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AN ASSESSMENT OF HARVEST AND POSTHARVEST HANDLING PRACTICES AND THEIR IMPACTS ON LOSSES IN AFRICAN INDIGENOUS VEGETABLES: A CASE STUDY OF KAKAMEGA AND KISII COUNTIES OF KENYA

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ABSTRACT

African Indigenous Vegetables (AIVs) play a vital role in the nutritional and economic lives of Kenyan farmers, but postharvest losses are a major challenge in the value chain. The objective of the study was to assess harvesting and postharvest handling practices and their impact on postharvest losses among 346 AIV farmers in Kakamega (n = 185) and Kisii (n = 161) counties. Data was collected using a semi-structured questionnaire and analysed using descriptive statistics, chi-square tests, t-tests, GLM, logistic regression and multiple linear regression. Postharvest losses of AIVs varied between 4% and 13%, with the greatest losses being experienced on harvesting, storage, transport and packaging practices, while shelf life was significantly ($p<0.05$) longer in the wet season, 2.35-2.77 days and 1.6-1.85 days dry season, depending on the county and practices. Logistic regression analysis revealed that combined harvesting practices (OR = 0.068, p = 0.040) and combined field heat reduction methods (OR = 0.093, $p < 0.001$) were significantly associated with reduced postharvest losses. Shelf life was significantly longer in the wet season ($p < 0.001$), and postharvest storage and exposure conditions significantly affected shelf life duration ($R^2 = 0.095$). Gender differences were not significant, but county differences were observed and reflect the importance of local environmental factors. The findings demonstrate the significant role of harvesting and postharvest handling practices, as well as seasonal (wet and dry) variations, in reducing postharvest losses and increasing the shelf life of AIVs among smallholder farmers. Targeted interventions to promote appropriate postharvest handling practices, such as low-cost evaporative cooling (charcoal cooler, zero-energy brick cooler, and solar-powered cooler) and better packaging (use of stackable crates), could help reduce losses and improve the shelf life of AIVs, thereby improving food security and income for smallholder farmers. Strengthening farmers capacity through targeted training and access of postharvest technologies is essential for improvement of efficiency and sustainability of AIVs value chain.

Key words: African Indigenous Vegetables, harvest, postharvest practices, postharvest losses, Kakamega, Kisii, Kenya

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INTRODUCTION

African Indigenous Vegetables (AIVs) have been grown and consumed in sub-Saharan Africa for many years and are very important in food security and nutrition [1]. Some commonly consumed AIVs include vegetable amaranth (*Amaranthus spp*), African nightshade (*Solanum spp*), spider plant (*Cleome gynandra*), cowpea leaves (*Vigna unguiculata*), jute mallow (*Corchorus olitorius*), slender leaf (*Clotalaria ochroleuca*), and pumpkin leaves (*Cucurbita moschata*) [2]. African Indigenous Vegetables contain higher levels of micronutrients such as carotene, iron, zinc, calcium, phytochemicals, and vitamin C compared to exotic vegetables [3,4].

However, AIVs are very perishable and prone to postharvest losses because of high respiration rates, moisture loss, and mechanical damage. Postharvest losses of fruits and vegetables in Africa are estimated to range between 30-50%, with smallholder farmers being the most affected due to inefficient harvest and postharvest management, lack of appropriate processing facility and marketing facilities [5].

Most AIVs have a high growth rate and can reach harvest maturity in 30 to 50 days after planting [6]. Harvesting is normally done manually, either in the early morning or late in the evening to maintain freshness[7]. There are three different harvesting techniques: uprooting, which is done within 4-6 weeks, cutting 10 cm above the ground to allow lateral growth for subsequent harvesting, and continuous harvesting, where leaves are harvested at regular intervals [8]. The vegetables are then packed under a shade to eliminate field heat and prevent water loss [9]. Postharvest handling practices include sorting, grading and packing in wooden boxes, sacks or heaps for easy transport [10]. Farmers use wheelbarrows, carts, bicycles, motorbikes, tuk-tuks, or carry by hand or head from the farm to market. Unsold produce is stored in shades or homes, with frequent sprinkling of water to keep fresh. In some instances, processing is employed as a means to improve shelf life and marketability [11].

Despite their relative significance, AIVs in Kenya are faced with major postharvest losses in terms of quantity and quality due to challenges associated with harvesting, handling, storage and transport [12,13]. Small-scale farmers in Kenya do not have appropriate packaging and transportation facilities and asses to storage technologies which contribute to the losses [14] .

Recent research suggests that sustainable postharvest technologies can greatly reduce losses and extend the shelf life of perishable vegetables. For instance evaporative cooling technologies such as charcoal cooler, zero energy brick cooler, passive blanket cooling has shown to reduce postharvest losses of vegetables by 30-45% and extended shelf life by 3 to 4 days [15]. In addition solar powered cooler

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has shown to reduce spoilage by 2% and loss reduction of 30-40% [16]. These technologies work by maintaining high relative humidity and lowering temperature which help which slows down spoilage, microbial growth and moisture loss. Although the technologies are effective, their uptake among small-scale farmers in Kenya is low because of the high costs of investment, lack of credit, lack of awareness, lack of technical knowledge and poor cold chain infrastructure [17].

Although postharvest losses of AIVs in Kenya have been well documented [18], most of the research has been based on estimates or descriptive analysis of postharvest practices. There is little empirical data on the statistical relationship between particular harvesting and postharvest practices, losses and shelf life. Moreover, there is little data on postharvest practices and their impact on different agro-ecological regions. The objective of the study was to evaluate the current harvesting and postharvest handling practices of AIVs, establish the major factors contributing to postharvest losses and shelf life reduction and compare the trends in the two counties of Kakamega and Kisii. The significance of this study lies in the fact that the postharvest losses of AIVs are still high among small-scale farmers and this has a negative effect on the availability of food, income for farmers, and efficiency in the market. It is a fact that the nutritional and economic value of AIVs is high, but there is little information available about postharvest handling practices and their contribution to losses in the region.

MATERIALS AND METHODS

Study Area

The study was conducted in Kakamega and Kisii counties, located in western Kenya. The counties were purposively selected for being among the major AIVs production zones and outlets to the peri-urban and urban centres in Kenya [19]. They fall within favorable agro-ecological zones characterized by adequate rainfall and moderate temperatures which support AIV production throughout the year. Besides, the regions are characterized by high population density and predominantly small landholdings of about 0.25-0.5 hectares where AIVs are vital for household food security and income generation [20]. African Indigenous Vegetables constitute a priority value chain as well as an important enterprise for women and the youth [21]. These features make the counties suitable for an in-depth assessment of postharvest handling practices and loss patterns among smallholder AIV farmers in western Kenya.

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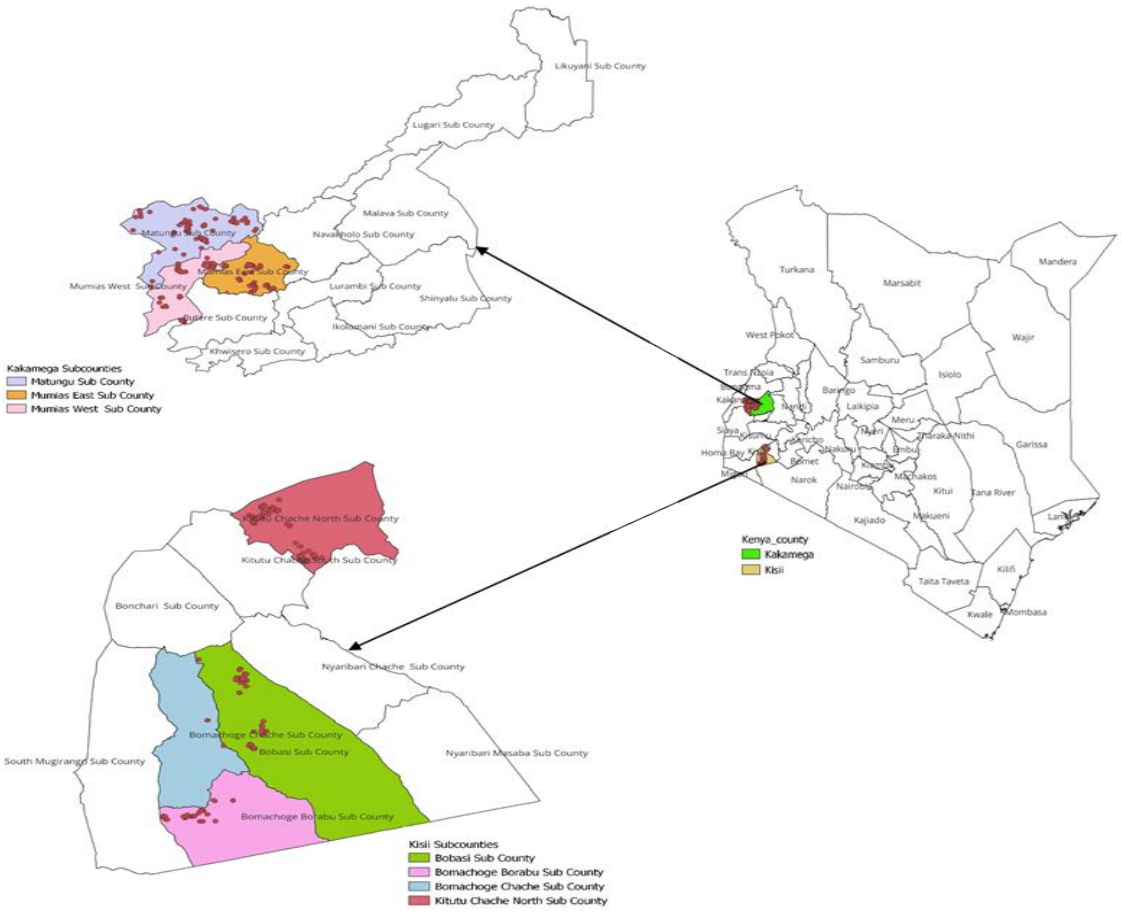


Figure 1: Map Distribution of AIV Farmers in Kakamega and Kisii Counties

Study Design

Cross-sectional study design was employed to gather information from AIV farming households in Kakamega and Kisii Counties. A multi-stage sampling technique was utilized, where counties, sub-counties and wards were systematically selected. Twenty-four (24) study locations were selected in the two counties. Out of the sites, 346 respondents (191 Female and 155 Male) were randomly sampled from the two counties. In each of the county, 185 were from Kakamega and 161 from Kisii.

Study Population

The target population of this study consisted of smallholder households that practiced AIVs farming in Kakamega and Kisii County. The two counties have been identified as key AIV-producing areas in western Kenya [19] and many households practice smallholder vegetable farming.

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Sample Size Determination

The sample size was calculated using the Cochran's [22]formula for calculating sample size for proportions in large populations or populations of unknown size for 95% confidence level and 5.6% margin of error:

$$n = \frac{p(1-p)Z^2}{E^2}$$

Where,

n is the sample size
Z is the desired confidence level taken at 95% (1.96)
p is the maximum variance assumed to be 0.5 since the proportion of AIV farmers is unknown, (1-p)
E is the allowable margin of error (0.056) that the researcher is willing to accept.

$$n = \frac{(0.5)(1-0.5)1.96^2}{0.056^2}$$=307 farmers

To enhance statistical power, precision and address the possibility of non-response and variability, a total of 346 farmers were surveyed, including 185 respondents from Kakamega County and 161 respondents from Kisii County.

Sampling Procedure

A multistage sampling procedure was employed in selecting respondents. In the first stage, Kisii and Kakamega Counties were purposively selected because of the widespread production of AIVs. The second stage involved purposively selecting three sub-counties in each of the counties with the help of county agricultural extension officers. In Kisii County, the sub-counties selected were Bomachoge Borabu, Kitutu Chache North and Bobasi. In Kakamega County, Matungu, Mumias West and Mumias East sub-counties were selected. In the third stage, wards were randomly selected from each sub-county. In cases where sub-counties had less than four wards, all wards were selected, and other wards were randomly selected from sub-counties with more wards to make a total of 24 wards in the two counties. In the final stage, farming households were selected using simple random sampling from farmer lists collected with the help of Ward agricultural extension officers. Fourteen households were targeted per ward, making a total sample size of 336 households. However, due to differences in the availability of farmers and replacement of non-responding households, the final sample size was 346 households, with 185 respondents from Kakamega County and 161 respondents from Kisii County.

A household was considered eligible if it was actively engaged in the production of at least one AIV species during the survey period. The study specifically targeted household-based smallholder farmers; hence, commercial farms, institutional farms and other non-household production units were not considered. The primary

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respondent in each household was the person having direct charge of AIVs production, either the household head or another household member who was actively engaged in making farm decisions. If the selected household was not available during the first visit, follow-up visits were made to accommodate participation. Replacement households were only considered if the selected households were permanently unavailable or refused to participate. The replacement households were selected based on the same criteria for sampling and from the same locality to reduce bias.

Data Collection

The tool used to collect the data was a questionnaire that was developed based on the objectives of the study. The tool was administered electronically using Kobo collect. To ensure validity, an expert check of the questionnaire was conducted by three experts in AIV production and postharvest handling. Their input was utilized to refine the questions regarding clarity, relevance, and comprehensiveness. To ensure the reliability of the data collection tool, a pre-test was carried out among 20 households outside the main study sites. The pre-test was useful in assessing the questions' clarity, relevance and consistency of responses from the respondents. The exercise was useful in making minor changes to the tool before the actual survey.

Ethical Consideration

The study was implemented under the mandate of the Kenya Agricultural and Livestock Research Organization (KALRO) in collaboration with the County Departments of Agriculture in Kakamega and Kisii. The aim of the study was clearly explained to all participating farmers before data collection. Participation was voluntary and informed consent was obtained from each respondent. Participants were assured of confidentiality and anonymity, and they retained the right to withdraw from the study at any point without any consequences; and that the results will be used solely for the research purpose for which they were collected.

Statistical Data Analysis

The dataset was exported and processed in IBM SPSS Statistics version 25 [23] for cleaning and coding. The data was checked for completeness and consistency through electronic data collection using the KoBoCollect. Categorical variables were coded using numbers, while continuous variables were recorded using their actual values. A summary of variables and their coding is provided in Table 1. Descriptive statistics were employed to analyze socio-demographic information, postharvest handling practices, and technology adoption. Inferential statistics were employed to examine relationships and differences between variables. Independent samples t-tests and univariate General Linear Model (GLM) were employed to compare the mean shelf life by county, season, and handling practices, while chi-square tests

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were employed to explore associations between categorical variables. Multiple linear regression analysis was employed to establish factors influencing shelf life, while logistic regression was employed to establish determinants of postharvest losses. The assumptions of the models were checked before analysis. The regression models controlled for potential confounding variables such as socio-demographic factors, farm factors, and handling practices. Normality was checked using the Shapiro-Wilk test, histograms, and Q-Q plots. Homogeneity of variance was checked using Levene's test, while multicollinearity was checked using variance inflation factor (VIF) statistics. The model's fit was checked for logistic regression using a Hosmer-Lemeshow test. The level of significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

Social Demographic Characteristics of African Indigenous Vegetables Farmers in Kakamega and Kisii Counties of Kenya

The socio-demographic characteristics of AIVs farmers are presented in Table 2. The proportion of female farmers was higher than male farmers in both counties, contributing 50.3% in Kakamega and 60.9% in Kisii. There was a significant difference in gender distribution between the two counties ($\chi^2 = 3.911$, df = 1, $p < 0.048$). This may be attributed to cultural, socio-economic, or labor allocation factors, with women being engaged more in AIV production, which may be considered a household or small-scale crop. This result is consistent with previous studies that women contribute significantly to planting, harvesting and post-harvest handling of AIVs [24,25]. The average age of farmers was 48.4 years in Kakamega and 50.1 years in Kisii, with an overall mean of 49.2 years, indicating that AIVs farming is largely practiced by middle-aged farmers. This suggests that the production of AIVs is mainly carried out by experienced farmers who are likely to have the necessary skills in farming and knowledge of traditional practices of cultivation and postharvest handling of the vegetables. The dominance of middle-aged farmers may also suggest that younger adults are less involved in the production of AIVs, which may have implications for the adoption of new technologies in the future. The results of this study are consistent with another research that has been conducted in other parts of Sub-Saharan Africa [9] The level of education was not significantly different among the two counties ($\chi^2 = 7.61$, df = 3, $p = 0.107$). The majority of the farmers had secondary education (46.5% in Kakamega and 50.9% in Kisii), followed by primary education (47.6% and 41.0%, respectively). Only a small proportion of farmers had postgraduate education (4.3% Kakamega and 3.7% Kisii), while very few had no formal education (1.6% Kakamega and 4.3% Kisii). The findings suggests that most of the AIV farmers have basic formal education, which may help in the adoption of improved agricultural and postharvest handling techniques, but limited higher education may limit access to advanced postharvest technologies and

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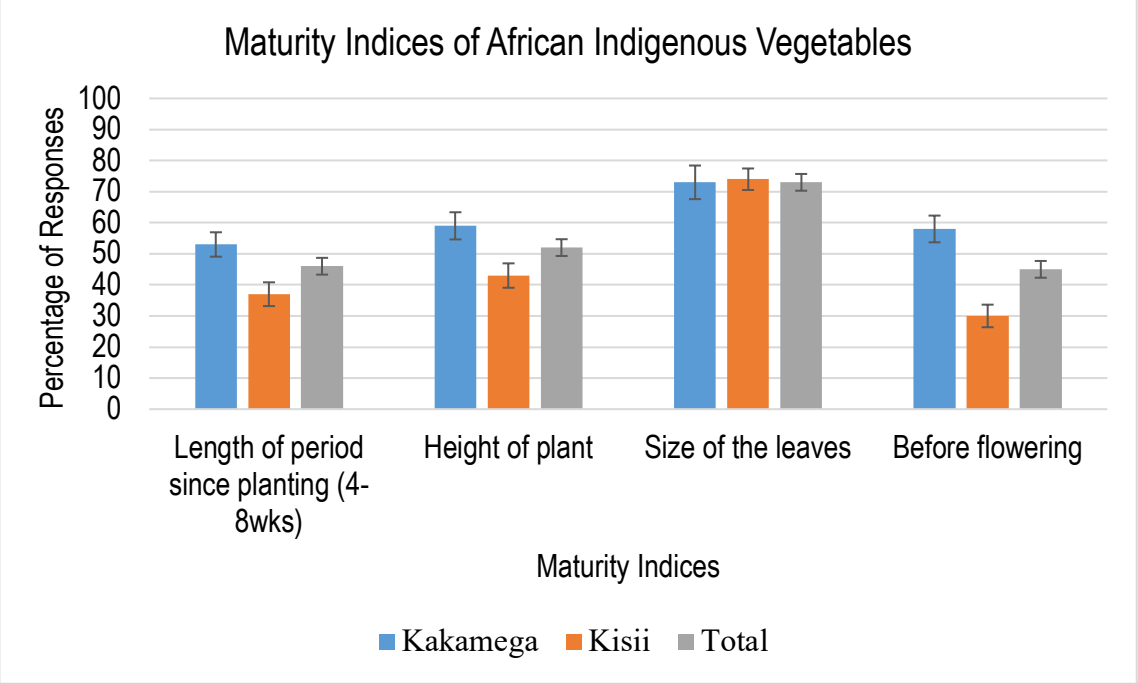
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information [26]. The average farm size was significantly larger ($p<0.05$) in Kakamega (2.1 acres) compared to Kisii (1.2 acres), with an overall mean of 1.6 acres. Small farm size suggests that the production of AIVs is to a large extent a subsistence or semi-commercial enterprise that can be combined with other crops. Small farm size may limit the production scale, resource availability for improved postharvest technology and adoption of innovations such as improved storage or handling practices. The results are in line with previous studies conducted in Kenya and Africa, which suggests that AIV and other horticultural crops are mainly grown on smallholder farms that range from 0.5 to 2 acres [27, 28].

Harvesting Practices for African Indigenous Vegetables in Kakamega and Kisii Counties

Maturity Indices

Leaf size was the most commonly used indicator of maturity among farmers, with 72.5% in Kakamega and 74.4% in Kisii relying on this criterion (Figure 2). A higher proportion of farmers in Kakamega used plant height (59.3%) compared to Kisii (43.1%) ($\chi^2 = 8.967$, df = 1, p= 0.003), length of time since planting (4–8 weeks) (53.6% vs. 36.9%, $\chi^2 = 9.256$, df = 1, p = 0.002), and harvesting before flowering (57.7% vs. 30.0%, $\chi^2 = 26.411$, df = 1, p < 0.001).



Error bars represent standard error of the mean

Figure 2: Maturity Indices of African Indigenous Vegetables in Kakamega and Kisii counties

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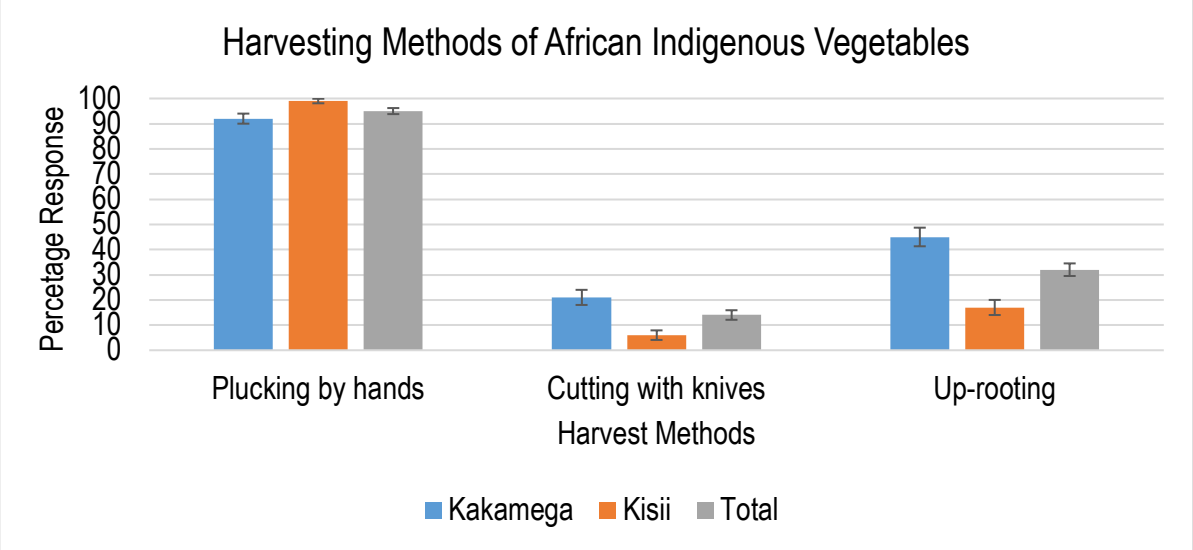
The maturity indices of AIVs is usually based on subjective evaluation of leaf size, length of period since planting, plant height and before flowering [29]. In both counties AIVs were harvested depending on the leaf size. Although leaf size is the most popular maturity indicator, using duration after planting (4-8 weeks) alone can be hazardous, as factors such as rainfall, temperature and soil nutrient content may hasten or retard growth, thus rendering time an unreliable indicator of the best harvest time. In addition, harvesting using the criterion of larger leaf size without taking into consideration physiological development may enhance lignification, thus potentially reducing tenderness, palatability and some nutritional value [30]. Farmers in Kakamega, who make use of a combination of maturity indicators, are most likely to harvest leaves at the optimal stage. On the other hand, farmers in Kisii, who make use of leaf size or time of harvest, are likely to harvest over-mature leaves, which are more susceptible to wilting, loss of nutrients and have shorter shelf life. This can have a negative effect on market quality and nutritional value of AIVs, which will lower consumer acceptance and thus the potential income for smallholder farmers [31].

Harvesting Methods

Hand plucking was the predominant practice in both counties, reported by 91.9% of farmers in Kakamega and 98.8% in Kisii, although the difference was statistically significant ($\chi^2 = 8.686$, df = 1, $p = 0.003$) (Figure 3). Hand plucking is generally considered a less destructive harvesting method, as it allows selective removal of mature leaves while preserving plant integrity for continued production [32]. In contrast, more destructive harvesting methods such as uprooting (44.9% in Kakamega vs. 17.4% in Kisii, $\chi^2 = 29.82$, df = 1, $p < 0.001$) and cutting with a knife (20.5% vs. 6.2%, $\chi^2 = 14.793$, df = 1, $p < 0.001$) were significantly more common in Kakamega.

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Error bars represent standard error of the mean

Figure 3: Harvesting methods of African Indigenous Vegetables in Kakamega and Kisii County

These findings suggest that farmers in Kakamega employ a wider range of harvesting techniques compared to those in Kisii. Hand plucking is preferred in most horticultural production systems because it results in fewer mechanical injuries compared with more forceful harvesting techniques (cutting or uprooting), which may cause bruising and tearing of plant tissues, thereby providing entry points for microorganisms, resulting in increased respiration, transpiration, and microbial decay [33] Although less injurious in principle, improper manual harvesting techniques may also result in mechanical injuries such as tearing or bruising, which may affect the aesthetic appeal, texture and marketability of AIVs. Mechanical injuries sustained during harvesting have been identified as a contributing factor to postharvest vegetable deterioration, as tissues with higher respiration and transpiration rates are more prone to decay during storage and handling. Uprooting and cutting with knife practices can be used to accelerate the harvesting process or in situations where labor is scarce, but they are likely to be more mechanically damaged and less conducive to frequent harvesting, which is an important approach for small-scale leafy vegetable production systems [34]. For instance, research on African leafy vegetables has demonstrated that harvesting only edible plant organs (that is, harvesting individual leaves) instead of uprooting the whole plant can help maintain plant health and prevent nutrient mining from the soil, thus allowing for more frequent production cycles and improved yield stability [35]. These results concur with a study carried out in Ethiopia that most small-scale farmers harvest fruits and

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vegetables using traditional practices that cause mechanical damage and result in high postharvest losses [36].

Postharvest Handling Practices of African Indigenous Vegetables

Storage of Harvested African Indigenous Vegetables

Storage under shade was the most common practice reported by farmers in both Kakamega (89.7%) and Kisii (83.2%), with no statistically significant difference between the counties ($\chi^2 = 3.155$, df = 1, $p = 0.076$) (Table 3). This suggests widespread awareness among farmers of the importance of protecting vegetables from direct solar radiation. Exposure to direct sunlight accelerates physiological deterioration through increased respiration, moisture loss, and wilting [14]. The low proportion of farmers exposing vegetables to direct sunlight (0.9%) suggests that most farmers recognize the negative effects of heat exposure. The minimal use of sacks for storage (1.7%) suggests that farmers primarily rely on temporary shade rather than enclosed storage systems. While shade reduces temperature exposure, it does not actively remove field heat or control humidity, which may limit its effectiveness in prolonging shelf life [37]. Such losses have also been documented in Uganda, Tanzania, and Nigeria, indicating that the issue of suboptimal postharvest practices is a common challenge in East and West Africa for AIVs production [38].

Field Heat Reduction Practices

A higher proportion of farmers in Kakamega (76.8%) used shade compared to Kisii (53.4%) ($\chi^2 = 20.868$, df = 1, $p < 0.001$), while sprinkling vegetables with water was more common in Kisii (45.3%) than in Kakamega (32.4%) ($\chi^2 = 6.062$, df = 1, $p = 0.014$) (Table 3). These findings suggest regional variation in precooling practices, possibly influenced by differences in resource availability, climatic conditions, or farmer knowledge [39,40]. Field heat removal is a critical step in maintaining vegetable quality, as elevated temperatures accelerate respiration and senescence. Shade provides passive cooling by preventing heat accumulation, while sprinkling water promotes evaporative cooling [41]. However, excessive wetting without proper drainage will increase microbial growth and accelerate spoilage [42].

Packing Practices

Sacks were the dominant packaging material overall (85.3%), while the use of buckets (6.6%), cartons (2.3%), and crates (1.2%) remained low and showed no significant differences between counties ($\chi^2 = 0.988$, df = 1, $p > 0.05$) (Table 3). Packing practices differed significantly between counties, with sack use being more prevalent in Kakamega (90.3%) compared to Kisii (79.5%) ($\chi^2 = 7.941$, df = 1, $p = 0.005$). Although sacks are inexpensive and readily available, they provide limited protection against mechanical damage and restrict airflow, which will accelerate

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deterioration. Poor ventilation increases heat accumulation and moisture condensation, creating favorable conditions for microbial growth [43]. The extremely low use of crates, which offer better ventilation and physical protection, suggests limited adoption of improved packaging technologies. This suggests that cost, availability, and lack of awareness may be barriers to improved packaging adoption [44].

Transport Methods

Motorbikes were the primary mode of transport in both Kakamega (62.7%) and Kisii (63.4%), ($\chi^2 = 0.016$, df = 1, $p = 0.900$). Human transport was also commonly used (18.9%), reflecting the small-scale nature of vegetable production and marketing. However, the use of carts was significantly higher in Kakamega (10.8%) compared to Kisii, where none of the farmers reported using carts ($\chi^2 = 18.473$, df = 1, $p < 0.001$) (Table 3). Motorbikes provide rapid and flexible transport, especially in rural areas with limited road infrastructure. However, vegetables transported by motorbikes are often exposed to ambient temperatures and mechanical injury, particularly when transported in sacks without protective structures. Such handling accelerates physiological deterioration and increases susceptibility to spoilage, contributing to postharvest losses [45].

Preservation Practices

Timely delivery to markets was the most commonly reported preservation method, with more farmers in Kakamega (63.8%) than Kisii (49.7%) adopting this approach ($\chi^2 = 6.986$, df = 1, $p = 0.008$) (Table 3). The increased adoption in Kakamega can be attributed to better access to local markets, reduced distances to market centers, and the existing vegetable marketing channels compared to Kisii. Kakamega County has major urban markets and is situated along major transport routes in western Kenya, which makes it easier for produce to move from farms to markets. On the other hand, Kisii's topography and scattered farm sites may make it more difficult and time-consuming to transport the produce, thus increasing the chances of postharvest losses before reaching the market. This has also been observed in Kenya and other Sub-Saharan African nations, where poor market access and lack of adequate transport infrastructure have been identified as major factors in postharvest losses of perishable vegetables [46]. Proper packaging improves quality during handling and transport [47], which was reported more in Kisii (19.3%) compared to Kakamega (9.2%) ($\chi^2 = 7.299$, df = 1, $p = 0.007$), indicating slightly better adoption of preservation-enhancing practices in Kisii. However, cold storage was rarely used (0.6%) by farmers in Kakamega and none in Kisii. This highlights a major gap in access to temperature-controlled storage facilities. Cold storage is one of the most effective methods for extending shelf life by slowing respiration, moisture loss, and microbial growth [48]. Its minimal use suggests infrastructural and

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economic constraints, including limited availability, high cost, and lack of access to electricity in rural areas [49].

Effect of County, Gender and Postharvest Handling Practices on Shelf Life of African Indigenous Vegetables During Dry and Wet Seasons

The shelf life of AIVs was highly variable between counties, seasons, and postharvest handling practices (Table 4). In the dry season, there was no significant difference between Kakamega (1.62 ± 0.70 days) and Kisii (1.70 ± 0.81 days) ($p = 0.339$), whereas in the wet season, vegetables from Kisii had a significantly longer shelf life (2.77 ± 1.01 days) compared to Kakamega (2.42 ± 1.08 days) ($p = 0.002$), indicating that environmental factors, such as humidity and temperature, play a role in the observed seasonal and regional differences. Gender had a significant effect on shelf life in wet season ($p<0.05$), suggesting that male and female farmers maintained different levels of postharvest handling practices.

Harvesting practices had a noticeable impact on shelf life of AIVs, with uprooting showing significant differences between counties in dry season (1.85 ± 0.83 days; $p = 0.001$). Storage under shade greatly increased shelf life in both dry (1.65 ± 0.75 days; $p = 0.006$) and wet seasons (2.61 ± 1.09 days; $p = 0.007$). Transport also affected shelf life, with carts and pick-ups giving a longer shelf life in both seasons ($p < 0.05$), and human transport being significant in the wet season ($p = 0.003$). Packaging materials affected shelf life in the wet season, with differences among sacks, and crates ($p < 0.05$), but no differences were found in the dry season.

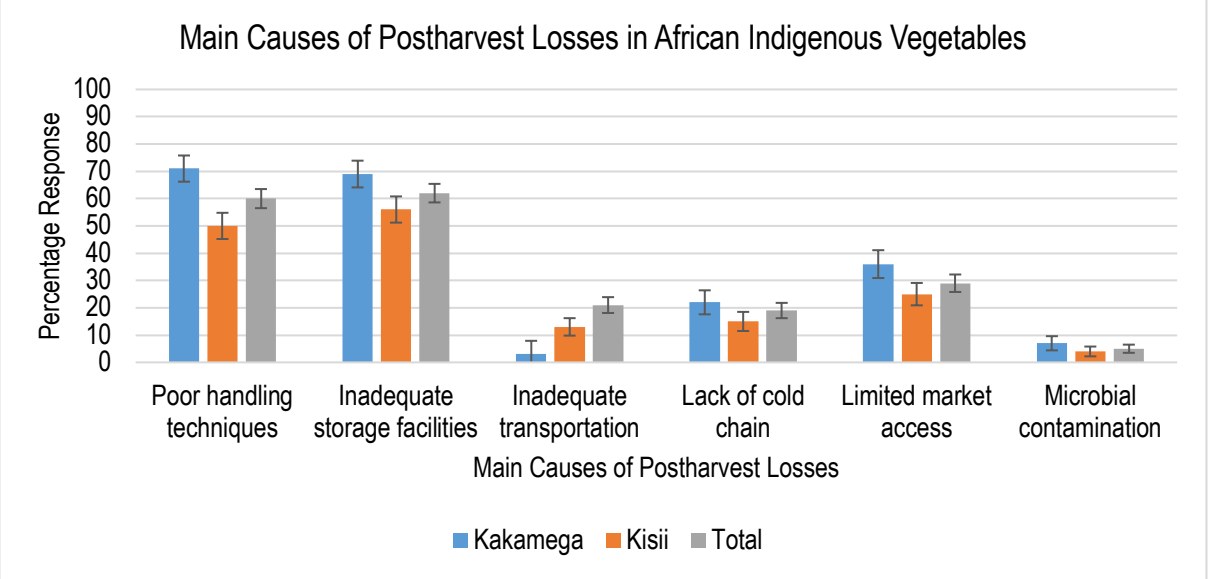
These findings suggest that postharvest handling techniques, such as careful harvesting, storage in shade, proper transport and proper packaging, play a crucial role in increasing the shelf life of vegetables. The overall longer shelf life in the wet season is consistent with earlier findings that higher humidity slows down transpiration and wilting of leafy vegetables [50,51]. Likewise, the role of harvesting, storage, transportation and packaging in shelf life tends to support previous evidence that mechanical damage, temperature and moisture are important factors affecting postharvest quality and marketability [52].

Major causes of Post-Harvest Losses in AIVs

The main causes of AIVs postharvest losses were inappropriate handling practices, inadequate storage facilities, and inappropriate transportation (Figure 4). Poor handling practices were the most important factor, contributing 59.5% to postharvest losses, significantly higher in Kakamega (71.1%) than in Kisii (50.0%; $\chi^2 = 9.155$, $df = 1$, $p = 0.002$).

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Error bars represent standard error of the mean

Figure 4: Main causes of Postharvest losses in African Indigenous Vegetables in Kakamega and Kisii

This can partly be attributed to the larger average sizes of farms and production quantities evident in Kakamega, which may need more handling during the harvesting, sorting and transportation processes. The higher handling frequency increases the chances of mechanical damage such as bruising, compression and tearing of leaves, which contributes to faster moisture loss, contamination and physiological damage. Inadequate storage facilities contributed 62.0% to postharvest losses, slightly higher in Kakamega (68.9%) than in Kisii (56.4%; χ^2 = 3.296, df = 1, p = 0.069), while poor transportation contributed 20.5% to postharvest losses, significantly higher in Kakamega (30.0%) than in Kisii (12.7%; χ^2 = 9.062, df = 1, p = 0.003). These findings suggest that physical and environmental factors of handling, as well as inadequate storage and transport infrastructure, are the main factors that contribute to postharvest losses of AIVs. This is in line with previous research in Africa, which found that poor handling, inadequate storage and transport to be important factors that contribute to postharvest deterioration and reduced marketable yields of leafy vegetables [53,54].

Effect of Handling Practices on Postharvest Losses

Handling practices showed variation in postharvest losses of AIVs, although there were no statistical differences (p>0.05) (Table 5). The losses associated with harvesting techniques that involved uprooting and cutting using knives were slightly higher (8.2 ± 9.8% and 9.2 ± 9.8%, respectively) than those with hand plucking (8.1 ± 9.7%), possibly because of the destructiveness associated with these techniques which could lead to higher levels of mechanical damage. There was variability

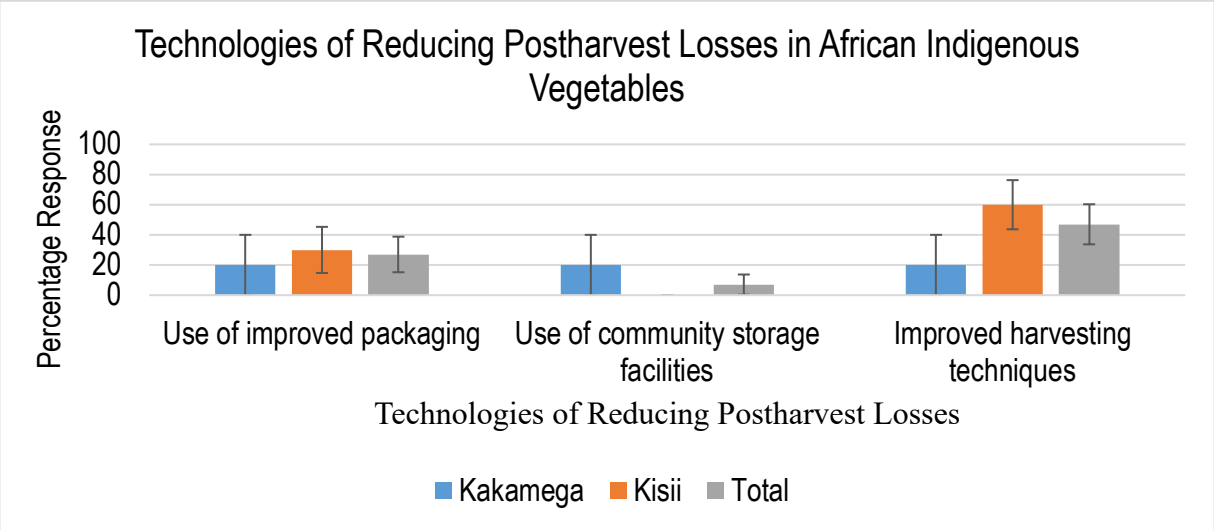
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between counties when it comes to storage practices, with Kakamega having higher average losses (11.3 ± 8.3%) as compared to Kisii (5.6 ± 10.9%), probably due to differences in microclimatic factors and handling frequency. However, this difference is not statistically significant. The same is true with transport practices, with the use of motorbikes being associated with higher average losses in Kakamega (11.9 ± 9.8%) than Kisii (5.2 ± 6.9%), while in case of human transport there were high variations in terms of average losses (10.4 ± 19.2%). With regard to packaging materials, buckets had relatively lower average losses (4.2 ± 3.3%) than sacks. Although these differences were not statistically significant, the observed trends highlight the potential importance of improved handling, storage, transport and packaging practices in reducing postharvest losses. These findings are consistent with previous research which yielded similar results, whereby mechanical damage and the surrounding environment were determined to be the major factors responsible for degradation in leafy vegetables [55,56].

Technologies for Reducing Postharvest Loses in African Indigenous Vegetables

The results in Figure 5 shows low overall adoption of AIV farmers to postharvest technologies, with 53.3% adopting improved harvesting methods (60.0% in Kisii and 20.0% in Kakamega, p = 0.143), 26.7% adopting improved packaging methods (30.0% in Kisii and 20.0% in Kakamega, p = 0.680), and only 6.7% adopting community storage facilities, with none in Kisii.



Error bars represent standard error of mean

Figure 5: Technologies of reducing postharvest losses in African Indigenous Vegetables

These suggests that many farmers are still using traditional harvesting, packaging and storage practices, which may be contributing to higher postharvest losses.

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These emphasizes the need for improving access to simple postharvest technologies and infrastructure such as provision of shade, proper packaging, and community storage to reduce damage, moisture loss, and quality deterioration. This is consistent with previous study, which have demonstrated that improved harvesting and handling practices have greatly reduced PHLs, while poor storage and packaging practices have contributed to deterioration [57]. Low-cost cooling technologies such as charcoal coolers and zero-energy brick coolers are relatively inexpensive and can be adopted by smallholder farmers, potentially reducing losses by up to 45% while requiring minimal investment, thereby improving profitability and household income [58, 59].

Determinants of Postharvest Losses

County, harvesting methods, and postharvest exposure conditions were major determinants of postharvest losses, whereas gender, level of education, farm size, packaging, and transportation were not statistically significant (Table 6). However, county had a marginally significant effect on postharvest losses (Odds Ratio [OR] = 1.721, p = 0.053), which means that the likelihood of PHLs was 1.7 times higher in one county compared to the reference county. This suggests that geographical and environmental differences, such as climate, play an important role in determining the level of postharvest losses. These results are consistent with previous studies that have found environmental differences, market access, and availability of infrastructure to be significant factors in determining the variability of postharvest losses [60,61,62].

Gender was not a significant predictor of PHLs (OR = 0.801, p = 0.421), although the OR suggests that female farmers were slightly less likely to have losses than male farmers. This result suggests that both male and female farmers may have equal access to postharvest knowledge, handling practices, and resources in the study areas. However, gender differences in postharvest management have been observed in other research studies, where women are often primarily involved in harvesting, postharvest handling and marketing thereby affecting postharvest outcomes due to their handling practices [63,64]. Although gender was not a significant predictor of postharvest losses PHLs, the dominant role of women in planting, harvesting, and market handling suggests that training women on the intervention could be more effective.

Harvesting practices were found to be an important factor affecting postharvest losses. The combined practice of plucking by hand and cutting with knives was found to significantly lower the chances of PHLs (OR = 0.068, 95% CI = 0.005–0.891, p = 0.040), which means that farmers adopting proper harvesting practices were 93.2% less likely to face losses compared to those adopting cutting with knives. This result highlights the significance of proper harvesting practices in maintaining produce

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quality and preventing mechanical damage. Inappropriate harvesting practices can lead to physical damage, enhanced respiration rates, and accelerated deterioration, ultimately resulting in enhanced losses. The current study is in line with previous research, which established harvesting practices as a major determinant of postharvest quality, with proper harvesting practices significantly reducing physical damage and increasing shelf life [65].

The postharvest exposure conditions were also important factors in the levels of losses. Farmers who managed shade and water effectively had significantly lower odds of loss (OR = 0.093, $p < 0.001$), suggesting that there was a reduction of about 90.7% in the odds of postharvest losses compared to farmers who did not use the two practices. This result emphasizes the need to protect vegetables from direct sunlight and excessive water loss, as high temperatures can accelerate respiration, transpiration, and wilting. These results are in agreement with [66] that suggested effective management of shading, cooling and moisture is critical for preserving quality and preventing PHLs in vegetables. While storage under shade alone had a positive but marginally significant effect (OR = 1.999, $p = 0.090$), it appears that the management of both shade and moisture is more effective in preventing losses.

Factors Influencing Shelf Life Duration

There was a moderate positive relationship between postharvest exposure variables and shelf life (Dry Season R=0.456 and wet season R = 0.308), with exposure conditions accounting for only 20.8% and 9.5% of the variation in shelf life duration ($R^2 = 0.208$ and 0.095; Adjusted $R^2 = 0.199$ and 0.084, respectively). This suggests that although postharvest exposure conditions are significant contributors to shelf life variation, a large proportion of the variation is likely to be accounted for by other variables not considered in the model. The standard error of the estimate (1.015 days) suggests that there is an average difference of about one day between the predicted and actual values of shelf life. The regression coefficients suggest that the storage of AIVs under shade had a statistically significant positive impact on shelf life (B = 0.316, $p < 0.001$) (Table 7), which means that AIVs stored under shade had a longer shelf life compared to the reference exposure category. On the other hand, the other exposure categories had statistically significant negative impacts on shelf life, including some related to shade and water (B = −0.731, $p < 0.001$; B = −0.688, $p = 0.003$; B = −0.892, $p < 0.001$). The negative coefficients imply that, compared to the reference category, these exposure categories were associated with a shorter shelf life. The standardized beta coefficients also suggest that some exposure categories had a relatively greater impact on shelf life than others. These results suggest that proper management of the environment during postharvest handling, especially the avoidance of direct sunlight exposure, is very important for extending shelf life. The results agree with previous studies that suggested direct sunlight

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exposure can raise the temperature of the product, respiration rate and transpiration, leading to increased moisture loss, wilting and senescence of leafy vegetables[67, 68].

Comparison of Shelf Life and Losses Across Counties and Seasons

The regression analysis was statistically significant for both dry and wet seasons ($F = 21.82$, $p < 0.001$, and $F = 8.929$, $p < 0.001$, respectively) (Table 8), suggesting that the variables were significant in explaining the shelf life and postharvest losses. The higher F-value and lower residual mean square in the dry season suggest that postharvest and environmental factors had a stronger and more predictable effect on shelf life and postharvest losses in the dry season compared to the wet season. African Indigenous Vegetables harvested in the wet season had a significantly longer shelf life than those harvested in the dry season ($p<0.05$). This could be due to the higher relative humidity in the wet season, which reduces transpiration and moisture loss, thus preventing wilting and slowing down physiological deterioration [69]. Significant differences were also noted among the counties, suggesting that local environmental factors and postharvest handling practices are important in determining shelf life and PHLs. These results agree with previous studies that have suggested temperature, relative humidity, and handling practices to be important factors in determining postharvest quality and shelf life of leafy vegetables, with high temperatures and low humidity being responsible for senescence, moisture loss, and deterioration of quality [70,71].

STUDY LIMITATIONS

The nature of the study was cross-sectional, which makes it impossible to determine causality. Estimates of post-harvest losses were obtained from the farmers, which makes it difficult to establish the accuracy of the data, as it might have been influenced by recall bias. Environmental factors, such as temperature and humidity, were not measured, which might have affected the shelf life.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

This study suggests that the postharvest loss for AIVs varied between 4% and 13% for small-scale farmers in Kakamega and Kisii counties. Harvesting practices, postharvest exposure conditions, storage, and transport were significantly associated with postharvest loss and shelf life. Shelf life was significantly longer during the wet season compared to the dry season. The results suggest that the PHLs of AIVs are mainly driven by factors that can be addressed in relation to harvesting, handling, storage, and transportation practices. It therefore, provides a major opportunity to improve harvest and postharvest handling practices hence longer the shelf life, reduced losses, and improve marketable yields and farmers'

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income. Based on the findings of the research the following recommendation can be suggested;

1. Capacity building of farmers and other stakeholders on harvesting and post harvesting management Technologies, Innovations and Management Practices (TIMPs)
2. Investment in low-cost, affordable storage and preservation technology.
3. There is need to use agricultural extension approaches which involves both men and women to ensure equality of knowledge trained on harvest and postharvest handling practices.
4. Policy support and research on cost-saving innovative processing and storage technologies need to be introduced to cement commercialization, improve household food security, and increase the income levels of small-scale AIV farmers.

Further studies should focus on evaluating cost effective, gender inclusive and climate smart postharvest technologies and intervention to minimize losses and enhance marketability of AIVs. Also, studies should include socio-economic, technical and other postharvest factors in the multivariate regression models to gain a more complete understanding of the determinants of the shelf life of African Indigenous Vegetables.

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Conflicts of Interest

The authors report no competing interests to declare.

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Table 1: Description and Coding of Variables Used in Regression and Logistic Analysis

Variable	Type	Coding	Reference
County	Categorical	0=Kakamega, 1=Kisii	
Gender of the farmer	Categorical	0=Female, 1=Male	
Education level	Categorical	0=No formal education, 1=Primary, 2=Secondary, 3=Post-secondary	No formal education (0)
Farm size	Continuous	Acres	
Harvesting method	Categorical	0=Cutting with knives, 1=Hand plucking, 2=Uprooting	Cutting with knives (0)
Storage	Categorical	0=Exposed to direct sunlight, 1=Put under shade, 2=Sprinkling water	Exposed to direct sunlight (0)
Packing	Categorical	0=Cartons, 1=Crates, 2=Sacks	Cartons (0)
Transport	Categorical	0=Cart, 1=Motorbike, 2=Human transport, 3=Pick up	Cart (0)
Shelf life	Continuous	Days	Dependent variable (Linear Regression)
Postharvest loss	Binary	0=No, 1=Yes	Dependent variable (Logistic Regression)

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Table 2: Socio-Demographic Characteristics of African Indigenous Vegetables Farmers by County

Demographic characteristic	Levels	Kakamega %	Kisii %	Total %	Test (X^2 or t)	df	p value
Gender							
	Male	49.7	39.1	44.8	3.911	1	0.048
	Female	50.3	60.9	55.2			
Age	mean±sd	48.4±14.3	50.1±13.2	49.2±13.8	-1.137	344	0.256
Education							
	No formal education	1.6	4.3	2.9	7.610	4	0.107
	Primary	47.6	41.0	44.5			
	Secondary	46.5	50.9	48.6			
	Tertiary	4.3	3.7	4.0			
Farm size	means±sd	2.1±2.3	1.2±1.0	1.6±1.8	4.530	344	0.001

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Table 3: Postharvest Handling Practices of African Indigenous Vegetables in Kakamega and Kisii Counties of Kenya

Parameters	Kakamega %	Kisii %	Total %	P-value
Storage of harvested AIVs				
Put under shade	89.7	83.2	86.7	0.076
Sacks/gunny bags	1.1	2.5	1.7	0.319
Exposed direct sunlight	1.1	0.6	0.9	0.645
Methods of reducing field heat				
Putting under shade	76.8	53.4	65.9	0.000
Sprinkling with water	32.4	45.3	38.4	0.014
Packing				
Sacks	90.3	79.5	85.3	0.005
Buckets	5.4	8.1	6.6	0.320
Cartons	2.7	1.9	2.3	0.604
Crates	1.1	1.2	1.2	0.889
Transport method				
Motorbike	62.7	63.4	63.0	0.900
Human transport	17.1	21.3	18.9	0.372
Carts	10.8	0.0	5.8	0.000
Pick up	0.0	1.2	0.6	0.128
Preservation method				
Timely delivery to market	63.8	49.7	57.2	0.008
No preservation done	17.8	18.6	18.2	0.848
Proper packaging	9.2	19.3	13.9	0.007
Putting under the shade	48.1	43.5	46.0	0.389
Proper transportation	6.5	7.5	6.9	0.724
Cold storage	1.1	0.0	0.6	0.186

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Table 4: Effect of County, Gender and Postharvest Handling Practices on Shelf Life of African Indigenous Vegetables During Dry and Wet Seasons

Category	Subgroup	Dry season shelf life (Mean ± SD)	Wet season shelf life (Mean ± SD)	Test statistic (F)	p-value (dry)	Test statistic (F)	p-value (wet)
County	Kakamega	1.62±0.7	2.42±1.1	0.919	0.339	9.830	0.002
	Kisii	1.70±0.8	2.77±1.0				
Gender	Female	1.69±0.8	2.73±1.1	0.751	0.387	8.078	0.005
	Male	1.62±0.7	2.40±1.0				
Harvesting	Hand plucking	1.65±0.7	2.57 ±1.0	1.566	0.212	0.248	0.619
	Cutting by knife	1.63±0.7	2.35 ± 1.0	0.124	0.725	2.558	0.111
	Uprooting	1.85±0.8	2.62 ±1.1	10.358	0.001	0.240	0.625
Storage	Putting under shade	1.65±0.8	2.61 ±1.1	9.305	0.006	8.330	0.007
	Sacks/gunny bags	1.83±0.8	2.33 ±1.0	0.323	0.570	0.332	0.565
Transport	Motorbike	1.65±0.8	2.65 ±1.1	0.047	0.828	2.280	0.132
	Cart	2.05±0.2	3.15 ±0.6	5.799	0.017	6.201	0.013
	Human transport	1.57±0.6	2.24 ±0.9	1.108	0.293	9.231	0.003
	Pick up	3.00±2.8	4.00 ±1.4	6.511	0.011	3.627	0.058
Packing	Carton	2.00±1.3	2.63±1.2	1.680	0.196	0.014	0.906
	Sacks	1.63±0.7	2.55±1.0	4.390	0.037	1.800	0.181
	Crates	1.50±0.6	2.00±1.2	0.184	0.668	1.214	0.271

Values are mean shelf life (days) ± standard deviation. F=F-statistic from the Univariate General Linear Model (GLM)

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Table 5: Effect of Handling Practices on Postharvest Losses

Handling practices	Kakamega	Kisii	Total	F(Total)	p-value
Harvest method					
Hand plucking	11.4±8.0	5.4±10.1	8.1±9.7	0.320	0.572
Uprooting	10.6±11.1	3.3±2.9	8.2±9.8	1.290	0.258
Cutting with knives	11.5±10.6	3.8±4.6	9.2±9.8	0.067	0.796
Storage method					
Under shade	11.3±8.3	5.6±10.9	8.3±10.1	0.387	0.535
Sacks/gunny bags	10.0±0.0	8.5±4.0	9.0±3.2	0.061	0.805
Transport					
Motorbike	11.9±9.8	5.2±7.0	7.9±8.8	0.077	0.781
Human transport	7.5±4.7	13.1±26.5	10.4±19.2	0.603	0.438
Cart	10.4±2.2	0.0	10.4±2.2	0.076	0.783
Packing					
Sacks	11.1±8.3	6.2±11.2	8.6±10.2	0.681	0.410
Buckets	7.5±2.9	2.5±2.0	4.2±3.3	2.048	0.154

Values are mean handling practices ± standard deviation. F=F-statistic and p-value from the Univariate General Linear Model (GLM)

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Table 6: Logistic Regression Analysis of Factors Influencing Postharvest Losses Among African Indigenous Vegetable Farmers

Variable	B	S.E.	Odds ratio	95% CI Lower	95% CI Upper	p-value
Constant	19.827	7352.82				0.998
County	0.543	0.28	1.721	0.993-2.981	2.981	0.053
Gender	-0.222	0.276	0.801	0.466-1.378	1.376	0.421
No formal education	Reference					
Post secondary	-1.218	0.777	0.296	0.065-1.356	1.356	0.117
Primary school	0.024	0.38	1.025	0.487-2.156	2.156	0.949
Secondary school	0.526	0.386	1.691	0.794-3.601	3.601	0.173
Farm size	-0.066	0.071	0.936	0.814-1.077	1.077	0.357
Maturity indices	19.658	7352.82	3.4E+08			0.998
Cutting with knives	Reference					
Plucking by hands	0.652	0.718	1.92	0.47-7.838	7.838	0.363
Plucking by hands Cutting with knives	-2.686	1.305	0.068	0.005-0.879	0.879	0.04
Plucking by hands Cutting with knives Up-rooting	0.668	0.93	1.951	0.315-12.077	12.077	0.472
Plucking by hands Up-rooting	0.148	0.741	1.159	0.271-4.951	4.951	0.842
Plucking by hands Up-rooting Cutting with knives	-0.397	0.993	0.672	0.096-4.707	4.707	0.689
Up-rooting	-0.686	1.004	0.504	0.07-3.601	3.601	0.494
Up-rooting Plucking by hands	-0.236	0.878	0.79	0.141-4.414	4.414	0.788
Exposed to direct sunlight	Reference					
Put under shades	0.692	0.409	1.999	0.897-4.451	4.451	0.09
Water	Reference					
Putting under shade	-0.501	0.326	0.606	0.32-1.147	1.147	0.124
Putting under shade Water	-0.373	0.541	0.689	0.239-1.988	1.988	0.49
Water Putting under shade	-2.379	0.543	0.093	0.032-0.269	0.269	0
Cartons	Reference					
Crates	1.78	2.059	5.931	0.105-335.573	335.573	0.387
Sacks	-0.211	0.389	0.809	0.378-1.735	1.735	0.587
Carts	Reference					
Motorbike	0.285	0.282	1.33	0.765-2.312	2.312	0.313

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Table 7: Regression Coefficients for Factors Influencing Shelf Life Duration

Model	B	Std. Error	Beta	T	p-value
(Constant)	2.536	0.142		17.822	0.000
Exposed to direct sunlight	-				
Put under shades	0.316	0.086	0.107	3.698	0.000
Exposure to water	-				
Putting under shade	-0.731	0.133	-0.345	-5.481	0.000
Putting under shade Water	-0.688	0.232	-0.168	-2.96	0.003
Water Putting under shade	-0.892	0.22	-0.233	-4.058	0.000

Table 8: ANOVA Summary of Multiple Linear Regression Analysis for Shelf Life and Losses Across Counties and Seasons

Model	Regression	Df (regression)	MS (regression)	Residual	DF (residual)	MS (residual)	F	p-value
Dry	74.32	5	14.864	283.5	416	0.681	21.82	0.000
Wet	36.808	4	9.202	351.426	341	1.031	8.929	0.000

Multiple linear regression analysis was used to assess the impact of county and season on shelf life and loss. ANOVA was used to assess the overall significance of the regression models

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