annual income from tomatoes was Birr 1,591,477.78, which was obtained by selling 370.11 quintals of tomato. Similarly, in Woyo Gebriel, the average annual income from tomato was Bir 707,247.62, derived from selling 164.48 quintals of tomato. Tomato cultivation in both kebeles relied primarily on irrigation methods using water from the Meki River and groundwater through the use of water pumps.

According to Table 4, there were notable variations in the quantities sold and prices in different kebeles of the study areas. For example, in Dodota Denben kebele, 370.11 quintals of tomato were sold, generating an average annual income of Birr 1,591.477.78. On the other hand, in Tuchi Denbel kebele proportionally a lower quantity of the same vegetable (155.34quintal) fetched relatively lower average annual income of Birr 605,837.14. This indicated that the price per kg of tomato in Dodota Denbel is 4Birr higher than the Tuchi Denbel. These variations can be attributed to the different market outlets used by farmers in each kebele, season of production as well as variations in product quality. Farmers in Dodota Denbel kebele primarily sold their produce to whole-sellers, while those in Tuchi Denebel kebele mainly used middle men (chapter 5). Besides, the prices in these markets can fluctuate depending on the forces of supply and demand.

Similarly, the survey result according to Table 4, kale was identified as the second most lucrative crop in terms of revenue generation in the study areas. This crop made a significant contribution to the income of farmers in the kebeles of Edo Gejela, Woyo Gebriel and Dodota Denbel, providing them with substantial amounts of income. In Edo Gejela, farmers earned an average annual income of Birr 309,331.25 by selling 71.94 quintals of kale. Similarly, in Woyo Gebriel and Dodota Denbel, the annual average income the farmers obtained were Bir 200,477.86 and 198,768.21 from the sale of 46.62 and 44.17 quintals of kale respectively.

Table 4
Quantity sold and income generated

Crop	ATJK Woreda						Dugda woreda					
	Kebele						Kebele					
	Bochesa		Dodicha		Edo Gejela		Dodota Denbel		Tuchi Denbel		Woyo Gebriel	
	Average quantity sold (Qtl/season)	Average income (Birr/season)	Average quantity sold (Qtl/season)	Average income (Birr/season)	Average quantity sold (Qtl/season)	Average income (Birr/season)	Average quantity sold (Qtl/season)	Average income (Birr/season)	Average quantity sold (Qtl/season)	Average income (Birr/season)	Average quantity sold (Qtl/season)	Average income (Birr/season)
Tomato	71.37	321,175	–	–	168.08	756,353	370.11	1,591,477	155.34	605,837	164.48	707,247
Kale	29.72	124,844	25.90	108,776	71.94	309,331	44.17	198,768	40.36	181,625	46.62	200,477
Papaya	43.57	108,928	–	–	138.66	318,919	–	–	–	–	85.59	213,977

1ETB=0.0177USD as of 31Dec 2023
Source: Survey data

In contrast, the study findings revealed that papaya, although it was not produced by the sample respondents in the three kebeles of Dodicha, Dodota Denbele, and Tuchi Denbel, emerged as the third most profitable crop in terms of revenue generation from the studied crops. This highlights the potential of papaya cultivation in the study kebeles. In Edo Gejela, the average annual income generated from selling 138.66 quintals of papaya was Birr 318,919.92, while in Woyo Gebriel and Bochesa, the average annual incomes from selling 85.59 and 43.57 quintals of papaya were Bir 213,977.27 and 108,928.85 respectively.

The reasons for the variations in yield and income could be attributed to factors such as soil quality, climate conditions, farming practices, market demand, and access to resources and infrastructure. Different kebeles may have different agricultural conditions that affect the productivity and profitability of specific crops. Additionally, factors such as market prices, competition, and the availability of buyers can also impact the income generated from selling crops.

In general, the study findings highlight the economic potential of the three crops in the study areas. These crops have proven to be lucrative sources of income for farmers, in both woredas. The results suggest that further investments and support in the cultivation of papaya and kale could greatly benefit farmers in terms of income generation.

3.4. Estimated postharvest losses of the studied crops

Table 5 summarizes data on the average estimated losses in yield (quintals per household) and revenue loss (Birr per household) for tomato, kale, and papaya crops in the study areas. The findings revealed that tomato demonstrates a high average yield of 174.33 quintals per household, but also experiences a substantial average yield loss of 19.81 quintals, resulting in an estimated revenue loss of Birr 87,175.46 and a percentage loss of 11.84 %. In comparison, kale yields average quintals of 41.90 with a yield loss of 3.62 quintals, leading to an estimated revenue loss of Birr 15,554.83 and a percentage loss of 8.62 %. Papaya, with an average yield of 103.28 quintals, faces the highest yield loss of 14.51 quintals among the studied crops, translating into an estimated revenue loss of Birr 33,371.08 and a higher percentage loss of 13.81 %. These figures underscore the varying degrees of production efficiency and vulnerability to yield losses among the three crops, influencing their economic viability and management strategies in agriculture.

Percentage wise, papaya experiences the highest loss at 13.81 %, more than tomato 11.84 % and kale 8.62 %. These comparisons highlight papaya's average production and revenue, along with its higher vulnerability to yield losses, while kale appears relatively more resilient in managing yield losses. This finding was significantly lower than the results reported by [34], which indicated that a study conducted in four districts of the East Showa zone in the Oromia region found postharvest losses of tomatoes at producers level due to inadequate postharvest management practices to be 20.5 %. However, the finding of [35] in the rural districts of Tanzania over 420 maize farming households found out that smallholder farmers experienced postharvest losses of as much as 11.7 %. Additionally, a similar study conducted on tomatoes in the Fogera districts of Amhara region in Ethiopia reported that postharvest losses at the producer level were 21.24 % before the produce reached wholesalers or local collectors [36].

Table 5

Estimated post-harvest loss of the studied crops

Crop type	Average yield produced (qtl)	Average yield consumed (qtl)	Average yield loss (qtl)	Average yield sold (qtl)	Average revenue/ income in birr	Average revenue loss ($/season)	Estimated percentage (%) loss
Tomato	174.33	0.43	19.81	154.09	570,388	87.175	11.84
Kale	41.90	0.73	3.62	37.56	162,960	15.554	8.62
Papaya	103.28	0.66	14.51	88.11	211,024	33,371	13.81

Source: Survey data

The elevated percentage loss of papaya, despite its average production volume among the studied crops, suggests potential challenges linked to specific vulnerabilities or environmental factors in its cultivation. This comparison underscores the importance of understanding absolute and relative losses in agricultural production. Farmers and policymakers can utilize these insights to prioritize initiatives aimed at enhancing yield resilience and minimizing losses, thereby bolstering overall agricultural productivity and economic sustainability. Understanding these dynamics is crucial to inform effective crop management strategies and risk mitigation approaches in agriculture.

3.5. Percentage share of factors affecting post-harvest losses at farm level

Figure 2 summarizes information on the main causes of post-harvest losses obtained from vegetable production during the 2023/24 cropping season as reported by sample respondents. The figure shows the proportion of respondents based on different causes of post-harvest losses (PHL) in three vegetable/fruit crops. The study adopted causes of PHL such as mechanical damage, pests and diseases, weather conditions, over maturity, rough handling, and delayed marketing. The y-axis represents the percentage of causes of PHL associated with each crop in the x-axis.

Tomato: Mechanical damage appears to be the leading cause of post-harvest loss at 27.73 %, closely followed by pests and diseases at 22.69 %. Weather conditions and over maturity are also significant factors, contributing 18.49 % and 15.97 %, respectively. Rough handling and delayed marketing are less impactful, but still notable at 8.40 % and 6.72 %, respectively. Nevertheless, a study carried out in Zimbabwe by [37] revealed that a significant majority of farmers, approximately 90 %, identified pests and diseases as the primary factors contributing to the substantial post-harvest losses experienced in tomato production. The study by [37] further explained that farmers involved in the production of rape, covo, and tomatoes identified decay and rough handling as the second and third leading contributors to post-harvest losses, respectively. The significant amount of vegetables that damage or rot can be attributed to a lack of knowledge of proper handling, road conditions and inadequate or nonexistent of storage facilities in the areas under study.

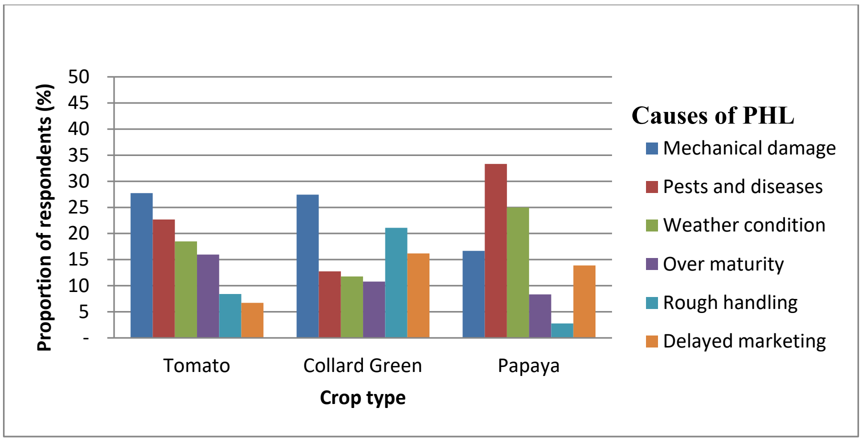

Figure 2

Main causes of vegetable post-harvest loss

PHL: Post-harvest Loss

Source: Survey data

Kale: mechanical damage is the leading factor contributing to a loss of 27.45 % closely followed by rough handling at 21.08 %, suggesting that the physical handling of the crop needs improvement. Other factors such as pests and diseases, weather conditions, and delayed marketing account for 12.75 %, 11.76 %, and 16.18 % of the loss, respectively. Over maturity is responsible for a smaller portion of the loss, at 10.78 %.

Papaya: For papaya, pests and diseases are the leading cause of post-harvest loss, accounting for 33.33 %. Weather conditions play an important role as well, contributing 25 % to the loss. Mechanical damage is also a major factor, accounting for 16.67 % of the loss. Delayed marketing and over maturity contribute 13.89 % and 8.33 %, respectively, while rough handling has the smallest impact at 2.78 %. These findings highlight the specific factors contributing to post-harvest loss in each crop and emphasize the importance of addressing these issues to minimize loss and improve overall crop quality.

3.6. Factors associated with post-harvest losses at farm level (Multiple Linear Regression Model)

As the variables in Table 6 indicated, the postharvest losses (continuous dependent variable) of vegetables are caused by multiples of explanatory variables like demographic, socioeconomic, biophysical, and sociocultural factors such as yield, area allocated for vegetable production, age of the household head, and experience of the household head in vegetable production. These variables are a continuous variable used as predictors. Besides educational status of the households, availability of storage for the vegetables, weather condition during the postharvest period, availability of transportation for the shipment of the produces, and labour availability for the harvesting and other activities of the vegetables are also the other predictor variables considered as dummy variable.

Table 6 summarizes the results of a multiple linear regression (MLR) analysis conducted using SPSS version 24.0, focusing on the studied crops: Tomato, Kale, and Papaya. Postharvest loss in this study is the dependent variable. The analysis reveals that some independent variables included in the model are strong predictors of postharvest losses of the three crops, as evidenced by the high R^2 values for all three models 0.977 for Tomato and Kale, and 0.986 for Papaya. These values indicate that the model explains a significant proportion of the variance in yield loss for each crop. The results of the multiple linear regression show high F-statistics for tomato (522.292), kale (932.685), and papaya (234.860). Additionally, the adjusted R^2 values are impressive at 0.977 for both tomato and kale, and 0.986 for papaya. These findings reinforce the statistical significance of the models, allowing for the rejection of the null hypothesis.

Table 6
Factors affecting post-harvest losses at farm level (Multiple Linear regression Model)

Explanatory variable	Tomato			Kale			Papaya		
	Standardized Coefficient	T	P-value	Standardized Coefficient	t	P-value	Standardized Coefficient	t	P-value
	Beta			Beta			Beta		
(Constant)		–0.405	0.686		3.456	0.001		1.143	0.263
Yield	1.720	–0.405	0.000***	1.034	19.926	0.000***	1.025	10.35	0.000***
Area	–0.885	10.132	0.000***	–0.173	–3.717	0.000***	–0.094	–1.142	0.263[NS]
Age of hhh	0.079	–5.925	0.182	–0.120	–1.925	0.056	–0.285	–2.498	0.019*
Experience of hhh	–0.145	1.343	0.036**	–0.168	–2.612	0.010**	0.251	2.715	0.011**
Education of hhh	0.027	–2.122	0.569[NS]	0.138	3.935	0.000***	0.008	0.115	0.909[NS]
Storage Dummy	0.000	0.571	0.992	0.007	0.617	0.538	0.016	0.577	0.569[NS]
Weather Dummy	0.079	0.010	0.001**	–0.004	–0.381	0.704	0.048	1.759	0.090[NS]
Transport Dummy	0.029	3.426	0.073	–0.029	–2.634	0.009**	0.015	0.603	0.552[NS]
Labour Dummy	–0.001	1.808	0.936	0.001	0.061	0.951	1.025	10.35	0.000***
F	522.292			932.685			234.860		
R	.989[a]			.989[a]			.993[a]		
R^2	0.977			0.977			0.986		

* Significant at p<10, ** Significant at p<5, *** significant at p<1, [NS] not significant, hhh = household head

In terms of key variables, the yield variable consistently exhibits a highly significant correlation with the dependent variable, post-harvest loss, for the three crops at $p < 0.01$ significance level. This suggests that higher yields are strongly and positively correlated with higher post-harvest losses of the three crops considered in the study. A unit increase in yield increases the post-harvest losses of tomato, kale and papaya by a factor of 1.720, 1.034, and 1.025 respectively with other factors held constant. Several studies support the finding that higher yields are often associated with increased post-harvest losses due to constraints in handling, storage, and marketing. For example, [38] reported that farm-level factors such as landholding size and production scale significantly influenced post-harvest losses in Ethiopia, while [39] found that higher production potential in northern Ethiopia often translated into greater losses when market access and infrastructure were inadequate. Similarly, [40] highlighted that poor handling practices and sociodemographic factors were major contributors to post-harvest losses of fruits and vegetables, indicating that increased production without improved post-harvest management can exacerbate the problem. Collectively, these studies reinforce the conclusion that while higher yields can boost output, they also heighten vulnerability to post-harvest losses if not matched by adequate infrastructure, labor, and management practices.

The area variable shows a negative and significant correlation with post-harvest losses of tomatoes and kale at $p < 0.01$ significance level. This implies that a unit increase in area results in reduction of 0.885 and 0.173 units of post-harvest losses in tomato and kale respectively, with other factors held constant. This contradictory finding may suggest that as area increases, the farmers may hire efficient labour, better funding, and appropriate marketing channels. For Papaya, the area variable is not significant ($p = 0.263$), indicating that it does not substantially affect yields. The age of the household head presents varying significance across the crops; it is not significant for tomatoes ($p = 0.182$), marginally significant for kale ($p = 0.056$) and significant for papaya ($p = 0.019$). This negative correlation implies that a unit increase in age of the farmer reduces the postharvest losses kale and papaya by 0.120 and 0.285 units respectively, with other factors held constant. This suggests that older household heads may be more associated with a less post-harvest loss of kale and papaya due to efficiency in managing the crop.

The experience of the household head in tomato and kale vegetable production yields a negativeand significant correlation with postharvest losses (at $p < 0.05$); while for papaya, experience has a positive correlation with the postharvest losses (at $p < 0.05$). This result for tomato and kale do not violate the null hypothesis that having greater experience in vegetable production will lead to lower postharvest loss. The value of the standardized coefficient (beta) for tomato and kale is -0.145 and -0.168, respectively. This implies that one unit increase in the experience of the household head in vegetable production reduces post-harvest losses of tomato and kale by factors of -0.145 and -0.168, respectively. For papaya, experience has a positive correlation with the postharvest losses ($b = 0.251$; $p < 0.05$). Thus, a unit increase in experience results in 0.251 units increase in postharvest losses, with other factors held constant. This is contrary to expectation, and may be due to lack of other critical resources. Experienced farmers may stick to traditional handling and storage practices rather than adopting improved post-harvest technologies for delicate crops like papaya. Familiarity with production may not translate into market-related post-harvest practices, especially when papaya requires specialized handling due to its fragility. This suggests a knowledge – practice gap where experience reinforces habits that are not optimal for minimizing losses. [41] highlighted that postharvest losses in papaya are often due to improper harvesting, mishandling, and inadequate storage and transportation practices. These issues may arise from a lack of awareness or resistance to adopting new technologies among farmers. [42] assessed farmers' knowledge and management practices regarding papaya mealybug control in Tanzania. The study revealed that despite some awareness of biological control methods, farmers lacked the knowledge, experience, and technical support to implement these practices effectively.

Regarding the level of education of the household head, it is significant only for kale ($p < 0.001$), suggesting that higher levels of education may positively influence kale post-harvest loss. This implies that a unit increase in level of education results in 3.935 units increase in postharvest losses, other factors held constant ($p < 0.001$). This is also contrary to expectation but the reason may be that most of their education might not be related to the field of vegetable production and marketing. Besides, the positive association between household head education and kale post-harvest loss is somewhat counterintuitive, suggesting complex underlying mechanisms. Educated farmers may prioritize market expansion, selling larger volumes quickly or reaching distant markets, which can compromise careful handling and storage. They may also adopt labor-saving or mechanized practices that are less gentle on delicate crops like kale, or delegate handling to less experienced labor due to off-farm employment or business activities, inadvertently increasing losses. Additionally, educated farmers might experiment with innovative storage or marketing strategies that initially result in higher losses until optimized. These findings highlight crop-specific dynamics and indicate that quantitative analysis alone may not fully capture the behavioral and contextual factors influencing losses. Further research – particularly mixed-method or longitudinal studies – could explore these pathways, including decision-making processes, risk perceptions, technology adoption, and interactions with market access, infrastructure, and climate variability. No significant effects were observed for tomato or papaya yields.

Additionally, the dummies for storage, weather, transport, and labor reveal varying levels of significance. The storage dummy does not show a significant effect across all crops. This could be due to the proximity of the main road and nearby towns. In addition, farmers sell their crops to whole sellers and middlemen at once. The weather dummy is significant for tomatoes ($p = 0.001$) but not for Kale ($p = 0.704$) or Papaya ($p = 0.090$), indicating that weather conditions can disproportionately impact tomato yields quality and postharvest losses. Tomatoes are highly sensitive to rainfall and temperature during harvest and storage, making them more vulnerable to weather variability. In contrast, kale can be harvested continuously over time, which buffers against short-term weather shocks, while papaya losses may be more strongly driven by handling and labor quality than by weather variation. These differences highlight the crop-specific nature of post-harvest vulnerabilities and the need for tailored interventions rather than one-size-fits-all strategies.

The Transport Dummy shows significant negative effects on kale ($b = -0.029$; $p = 0.009$) but not significant on tomato or papaya, suggesting that transportation logistics are more critical for kale production. Although kale is physiologically less perishable than tomato and papaya, the significant negative effect of transport on its post-harvest losses can be attributed to market and handling dynamics. Kale's economic value depends heavily on freshness and appearance, and even slight wilting or damage during transport can lead to rejection or price reduction. Its bulky leaves are more prone to mechanical damage if not properly packaged, and unlike tomatoes and papayas, which are often collected directly by middlemen, farmers frequently handle kale transport themselves, increasing exposure to loss. Additionally, kale has a shorter market-driven shelf life, as buyers demand crisp, visually appealing leaves. Thus, transport emerges as a critical determinant of kale losses despite its relative physiological resilience. This finding was consistent with the finding of [43] that it examines the supply chains of various vegetables, including Chinese kale, and identifies transportation as a significant factor contributing to post-harvest losses. The findings highlight how improper handling and packaging during transport can lead to quality deterioration, underscoring the importance of effective logistics in reducing losses. The study highlighted that the mode of transport and handling practices were critical factors influencing the quality and quantity of kale reaching the market. Besides, [44] investigated the impact of transportation, storage, and retail shelf conditions on lettuce quality and phytonutrient losses in South Africa. The study found that transportation significantly affected lettuce quality, leading to nutrient losses. While the focus was on lettuce, the findings are relevant to kale, given their similar handling requirements and perishability.

Lastly, the Labour Dummy is positive and significant for papaya ($b = 1.025$; $p < 0.001$). Thus, increase in labour results in increase in postharvest losses of papaya, other factors held constant. This may be due to poor quality of the labour; highlighting the importance of labor availability or quality in influencing papaya yields. Not all labor is skilled. In papaya cultivation, where the papaya fruits are fragile and highly perishable, careless or inexperienced labor may cause bruising, improper harvesting, or rough handling, increasing post-harvest damage. This highlights the importance of labor quality and training, not just quantity, in reducing losses. [45] found that harvesting and handling practices significantly determine papaya fruit quality during the supply chain. Improper manual handling causes bruising and microcracks, increasing microbial spoilage and postharvest loss. [46] in Ethiopia reported that poor handling, inappropriate packaging, and untrained labor during transport and storage were major drivers of papaya postharvest losses, confirming that labor quality is a critical factor.

In conclusion, the results indicate that while yield remains a consistently strong predictor of post-harvest losses across all crops, the influence of other factors such as area cultivated, farmer age, farming experience, education level, and the dummies for storage, weather, transport, and labor varies significantly by crop type. These differences suggest that post-harvest losses are not driven by a single dominant factor but rather emerge from a complex interaction of socioeconomic characteristics, production decisions, and environmental conditions. For instance, the varying impact of education and experience may reflect differences in farmers' adoption of improved post-harvest practices or market strategies, while the contrasting significance of weather across crops underscores the biological and physiological sensitivities of specific vegetables and fruits. Likewise, the insignificant role of storage highlights the importance of immediate market access and short supply chains in the study area. These findings call for more targeted, crop-specific approaches in designing interventions, rather than generalized recommendations for all perishable crops. Further investigation into farming practices, the quality and efficiency of market linkages, and localized environmental constraints would help uncover the underlying mechanisms of these relationships, thereby providing stronger empirical grounds for developing policies and technologies that minimize post-harvest losses and enhance food security among smallholder farmers.

4. CONCLUSION AND POLICY RECOMMENDATIONS

The study carried out in various kebeles reveals a demographic and socioeconomic status of smallholder farmers. The average age of the respondents is 39 years, indicating a workforce generally in the prime of their productive years. The average household size is 5, suggesting the typical family structure in the study areas. The respondents also have substantial experience in vegetable production, averaging around 10 years, which enhances their expertise and knowledge of crop management and market dynamics.

In terms of land allocated for vegetable cultivation, the average farm size per household is approximately 1.22 hectares. This land serves as the primary resource base for agricultural production and livelihood security for the respondents and their families.

Income diversification is crucial for these households, with sources that include vegetable sales, livestock rearing, salaries, pensions, and social safety nets. The overall percentage income contribution of vegetables, livestock, safetynet, salary and pension is 93.26, 6.41, 0.0.13, 0.13 and 0.08 %, respectively.

Post-harvest losses are a critical concern in agricultural productivity. The study identifies various stages, harvesting, handling, transportation, marketing, and storage, as vulnerable points where losses occur. Specifically, tomato, kale and papaya suffer losses of 11.84 %, 8.62 %, and 13.81 %, respectively at the producer level. Factors contributing to these losses include mechanical damage, pests and diseases, weather conditions, over maturity, rough handling, and delayed marketing.

For tomatoes, mechanical damage is the leading cause of losses at 27.73 %, closely followed by pests and diseases at 22.69 %. Weather conditions and over maturity also contribute significantly, accounting for 18.49 % and 15.97 % of losses, respectively. Kale face considerable losses due to rough handling (21.08 %) and mechanical damage (27.45 %), with weather conditions, pests and diseases, and delayed marketing adding to the losses. Papayas suffer mainly from pests and diseases (33.33 %) and weather conditions (25 %), with mechanical damage and over maturity also playing a significant role.

The multiple linear regression analysis provides valuable insights into postharvest losses for tomato, kale, and papaya crops. High R^2 values (0.977 for tomato and kale, 0.986 for papaya) indicate that the models effectively explain the variance in yield loss, supported by significant F-statistics. The yield variable consistently shows a strong positive correlation with postharvest losses across all crops, suggesting that higher yields lead to increased losses, which aligns with previous studies. Interestingly, the area variable negatively correlates with losses for tomato and kale, implying that larger farming areas may facilitate better management practices. Experience in vegetable production reduces losses for tomato and kale but has a counterintuitive positive correlation for papaya, potentially due to resource limitations. Education significantly affects kale losses, raising questions about its relevance in agricultural practices.

The findings of this study underscore the critical need for targeted policy interventions to address post-harvest losses and improve food and nutrition security among smallholder vegetable farmers in the East Showa zone of the Oromia region. Given the significant economic losses attributed to inadequate post-harvest management practices, it is imperative that government, smallholder farmers, value chin actors, and non-governmental organizations (NGOs) implement a comprehensive framework aimed at improving post-harvest management, enhancing market access, and ultimately boosting the livelihoods of smallholder farmers.

- ✓ Development of a post-harvest management improvement framework:

A structured framework should be established to guide smallholder farmers in implementing effective post-harvest management practices. This framework should include training programs focused on best-practices for harvesting, handling, storage, and transportation to minimize losses. Training should be tailored to address the specific challenges identified in the study, such as mechanical damage, pests and diseases, weather conditions, over-maturity, rough handling, and delayed marketing. Furthermore, the framework should promote the use of low-cost technologies and innovative practices that are suitable for local conditions.

- ✓ Strengthening market access and diversification

To reduce reliance on intermediaries or middlemen and improve farmers' income, policies should be developed to facilitate direct market access. This can be achieved by establishing and increasing farmer cooperatives that enable collective marketing, thereby increasing bargaining power of the producers and reducing transaction costs. Additionally, initiatives to diversify vegetable production should be promoted, encouraging farmers to explore high-value crops that can fetch better prices in the market. The government, smallholder farmers' cooperatives, market actors and NGOs should collaborate to provide market information and training on market trends, enabling farmers to make informed decisions.

- ✓ Investment in infrastructure:

Improving rural infrastructure, particularly roads and transportation facilities, is essential to reduce post-harvest losses and improve market access. The government should prioritize investments in feeder roads that connect farmers to major markets, thereby minimizing transportation costs and time. Additionally, establishing storage facilities in strategic locations can help mitigate losses due to spoilage and provide farmers with the flexibility to sell their produce at optimal times.

✓ Promotion of gender-sensitive policies:

Given the significant role of women in vegetable production, policies must be designed to empower female farmers. This includes providing targeted training and resources that enhance their participation in post-harvest management and market access. Gender-sensitive policies should also address the barriers women face in accessing credit and land ownership, ensuring equitable opportunities for all farmers.

In conclusion, the implementation of these policy recommendations can significantly reduce post-harvest losses, improve food security, and improve the livelihoods of smallholder vegetable farmers in the study areas in particular and in Ethiopia in general. By fostering a supportive environment that addresses the multifaceted challenges faced by these farmers, stakeholders can contribute to a more resilient agricultural sector and a more food-secure nation.

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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.

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