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POSTHARVEST LOSSES IN ETHIOPIA'S AVOCADO VALUE CHAIN: MAGNITUDE, DRIVERS AND IMPLICATIONS FOR FOOD SECURITY, NUTRITION AND ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT

Ethiopia's avocado sector has expanded rapidly since 2019/20, driven by government prioritization and smallholder-led clustered orchards. However, postharvest losses (PHL) remain a major constraint, reflecting poor harvesting and handling practices, limited cold-chain infrastructure, and market inefficiencies. Losses are both quantitative and qualitative-manifesting as physical damage and deterioration in firmness, edibility, and marketability-exacerbated by climacteric ripening under inadequate cooling and storage conditions. This study presents a 2023–2024 multi-region assessment across six major avocado belts (Oromia, Amhara, Sidama, South Ethiopia, Southwest Ethiopia, and Central Ethiopia). Evidence was generated through a 391-household producer survey, 72 key informant interviews, direct field and market observations, and five-stage load tracking from farm to retail. The analysis quantifies PHL, identifies critical loss points and underlying drivers, and proposes actionable interventions aligned with Ethiopia's avocado development agenda. Production systems differed markedly: unmanaged seedling trees dominated Jimma, Kaffa, Wolaita, and Sidama, whereas government-supported clusters in East Shewa, North Gojjam, and Silte cultivated Hass and Ettinger varieties under comparatively improved management, contributing to better shelf-life performance. Average PHL was estimated at 39–43% of total produce, leaving only about six of every ten kilograms available for consumption or sale. Survey-based estimates indicated 38.9% loss (23.2% quantitative, 15.7% qualitative), while load tracking confirmed 43.2% (24.5% quantitative, 18.7% qualitative). The largest losses occurred at harvesting (8.9%), wholesale storage (11.2%), and retail markets (12.5%). Using 2020/21 production and prevailing prices, annual economic losses are approximately USD 90 million. The estimated 63.7 million kg of fruit lost (35 million kg pulp) also implies substantial foregone nutrition, avoidable emissions (159,249 t CO_2e), and an effective loss of 7,494 ha of productive land. Key drivers of avocado postharvest loss include inappropriate harvesting tools and practices, rough handling, and inadequate packaging, transport, and storage—particularly within wholesale distribution. Reducing PHL by 25% could recover about Ethiopian Birr (ETB) 1.28 billion annually, avert 40,000 t CO_2e, and free 1,875 ha. Targeted, low-cost innovations in harvesting, grading, packaging, short-term cooling, transport, storage, and market governance could deliver immediate, measurable PHL reductions, while standardized survey and load-tracking protocols offer a practical basis for routine monitoring and accountability.

Key words: avocado, postharvest loss, Ethiopia, supply chain, impact, magnitude, drivers

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INTRODUCTION

Avocado has become one of Ethiopia's fastest-growing fruit crops, now covering about 19% of the national fruit-growing area and 17% of total fruit production. It ranks second in cultivated area after banana and third in production volume [1]. Both acreage and output have grown steadily since 2008/09 [2]. Domestic consumption dominates Ethiopia's avocado market, with demand rising through urbanization. Export trade, launched in 2020, is expanding toward Gulf and European markets with Hass variety, though strict quality and phytosanitary compliance remain essential. Domestically, avocados are sold ungraded and without cold-chain handling, increasing deterioration risks. Ethiopia has established processing facilities in four Integrated Agro-Industry Parks, including packhouses and crude oil units. Despite strong production potential, inefficiencies such as poor harvesting, weak postharvest handling, and careless practices [3], erode quality and market value. Postharvest loss includes quantitative (volume/weight) and qualitative (damage, firmness, edibility, nutrition, marketability) aspects. As a climacteric fruit, avocados continue ripening after harvest, with respiration and ethylene production spiking to 80–100 $\mu L\ L^{-1}$, thereby accelerating softening, browning, and decay [4]. Data remain fragmented, relying mainly on surveys with limited quality assessment.

This study combines surveys and load-tracking for loss quantification with the objective to:

i. quantify avocado losses through surveys and load-tracking.
ii. identify critical loss points along the avocado value chain.
iii. ascertain the key factors contributing to avocado losses.
iv. estimate the economic, nutritional, and environmental impacts of these losses.
v. support evidence-based decision-making across Ethiopia's avocado supply chain.

MATERIALS AND METHODS

Study Area and Production Systems

The study was conducted across six major avocado-producing regions of Ethiopia: Oromia (East Shewa, Jimma), Amhara (North Gojjam), Sidama (Central and Northern), South Ethiopia (Wolita), Southwest Ethiopia (Kaffa), and Central Ethiopia (Silte) (Figure 1). Production systems examined included both smallholder cluster commercial orchards, predominantly planted with grafted cultivars such as Hass and Ettinger, and traditional solitary seedling-based orchards, dominated by ungrafted local varieties.

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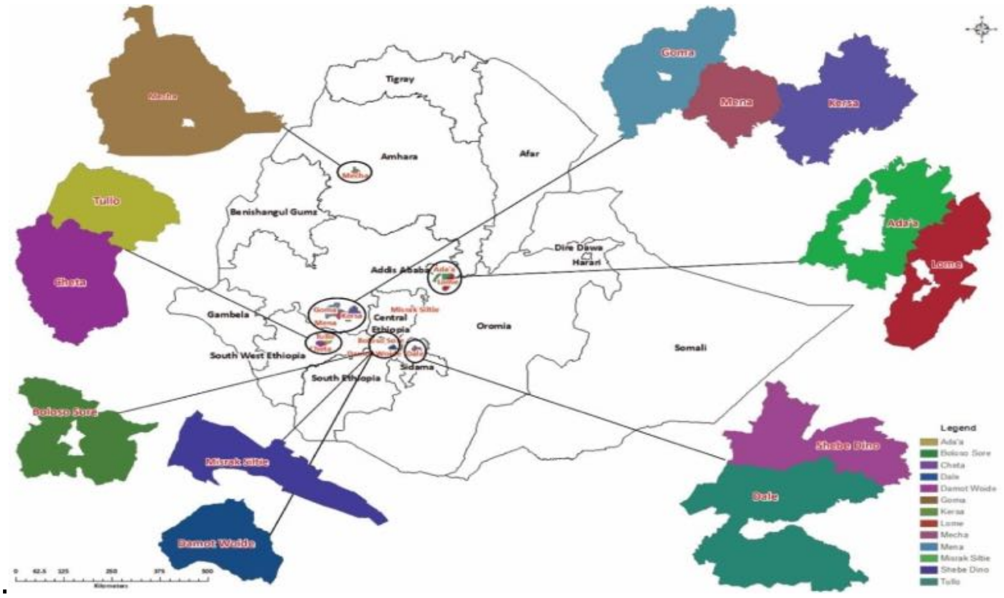

Figure 1: Map of the study Areas

Research Design and Data Collection

Study design

This research adopted a cross-sectional design, integrating both quantitative and qualitative approaches to evaluate postharvest losses of avocados from harvest to retail.

Sample size and sampling procedure

The study population included avocado producers and key value chain actors including wholesalers, retailers, exporters, researchers, extension experts, and representatives from the Ethiopian Horticulture Producer Exporters Association (EHPEA). Avocado producers were selected through a mix of purposive and random sampling procedure. First, six target regions were purposively chosen based on their production and marketing relevance. Next, key avocado-producing zones and *woredas* were identified within each region. Then, 2–3 *kebeles* were randomly selected per woreda. Finally, farmers were randomly drawn from *kebele* producer lists, yielding 391 respondents for the household survey. Conversely, key value-chain actors were deliberately chosen for their expertise in their respective fields.

Since accurate population proportions for the issue of interest (farmers facing significant losses) were unavailable, the default value p = 0.5 (50%) was used to estimate the largest possible sample size. The sample size of individual respondents was calculated using the following formula [5].

$$n = \sqrt{D \frac{Z^2 \, P\,(1-P)N}{ME^2(\,N-1) + \,Z^2 \, P\,(1-P)}}$$

Where, D = 1.5 (design effect), Z = 1.96 (95% confidence), P = 0.5 (maximum variability), ME = 0.05 (margin of error), and N = 1100 (avocado producers), and n= 391 respondents.

Additionally, 72 key informants were purposively selected to provide in-depth value chain insights, comprising wholesalers, retailers, exporters, researchers, extension experts, and representatives from the Ethiopian Horticulture Producer Exporters Association (EHPEA).

Data collection methods and tools

Data were collected between February 2023 and January 2024 using multiple complementary sources to ensure robustness and triangulation: (i) secondary data from official published and unpublished sources; (ii) a household survey of 391 avocado producers selected through a mix of purposive and random sampling procedure; (iii) 72 key informant interviews with value chain actors (wholesalers, retailers, exporters) and support institutions; (iv) direct field observations; and (v) five-stage load tracking (at harvesting, local market aggregation center, wholesale destination point, wholesale market outlet, and retail market outlet) along two representative market corridors—Bonga (humid climate, thicker skins) and Boditi (drier climate, thinner skins).

Document review – Twenty-four studies published between 2014 and 2023 were reviewed to establish baseline knowledge on avocado postharvest losses, determine methodologies, and identify postharvest loss and potential variables that contribute to avocado losses across the value chain.

Household survey – Structured and semi-structured questionnaire were administered via Kobo Toolbox to collect demographic, socio-economic, and production data. Interviews were conducted in local languages, audio-recorded, and translated into English.

Key informant interviews (KIIs) – Through open-ended interviews with 72 actors, information was collected regarding value-chain practices, constraints, and opportunities for interventions to minimize losses.

Direct observation – Field visits to orchards, markets, transport points, and avocado oil processing sites documented handling practices and visible losses.

Postharvest Loss Assessment and Quantification

Loss quantification combined survey estimates from farmers, traders, and transporters with direct load-tracking measurements [6] across harvest, transport, unloading, wholesale storage, and retail. This dual approach enabled triangulation: surveys provided breadth and stakeholder insights, while load tracking offered objective, stage-specific validation.

Quantity loss referred to measurable reductions in volume or weight from immature, damaged, infected, or dehydrated fruit rendered unfit for sale or consumption. Quality loss referred to the deterioration of the fruit's condition and the reduction of its marketability, or consumer acceptability due to defects, damages, or physiological disorders that occur during pre-harvest, harvest, or post-harvest handling, which ultimately downgrade the fruit's value. The value calculated as price differences between downgraded and sound fruit. Total economic loss combined revenue reductions from both quantity and quality losses through discounting.

Data quality and analysis

Data quality was ensured through Kobo Toolbox features, including skip logic, mandatory records, and error-check functions. Enumerators were selected for relevant experience, trained in survey protocols, and supervised during fieldwork. The questionnaire was pretested at one of the data collection sites in Wolita by interviewing selected avocado producer farmers before the actual data collection began to ensure clarity and flow, while spot-checks verified the consistency and accuracy of the tool. Then, errors identified during pretesting and spot-checks were revised and enumerators briefed on the corrected sections. Data analysis used Statistical Package for the Social Sciences (SPSS) version 26, applying descriptive statistics to summarize postharvest loss levels, practices, and costs. A 25% quantile regression was used to identify determinants of yield and loss, and stage-wise loss tracking using a digital balance at harvesting, local market aggregation center, wholesale destination point, wholesale market outlet, and retail market outlet highlighted the critical loss points. Load tracking validated survey estimates, with results presented through tables, charts, and graphs to enhance clarity and reliability.

Quantile Regression Equation

$$Q\{0.25\}(Y) = B_0+B_1X_1+B_2X_2+B_3X_3+B_4X_4+B_5X_5+B_6X_6+B_7X_7$$

Variables Fitted with the Model

X1: Local Variety – this variable measured the use of local cultivars and was coded as a binary variable in the model (1 = local avocado variety cultivated; 0 = improved variety).

X2: Avocado Pest Infestations - This variable measured the presence/absence of visible pest damage on fruit or trees and was codded as a binary variable in the model (1 = infestation observed; 0 = no infestation).

X3: Grafted Tree – This variable measured whether farmers used grafted trees, and was coded as a binary variable with 1 = orchard established with grafted trees; 0 = non grafted trees).

X4: Length of Maturity – This variable measured the average number of months from flowering to harvest, recorded by farmers and cross checked with field observations.

X5: Harvesting by Women – This variable measured whether harvesting was conducted by women and was coded as a binary variable in the model (1 = harvesting primarily conducted by women; 0 = otherwise).

X6: Harvesting at Any Time of the Day – This variable tracked the time of fruit harvesting during the day and was coded as a binary variable in the model (1 = harvesting conducted without time restriction; 0 = harvesting restricted to morning or evening hours).

X7: Harvesting Fruit in Contact with the Ground – This variable tracked whether harvesting was conducted in contact with the ground and was coded as a binary variable (1 = fruit collected after ground contact; 0 = fruit harvested directly from the tree without ground contact).

RESULTS AND DISCUSSION

Age Category of the Respondents

The demographic assessment of Ethiopian avocado producers reveals significant regional variation in age distribution and youth participation. Youth household heads (<25 years) are highly concentrated in the Sidama region, averaging 30% participation (33.3% in Northern and 26.7% in Central Sidama), but account for only 10% in Oromia (13.3% in East Shewa, 6.7% in Jimma) and are absent in North Gojjam and Kaffa. Conversely, older cohorts dominate production in the remaining regions. Middle-aged farmers (55–64) comprise 23.6% of producers in North Gojjam, while senior demographics dominate in Jimma and Wolaita; the 55–64 cohort represents 27.3% and 16.4% respectively, and those over 64 account for 25% in both areas.

Education Level

The study revealed that avocado farmers in Ethiopia generally have low formal educational attainment. Nationally, 41% of growers are illiterate or did not progress beyond grade four, with the highest rate recorded in North Gojjam at 61.2%, followed

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by Sidama at 36%. About 33% of farmers attained upper primary education (grades 5–8), while only 25% reached secondary school, college, or university level. This pattern indicates that the majority of avocado production is managed by farmers with limited schooling, which constrains their ability to adopt modern practices.

Production Context and Pre-harvest Determinants

Results showed that in Jimma, Kaffa, Wolaita, and parts of Sidama, avocado production was dominated by tall (>8 m), seedling ("local") trees that were unmanaged and genetically diverse, making harvesting difficult and ripening uneven. In contrast, government-supported smallholder clusters in East Shewa, North Gojjam, and Silte grew Hass and Ettinger varieties with lower canopies that eased management; Hass's thicker skin enhanced transport and shelf life (Table 1). Postharvest outcomes were strongly influenced by preharvest factors such as nutrition (notably N: Ca balance), water status, canopy light (pruning), and pest/disease pressure. Irrigation was common in North Gojjam and Silte but rare in high-rainfall, local-type zones.

Due to avocado's lack of true dormancy [7, 8], insufficient or disrupted irrigation caused flower and fruit drop, producing small, shriveled fruit and increasing rejection along the chain, consistent with [9, 10]. Consistent nutrient management was essential for stabilizing yield and quality; poor fertilization reduced yields by up to 70% [11]. Fertilization, especially organic inputs, was nearly universal: 100% in North Gojjam and Central/Northern Sidama; over 90% in East Shewa, Jimma, Silte, and Wolaita and 64.3% in Kaffa. Organic inputs dominated (compost 66.7%, manure 60.1%), while mineral use remained limited (Diammonium Phosphate, DAP 6.0%, urea 6.6%). Strengthening integrated nutrient management balancing mineral and organic sources and tailoring rates to tree age and orchard condition helped stabilize yields and improve marketable quality.

According to the key informants, there are eight avocado varieties registered nationally (Hass, Fuerte, Ettinger, Pinkerton, Nabal, Bacon, Avocado-Choquette, Avocado-AL1), with Hass and Ettinger being the most prominent. One respondent explained," Productivity levels at research centers ranged between 20–32.5 tons per hectare. As one researcher put it, "There is a varietal difference in terms of yield, quality, size, color fruit etcetera."

Harvest practices in time and phenology

Time from flowering to harvest varied by genetic background, agroecology, and management: Mexican types matured in 6–9 months, West Indian in 5–9 months, and Guatemalan in 10–16 months [12]. In Ethiopia, most trees were seed-derived and racially mixed, which made fixed maturity dates difficult. Surveyed growers most

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commonly reported intervals of 6–7 months (45%) and 8–9 months (47.6%), with fewer reporting up to one year. Systematic phenology records by variety and location remained lacking and were urgently needed.

Maturity indices and harvest readiness

To balance quality and early-season pricing, establishing a minimum maturity standard is essential. Key measures included oil content and dry matter. Oil content increased with maturation but varied within fruit and across cultivars and environments [13]. Fruit size and seed coat appearance served as complementary indicators but were less reliable for local types due to high variability. In the study areas, 97.7% of growers assessed maturity by external color and texture, and 56.0% by size (Figure 2).

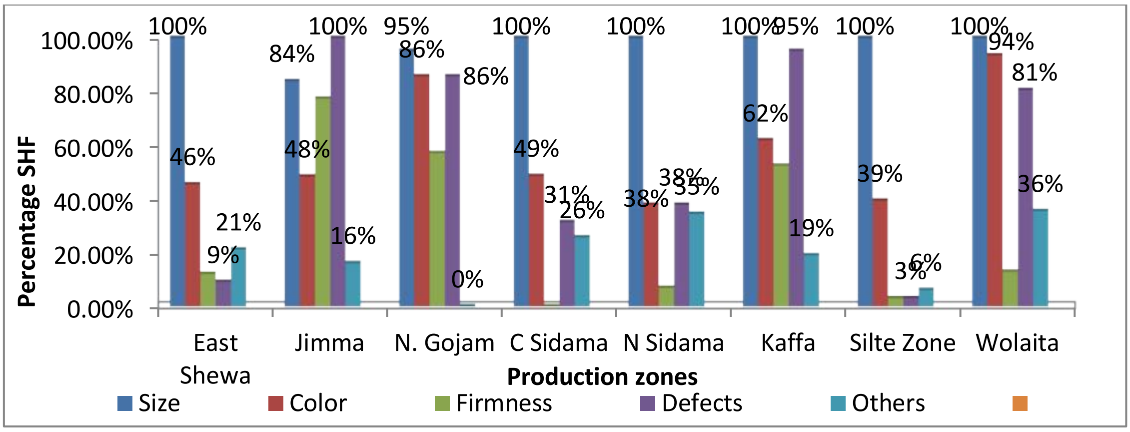

Figure 2: Maturity indicators of avocado fruits in the sample smallholder producers

The key informants from research centers consistently emphasized their institutions' role in supporting producers, processors, and traders. Variety improvement and pest management emerged as dominant themes. A plant breeder highlighted, "Improving avocado cultivars through selective breeding and genetic modification to enhance productivity, diseases and pest resistance and fruit quality is our key priority." Another researcher reinforced this by saying, "Our focus is on variety improvement, promotion and demonstration of improved variety, and grafted avocado seedling multiplication." Postharvest technologies were also emphasized, with one respondent stressing, "Less research emphasis on appropriate harvesting tools has led to high post-harvest loss."

Methods, tools, and peduncle management

Many orchards consisted of tall, seed-origin trees up to 15 m, which made safe harvest challenging. Common practices included hand-picking and dropping to the ground (55.5%), hand-picking into bags (49.1%), and to lesser extents, using poles, shaking, and sticks. Dropping and shaking caused cracks and invisible bruising, which facilitated pathogen entry (notably Colletotrichum spp.), and this was worsened by rough transport and storage. Variety mattered: 'Fuerte' required clipping, while 'Hass' could be snap-picked without harm [14]. Best practice involved placing fruit into soft bags or crates and moving them quickly to shade. According to this study, tools used included polypropylene (PP) bags (87.2%), harvesting poles (22.5%), and plastic crates (15.3%), along with wooden crates, secateurs, and ladders. A locally developed picking pole deserved wider on-farm demonstration [15]. Clipping to retain an 8–10 mm peduncle reduced respiration and pathogen entry [16]. In surveyed areas, peduncles were often removed in domestic trade; when retained, average length was 0.77 cm, reaching 1.4 cm in North Gojjam (Figure 3).

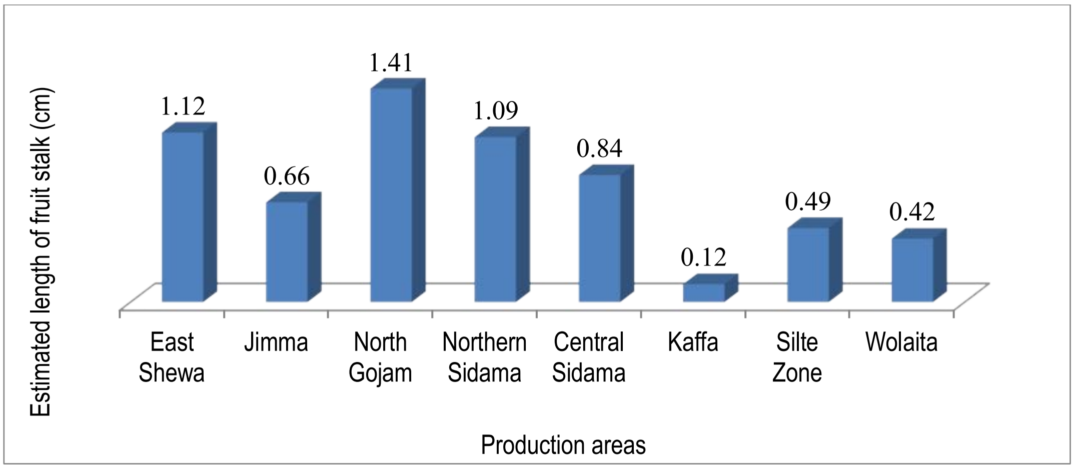

Figure 3: Estimated length (cm) of fruit stalk left on the avocado fruits at harvesting

Seasons, frequency, household participation, and conditions

Commercial varieties are mainly harvested between July–September; for example, 'Hass' from East Shewa is first picked in late September, with late harvests extending to February. Delayed removal suppresses the next flowering flush. Local types: small-fruited (Mexican-dominant) trees are typically harvested twice yearly (February–March and July–August), while larger-fruited, racially mixed locals in southwestern Ethiopia are harvested once annually. In areas with near year-round rainfall (example, parts of Kaffa), delayed picking can extend harvests almost year-round. However, rainfall just before harvest increases turgidity and vulnerability to mechanical damage [3].

Household harvesting participation was broad: children participated at 68.3%, husbands at 61.6%, and wives at 41.7%. In many sites, children climbed trees and used long poles to knock fruits onto bare ground, which caused frequent impact damage and short pedicels.

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Regardless of who harvests, fruit must be protected from cuts and abrasions [4]. Temperature and moisture are critical: exposure to >30°C between picking and cooling increases rots and flesh disorders, while wet weather harvesting raises lenticel damage and vascular browning [16]. The study revealed that harvesting occurred mainly in the morning (87.5%), but also midday (27.6%), evening (24.8%), and "any time" (7.9%). Harvesting was faster in short, grafted commercial trees and slower in tall, seedling-origin trees. The reported harvesting times (mean, min–max) were: East Shewa (22, 0–60), Jimma (53, 5–360), North Gojjam (15, 0–35), Central Sidama (49, 1–120), Northern Sidama (44, 5–120), Kaffa (58, 20–180), Silte (31, 0–90), and Wolaita (56, 1–600), (Table 2).

According to exporters' key informants, the avocado value chain is highly vulnerable during the transition from farm to packing house. Although exporters use specialized tools for export-grade fruit, such as clippers and plastic crates, nearly 40% of the harvest is rejected at the farm gate due to quality problems, including sunburn or improper sizing. Logistics remain the most critical bottleneck. Because farm-access roads are limited, fruit is often transported over distances of up to 30 km by human labor or animal-drawn carts, locally known as "Gari". These delays severely affect fruit quality, as avocados should ideally enter cold storage at 5–9°C within one hour of harvest. As a result, an estimated 20% of the product is lost during transport alone due to heat exposure and physical bruising.

Econometric Analysis

The quantile regression at the 25th percentile highlighted factors that drove lower-end economic losses in avocado postharvest handling. Losses increased with local (non-improved) varieties ($\beta = 0.939$, $p<0.01$), pest infestation ($\beta = 1.060$, $p<0.01$), longer maturity duration ($\beta = 2.533$, $p<0.01$), harvesting "any time" ($\beta = 2.865$, $p<0.05$), fruit harvested by wives ($\beta = 3.673$, $p<0.01$), and fruit contacting the ground ($\beta = 4.630$, $p<0.01$) (Table 3).

The findings of Muita *et al*. [17] revealed that avocado losses were significantly influenced by variety type, pest damage, inadequate storage, and transport delays, with average losses of about 30%.

In contrast, López *et al*. [18] emphasized pest infestation, ground contact, and poor harvest timing as the primary drivers of fruit rejection, leading to 20–30% economic losses across different stages of the value chain.

Local varieties were more damage-prone than improved types, contributing to higher losses. Pest pressure and extended maturity periods likely reflected delayed harvest and environmental exposure. When women harvested, they used methods such as tree shaking or pulling down fruit with long sticks curved at the end, which resulted in more damaged and immature fruit. Harvesting at unspecific times, especially midday, worsened bruising and heat stress. Ground contact further reduced fruit quality and market value.

Avocado fruit postharvest management

Ground contact was widespread (65.2% overall; up to 86% in some zones) despite recommendations to place fruit directly into clean, protective containers to prevent contamination and mechanical damage [19]. Most growers stored fruit under trees or simple shade, yet sun exposure still occurred, accelerating ripening. Pre-cooling was critical for slowing respiration, ethylene, and fungal growth, and ideally should have occurred within six hours of harvest. However, 93.9% of growers did not pre-cool, relying instead on night transport, which served as an inadequate substitute (Figure 4). Only some 'Hass' from East Shewa reached packhouses promptly; produce from other zones often traveled to Addis Ababa without temperature management.

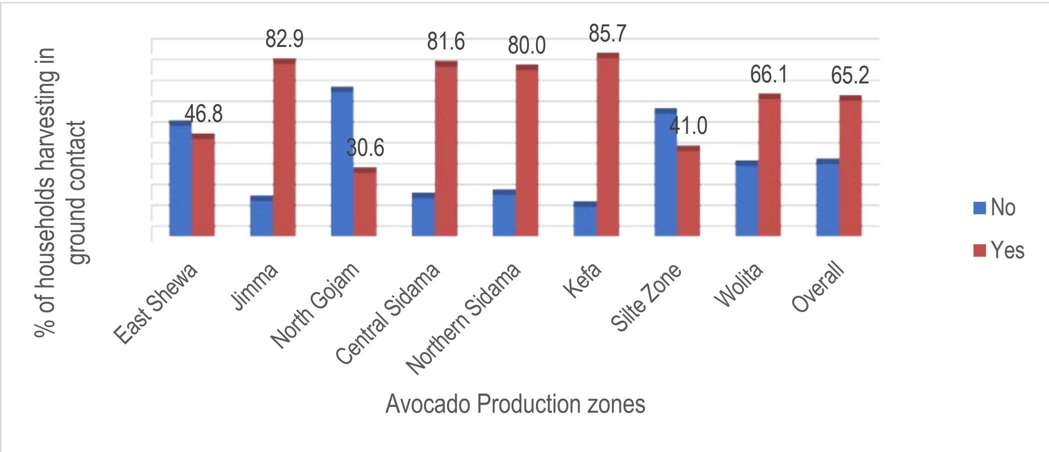

Figure 4: Percentage of households harvesting avocado fruits in contact with the ground

Sorting, grading, and storage

While 68% of growers sorted fruit in the field, grading remained inconsistent. Many defects, especially in 'Hass', were not externally visible and appeared after several days. Grading, practiced by 60.1% of respondents, relied mainly on size, maturity, and color but was hindered by genetic variability in seedling-origin trees. Exports followed The United Nations (UN) packhouse guidelines, yet the absence of uniform national grading standards for domestic markets caused inconsistency; fruit from southwestern Ethiopia was often transported ungraded and sorted in Addis Ababa before re-export.

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Short-term storage was common when fruit was not sold immediately, but methods often compromised quality. Bulk storage on mud floors (46%) and wooden crates (15.3%) increased contamination and compression risks. Self-reported durations ranged from over 11 days for 'Hass' in East Shewa to 1 day for local types in Jimma (not scientifically validated). Simple zero-energy cool chambers extended marketability: fruit remained viable for 12–13 days, while ambient-stored fruit became unmarketable by day 7 [20].

Packaging and first-mile logistics

Before temporary storage, 69.8% of growers packaged avocado fruit, with Polypropylene bags being the dominant packaging material (>90%). These limit airflow and contribute to bruising, whereas rigid, vented crates and small retail packs such as, perforated bags or net sleeves help maintain quality and enable higher-value urban market access (Figure 5). Strengthening packaging infrastructure near production areas, alongside controlled storage, could significantly reduce losses and improve returns for growers.

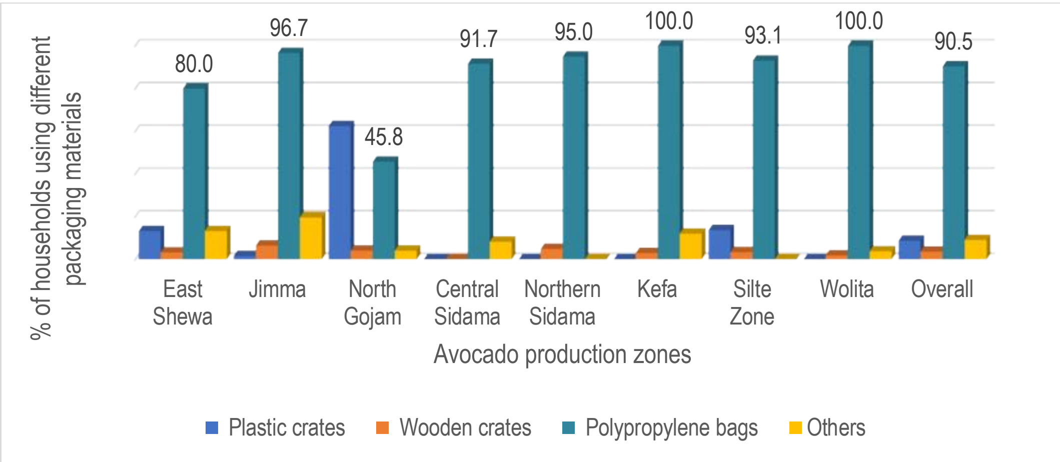

Figure 5: Types of avocado fruit packaging used by avocado growers

Transportation along the supply chain

Avocados, bulky and highly perishable, were marketed far from production zones without adequate control of temperature, humidity, or ventilation. The supply chain moved from farms to collection points, aggregation centers, and finally to local or central markets. In the field, handlers relied heavily on polypropylene sacks and dense stacking, which caused compression damage, heat buildup, and rapid ripening. Night transport reduced heat stress but did not replace cooling. Varietal differences were critical: clonal 'Hass' fruit, with thicker skins, endured longer, while seedling types with thinner skins suffered greater moisture loss, bruising, and deterioration. Smallholders typically carried fruit in sacks (89.8%) or bulk loads

(37.7%), with limited crate use. Losses were aggravated by poor handling and inspection practices, including workers stepping on sacks and contraband checks piercing loads, damaging up to 200 kg per truck. Transporters reported protective measures such as cleaning floors, avoiding mixed loads, and using canvas covers, but cooling and ventilation remained rare. Longer trips used trucks with floor loading, bruising fruit at the bottom and sides. Surveys showed mixed use of plastic crates (75%), wooden crates (50%), and bulk loading (50%). Typical loads ranged from 1–4 tons, with carriers averaging 7–10 trips annually, mostly at night or early morning.

Distances, timing, and costs

About 50.1% of growers were located 1–5 km from local markets, while 25.6% were within 1 km. Remote producers, especially in parts of Kaffa and Jimma, faced long, costly trips over poor roads. After harvest, 36.1% delivered within one hour and 32.5% within 1–2 hours; longer waits increased perishability. Local transport took 1–3 hours, and long-distance hauls from Jimma, Kaffa, and Wolaita to Addis Ababa were mostly overnight. Transport costs reflected accessibility: 200–300 ETB per 100 kg on poor roads versus 40–100 ETB where access was better. Shipments to Addis Ababa averaged 205–241 ETB per 100 kg. As noted by Selamawit [21], pricing was largely influenced by intermediaries, while wholesalers set prices in 75% of transactions, though negotiation remained relevant. Payments were usually prompt, with 80% of farmers receiving cash at the point of sale.

Most of the key informants agreed that downstream actors capture the larger share of the total benefit generated from the sector. One researcher stated, “The most monetary benefit goes to middlemen and wholesalers.” Another indicated “Retailers and wholesalers are making the most monetary benefit from the avocado production system.”

Magnitude and pattern of harvest and postharvest losses

This study detailed avocado losses in Ethiopia, combining surveys and direct measurements to refine estimates. Losses began at harvest and worsened along the supply chain, especially for seedling-based fruit outside export areas. Compared to clonal ‘Hass’, seedling fruit showed greater maturity variation, thinner skins, and weaker storage potential.

Survey-based estimates

The avocado value chain incurred substantial postharvest losses, totaling 38.9% (23.2% quantitative and 15.7% qualitative), with the most critical points occurring at harvest, wholesale storage, and retail distribution. These findings are consistent with evidence from comparable avocado and fresh-produce value chain studies [22, 23]. At the farm level, immature picking, fruit dropping, and improper handling accounted for 5.0% quantitative and 2.6% qualitative loss, which aligns with earlier reports highlighting similar on-farm loss drivers [24]. Additional deterioration occurred during temporary storage and transport to local markets, corroborating findings reported by Kelikay *et al.* [25]. Long-distance transport to central markets contributed a further 4.5% quality loss, while wholesaler storage resulted in 2.8% quantitative and 4.62% qualitative loss, largely due to heat exposure and poor handling practices, patterns similarly documented elsewhere [26]. Retailing was the most damaging stage, with 5.5% quantity and 4.5% quality loss from inappropriate packaging, poor storage, and spoilage, echoing observations from related studies [27]. Overall, these results highlight systemic inefficiencies across the chain and reinforce the need for strengthening harvesting practices, packaging, cooling, transport, storage, and market governance to reduce losses and improve quality (Table 4).

Load-tracking (objective) estimates

Load tracking estimated postharvest loss points with greater precision [28]. At harvest, supply chain (SC1), total losses averaged 9.5% (4.0% quantitative, 5.5% qualitative), mainly due to maturity errors and mechanical injury from picking and dropping fruit from tall trees. During loading, transport, and unloading to Addis Ababa markets (SC2), losses averaged 7.8% (3.0% quantitative, 4.8% qualitative). Losses at wholesaler intake/storage (SC3) averaged 2.9%, mostly quantitative, but rose sharply during wholesale storage and distribution (SC4) to 11.1% (8.1% quantitative, 3.0% qualitative) due to heat buildup and inconsistent sorting. These findings showed that while losses occurred throughout the chain, targeting wholesale distribution offered the greatest potential to reduce overall deterioration.

Overall, average harvest and postharvest losses were 41%, comprising 38.9% from survey data (23.2% quantitative and 15.7% qualitative) and 43.2% from load-tracking (24.5% quantitative and 18.7% qualitative). Only six out of every 10 kg harvested reached consumers in acceptable condition. The close alignment between methods, load tracking only 4 percentage points higher than surveys, consistent with the Food and Agriculture Organization (FAO) and Ethiopian Statistics Service [29], built confidence in the magnitude and distribution of losses and highlighted the value of routine, objective measurement for accountability.

Critical loss points (CLPs)

Critical loss points in the avocado supply chain were severe, affecting food security and economics. Surveys and load tracking revealed postharvest losses of 39–43%, concentrated at retail (12.5%), wholesaler storage/marketing (11.2%), and harvesting (8.9%) (Table 5). These findings aligned with prior Ethiopian studies [23, 30]. Critical loss points showed early mechanical damage and temperature defects leading to bruising, infection, and accelerated ripening. Losses were concentrated

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at the harvest, wholesaler storage, and retail stages. Reducing them required standardized Postharvest Loss (PHL) measurement, safe harvest tools, pre-cooling, ventilation, hygienic handling, sorting, and improved logistics with crate-based loads and data systems to track volumes, losses, and accountability across actors.

Causes of avocado loss along the chain

Evidence from surveys and field observations showed that losses began at orchard level due to poor practices producing undersized, deformed, or pest-damaged fruit. Harvest and postharvest losses were worsened by immature picking, rough handling, inadequate containers, bulk stacking, and lack of pre-cooling or cold chain. Transport and aggregation added mechanical injuries from sack use, poor facilities, and heat buildup during long-distance travel. At wholesale and retail, rough handling, poor packaging, and inadequate ventilation persists at storage. Losses were highest for seedling-based orchards in Jimma, Kaffa, Wolaita, and Sidama, with fragile, unevenly ripening fruit. Logistics challenges, weak infrastructure, and institutional issues such as weight-based payments and destructive inspections discouraged investment in quality-preserving practices, aligning with similar Ethiopian studies [31, 32].

Impacts of avocado postharvest loss

Postharvest Loss wastes embedded labor, land, water, fertilizers, and energy and imposes disposal burdens. When unsold or unused fruit is discarded, it also generates environmental burdens such as collection, transport, and landfill [33, 34]. In this study, with losses on the order of 41%, the foregone economic, nutrition, and environmental benefits were substantial.

Monetary impact and household welfare

Using Central Statistics Agency (CSA) 2020/21 smallholder output (259.9 million kg from 30,588 ha) and load-tracking losses (18.7% qualitative; 24.5% quantitative), the national losses are estimated at 5.13 billion ETB. Comparable high losses were documented in Tanzania [35]. Qualitative loss is valued at the price gap between sound and low-quality fruit (40 ETB/kg) and quantitative loss at the retail value of sound fruit (50 ETB/kg). These losses fall mainly on smallholders which 94% of growers are “lower income” (≤ $1,135) [36]. Without handling improvements, the burden will rise with area/yield expansion and longer market distances. The evidence implies that lowering PHL can have immediate poverty-reducing effects, as farmers benefit from greater realized sales and improved price premiums (Table 6).

Nutrition and food security

Based on this survey measured quantitative losses and a conservative pulp yield of 55% (reflecting larger seeds in local types), Ethiopia loses about 35.03 million kg of

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avocado pulp annually. At 1,600 kcal/kg of avocado, the loss corresponds to 56.1 billion kcal, which is sufficient to meet the annual energy requirements of 61,431 adults consuming 2,500 kcal per day. Micronutrients lost are also substantial: the lost pulp could supply the annual folate requirements of 194,371 adults, potassium for 133,009 adults, and magnesium for 66,276 adults [37, 38]. As an opportunity-cost benchmark, ETB 5.13 billion could purchase 73,282 t of wheat at prevailing Addis Ababa prices, yielding 249.16 billion kcal- or 99.7 million adult days of dietary energy (halved losses would still equal 136,526 adult-years) (Table 7).

Land use and environmental burden

The measured 63,699.5 t of quantitative losses corresponded to 7,494 ha of farmland that produced fruit which never reached consumers (at 8,500 kg/ha). Disposing of this volume required 9,800 medium dump-truck loads (6.5 t each). With a lifecycle footprint of 2.5 kg CO_2e per kg of avocados (World Economic Magazine), these losses represented 159,249 t CO_2e greenhouse gas emissions (Table 8), embedded in production and transport that delivered no food, income, or nutrition, consistent with FAO's carbon/land/water footprint framing [39].

Strengths, limitations, and measurement pathway

A dual-method design surveys for breadth/perceptions and load tracking for objective, stage-specific estimates offer a practical framework for annual monitoring. A sentinel-corridor design (for example Bonga, Boditi) can track progress against CLPs over time. Two caveats remain: (i) some national extrapolations rely on assumptions (for example 55% pulp yield, nutrient conversions) that should be standardized in a national PHL metrics protocol; and (ii) loss magnitudes vary by season, road conditions, and market dynamics, expanding load tracking across belts and seasons will sharpen estimates and targeting.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

Ethiopia's avocado postharvest losses are substantial but solvable: about four in ten fruits lose value between orchard and retail, mainly at harvest, wholesaler storage/marketing, and retail. Losses are driven by three critical causes: early injury and temperature abuse at harvest, wholesale storage that amplifies deterioration through stacking and poor ventilation, and retail practices where weak ripeness management, display, and stock rotation crystallize systemic weaknesses. Postharvest losses are concentrated at a few critical nodes: retail markets, wholesale storage and marketing, and harvesting stages. Reducing losses by just 25% at these points could recover ≈ ETB 1.28 billion annually, avert 40,000 t CO_2e, and free 1,875 ha of land-equivalent output benefits that would disproportionately support the 94% of growers who are low-income.

Priority interventions should be implemented through clearly assigned stakeholder responsibilities across the avocado value chain. Farmers and producer organizations should apply maturity indexing, harvest with safe tools, clip peduncles correctly, keep fruit shaded and off the ground, reduce dropping and rough handling, progressively adopt grafted shorter trees, and undertake basic field sorting and crate use. Government institutions (MoA/regional bureaus, standards bodies, and research–extension) should standardize and enforce maturity, grading, packaging, hygiene and transport Standard Operating Procedures(SOPs); expand training through Farmers Training Centers (FTCs); regulate and promote certified nurseries for quality planting material; facilitate quality-linked contracting and compliance mechanisms; and invest in enabling infrastructure such as feeder roads, market sheds, power, and cold-chain hubs while creating incentives and financing mechanisms for packhouses and logistics. Private sector actors (nurseries, aggregators, wholesalers, logistics providers, exporters and retailers) should replace sacks with rigid crates, palletize and ventilate loads, implement pre-cooling where feasible, strengthen grading, improve airflow and hygienic handling surfaces, upgrade storage and retail display practices (First-In, First-Out , FIFO rotation, limited stacking, rapid removal of damaged fruit), and co-invest in packhouses for sorting, cleaning and pre-cooling supported by crate pooling/return systems and quality-based pricing. Non-Governmental Organizations (NGO)s and development partners should catalyze adoption through training and demonstrations, support producer organization capacity and inclusive business models, co-finance pilots for low-cost handling and cold-chain solutions, and convene stakeholders to strengthen governance and scale proven practices to reduce losses and improve marketable quality.

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AUTHORS' CONTRIBUTIONS

Getachew Minas contributed to the study's tool preparation, conducted data analysis, and participated in report drafting. Dr. Fentahun Mengistu and Dr. Ermias Abate played key roles in drafting the report, editing content, and preparing the final manuscript. Dr. Edossa Itisa was involved in shaping the study design, overseeing data collection, and contributed report drafting. Aberash Tsehay and Oumer Taha were responsible for collecting nutrition-specific data. Binyam Tesfaye supported the study by developing and producing the geographic map of the study area.

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CONSENT FOR PUBLICATION

All individuals who provided information for the study gave their informed consent.

COMPETING INTERESTS

The authors declare that they have no financial or non-financial competing interests related to the content of this article.

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Table 1: Local and grafted avocado varieties under production by the smallholder farmers

Region	Zone	Type of varieties (%)							
		Local	Hass (A)	Fuerte (A)	Bacon (B)	Ettinger (B)	Pinkerton (A)	Nabal (B)	Others
Oromia	East Shewa	14.9	80.9	14.9	6.4	72.3	6.4	4.3	17.0
	Jimma	54.9	14.6	1.2	0.0	7.3	0.0	0.0	40.2
	Average	34.9	47.7	8.1	3.2	39.8	3.2	2.1	28.6
Amhara	N. Gojjam	0.0	100.0	0.0	0.0	98.0	0.0	2.0	0.0
Sidama	C. Sidama	39.5	94.7	73.7	57.9	97.4	39.5	47.4	0.0
	N. Sidama	22.9	80.0	22.9	11.4	82.9	8.6	45.7	8.6
	Average	31.2	87.4	48.3	34.7	90.1	24.0	46.5	4.3
SW. Ethiopia	Kaffa	50.0	11.9	0.0	0.0	9.5	0.0	0.0	47.6
C. Ethiopia	Silte	33.3	71.8	0.0	0.0	66.7	0.0	2.6	20.5
South Ethiopia	Wolaita	47.5	54.2	0.0	0.0	50.8	1.7	0.0	25.4
Average		35.0	58.3	11.3	7.4	54.7	5.6	9.7	22.3

Source: Computed from Survey Data, 2024

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Table 2: Harvesting time of avocado fruits by smallholder growers

Region	Zone	Harvesting time (%)			
		Morning	Evening	Noon	Any time
Oromia	East Shewa	91.5	48.9	29.8	2.1
	Jimma	97.6	2.4	19.5	2.4
	Average	94.5	25.7	24.6	2.3
Amhara	North Gojjam	100.0	57.1	2.0	0.0
Sidama	Central Sidama	97.4	21.1	23.7	0.0
	N. Sidama	91.4	42.9	34.3	0.0
	Average	94.4	32.0	29.0	0.0
SW Ethiopia	Kaffa	54.8	16.7	9.5	57.1
C. Ethiopia	Silte Zone	92.3	35.9	25.6	2.6
South Ethiopia	Wolaita	71.2	0.0	71.2	5.1
Average		**87.5**	**24.8**	**27.6**	**7.9**

Source: Computed from Survey Data, 2024

Table 3: Determinants of avocado postharvest loss with a 25-percentile quantile regression

Parameter	Coefficient	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
(Intercept)	1.166	2.9343	0.398	0.691	-4.607	6.940
Age of respondents	-0.004	0.0300	-0.138	0.890	-0.063	0.055
Sex of the respondent	1.202	0.9192	1.308	0.192	-0.606	3.011
Level of education*	-0.458	0.2759	-1.661	0.098	-1.001	0.085
Years of experience*	-0.793	0.4412	-1.798	0.073	-1.662	0.075
Training received	0.181	0.7315	0.247	0.805	-1.259	1.620
Variety local	0.939 ***	0.2085	4.504	0.000	0.529	1.349
Avocado pest infestations	1.060***	0.3311	3.200	0.002	0.408	1.711

Grafted trees	-2.593**	1.0911	-2.377	0.018	-4.740	-0.446
Length of maturity	2.533***	0.5747	4.406	0.000	1.402	3.663
A person involved in harvesting						
Husband	-1.030	0.8041	-1.280	0.201	-2.612	0.552
Wife	3.673***	0.8941	4.108	0.000	1.914	5.433
Children	-1.229	0.7710	-1.594	0.112	-2.746	0.288
Hired labor	1.168	0.7552	1.547	0.123	-0.318	2.654
Time of harvesting						
Morning	0.116	1.0823	0.107	0.915	-2.013	2.246
Evening	1.323	0.9024	1.466	0.144	-0.452	3.099
Noon	0.034	0.8951	0.038	0.969	-1.727	1.795
Any time of the day	2.865**	1.4039	2.040	0.042	0.102	5.627
Method of harvesting						
Using harvesting bag	0.703	1.1731	0.599	0.549	-1.605	3.011
Dropping Fruits	0.563	1.1152	0.505	0.614	-1.631	2.757
Using harvesting poles	1.405	0.8850	1.587	0.113	-0.337	3.146
Shaking trees	2.918	2.8992	1.006	0.315	-2.787	8.622
Hitting fruits with sticks	0.682	1.0537	0.647	0.518	-1.392	2.755
Length of the stalk in cm	0.081	0.3455	0.235	0.814	-0.599	0.761
Harvesting fruit in contact with the ground	4.630***	0.7693	6.019	0.000	3.117	6.144

****Significant at 1% level of significance, ** Significant effect at 5% level of significance*

**Significant effect at 10% level of significance*

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Table 4: Summary of estimated avocado postharvest loss and causes along the supply chain

No	Supply chain stage	Causes	Percent loss (%)	
			Quantity loss	Quality loss
1	Harvesting, temporary storage at farmers home (SC1)	Fruits fall on the ground, damage, maturity problem, timing of harvest not optimal, harvesting immature fruits, stacking together, use of sacks, removal of fruits stalk, over maturity, deformation and other reasons	5.00	2.60
		Storage loss/ stacking together, animal damage after harvest in the producers' home	2.00	1.81
		Transportation to the local markets Bruising, loading and unloading on animal backs, damage created during unloading, throw away from animal backs, motor bike, carts, other transportation	1.00	2.15
		Loss encountered by the farmers at market place during selling	2.4	
2	Loading, transportation and unloading to central and distance markets (SC 2)	Product disregarded /out-grades in supply chain, damage during loading, stacking, transportation, unloading, high temperatures created in the bulk, some ripened and over ripened fruits damage	4.5	
3	Storage of avocado fruits at the wholesaler when the retailers purchase fruits from the wholesalers (SC 3)	Stacking together, use of sacks, removal of fruits stalk, high temperatures in the bulk fasten ripening, some ripened and over ripened fruits damage others	2.8	4.62
5	Transportation to retail market and retailing, retailers-display, marketing, selling, distribution	Inappropriate packaging damages produces; damage during transport; spoilage over ripened fruits; poor handling; losses caused by poor storage, poor storage/ stock management	5.50	4.50
	Total		**23.2**	**15.7**
	Grand total		**38.9**	

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Source: Computed from survey data collection

Table 5: Summary of avocado fruit critical loss points along the supply chain

SC	Boditi	PH loss (%)		Total loss (%)
		Qualitative loss	Quantitative loss	
1	Harvesting (SC 1)	4.6	4.3	8.9
2	Transportation to aggregation place (SC 2)	5.6	5.1	10.7
3	Loading-transportation-offloading to central market (SC3)	1.3	2.9	4.2
4	Wholesale market storage (SC4)	4.3	10.9	15.3
5	Transportation to retailers' market and at time of retailing (SC5)	4.3	3.5	7.8
Sub-Total		**20.1**	**26.7**	**46.8**
Bonga				
1	Harvesting (SC 1)	5.6	3.2	8.8
2	Transportation to aggregation place (SC 2)	4.0	1.0	5.0
3	Loading-transportation-offloading to central market (SC3)	0.0	1.7	1.7
4	Wholesale market storage (SC4)	1.7	5.3	7.0
5	Transportation to retailer markets and at time of retailing (SC5)	6.0	11.2	17.2
Sub-Total		**17.3**	**22.4**	**39.7**
Cumulative Average		**18.7**	**24.5**	**43.2**

Source: Computed from load tracking data collection

Table 6: Estimated annual loss of avocado fruits in Ethiopia in monetary terms

Description	Amount
Area of production (CSA, 2020/2021)	30,587.74 ha
Productivity (yield, kg/ha), (CSA, 2020/2021)	8,500 kg/ha
Total production during 2020/2021 year	259,998,000 kg
Qualitative loss	18.70%
Quantitative loss	24.50%
Average value of low-quality fruit at Addis Ababa retail price	10 birr/kg
Amount of qualitative loss (kg)	18.7% X 259,998,000 = 48619626
Amount of quantitative loss (kg)	24.5% X 259,998,000 = 63,699,510
Average value of quality avocado fruit at Addis Ababa retail price	50 birr/kg
Value difference of low-quality fruit	40 birr/kg
Value of qualitative loss (Birr)	40 X 48619626 = 1,944,785,040
Value of quantitative loss (Birr)	50 X 63,699,510 = 3,184,975,500
Value of total loss	1,798,146,168 + 2,913,277,590 =5129760540
Estimated total loss during the 2020/2021 production year in monetary terms	5,129,760,540 Birr

Source: Computed from study result

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Table 7: Food security implications of the avocado postharvest losses

Description	Unit	Quantity
Economic loss of Avocado	ETB	5,129,760,540
Price of Wheat/kg	ETB	70
Volume of wheat that could be purchased with the lost money	Kg	73,282,293
Energy content of wheat/kg	Kcal	3,400
total lost energy	Kcal	249,159,797,657
Energy requirement of adult person/day	Kcal	2,500
Number of adults that could be fed/day	Person	99,663,919
Number of adults that could be fed/year	Person	273,052
Number of adults that could be food secured/year, if we reduce the loss by 50%,	Person	136,526

Source: Computed from study result

Table 8: Estimated Greenhouse gas emissions from disposal of avocado wastes

Types of environment impact (a)	Estimated quantitative loss (kg) (b)	Municipal Solid waste contribution (tons) c=(b/1000)	Amount of Greenhouse Gas emission/kg (d)	Total Greenhouse Gas emission (e)= c*d	Volume of land fill dump track (f)	Number of land fill dump tracks required for disposal of waste(g) = b/f
Solid waste contribution	63,699,510	63,669.5 tons			6.5 ton	63699.5/6.5 ton = 9800 dump trucks
Greenhouse gases emission	63,699,510	63,699.5 tons	2.5 kg CO_2 e	159248.8 tons of CO2 e		

Source: Computed from study result

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