Circular
Agricultural Systems

REVIEW

Open Access

https://doi.org/10.48130/cas-0026-0012
Circular Agricultural Systems **2026**, 6: e013

Policy, governance, and regulatory frameworks for sustainable postharvest management in Ethiopia: pathways to food security and reduced losses

Asfaw Shaka Gosa*

Horticulture Department, Ambo University, P.O. Box 19, Ambo, Ethiopia
* Correspondence: rehobot2015@gmail.com (Gosa AS)

Abstract

Postharvest losses are a major barrier to food security in Ethiopia, where smallholder farmers produce over 90% of crops. This study critically reviews and synthesizes evidence on policy, governance, and regulatory frameworks for sustainable postharvest management in Ethiopia, identifying challenges and opportunities to reduce losses and enhance food security. A systematic literature review (SLR) was employed, integrating qualitative and quantitative analyses. Data were collected from peer-reviewed journals, government reports, policy documents, and institutional studies. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework guided the review process, with thematic analysis applied to qualitative findings and descriptive synthesis used for quantitative data, including estimates of postharvest losses. Findings revealed that Ethiopia experiences postharvest losses of 15%–50% depending on crop type, driven by financial constraints, technical knowledge gaps, weak institutional coordination, limited regulatory enforcement, infrastructure deficits, socio-economic disparities, and climate-related vulnerabilities. Policies and programs such as the National Postharvest Management Strategy, Agricultural Growth Program, and Food Safety Proclamation provide important frameworks but remain fragmented, under-enforced, and insufficiently integrated into national food security strategies. Opportunities include expanding public-private partnerships, promoting innovative financing mechanisms, and enhancing regulatory and institutional capacities. In conclusion, reducing postharvest losses in Ethiopia requires coherent policy integration, improved governance, capacity building, stronger regulatory enforcement, and climate-smart, technology-driven interventions. Recommended actions include strengthening inter-ministerial coordination, improving access to finance and storage technologies, fostering stakeholder engagement, and establishing robust monitoring and evaluation systems to support adaptive management and advance national food security and Sustainable Development Goals.

Citation: Gosa AS. 2026. Policy, governance, and regulatory frameworks for sustainable postharvest management in Ethiopia: pathways to food security and reduced losses. *Circular Agricultural Systems* 6: e013 https://doi.org/10.48130/cas-0026-0012

Introduction

Postharvest management is a critical yet often overlooked component of food security in Ethiopia. Agriculture accounts for more than 30% of Ethiopia's GDP, employs over 65% of the labor force, and serves as the backbone of rural livelihoods[1,2]. However, the country continues to experience high levels of food insecurity, with recurrent droughts, population pressure, and limited infrastructure intensifying the challenge[3]. A significant contributor to this food insecurity is postharvest loss, which affects staple cereals, pulses, fruits, and vegetables. Estimates suggest that Ethiopia loses 15%–25% of grains and up to 40%–50% of perishable crops along the supply chain due to poor storage, inadequate handling, and limited processing facilities[4–6]. Recent studies indicate that postharvest losses are influenced not only by technical inefficiencies but also by socio-economic, institutional, and market factors, including gender disparities, rural financial constraints, and weak extension services[7,8].

While postharvest losses have direct implications on food availability, nutrition, and farmer incomes, they also represent a policy and governance challenge. Over the past two decades, Ethiopia has introduced various interventions, including the Agricultural Growth Program (AGP), the Grain Reserve Agency's initiatives, and postharvest loss reduction programs under the Ethiopian Agricultural Transformation Agency (ATA). Despite these efforts, evidence suggests that the adoption of improved storage technologies such as hermetic bags, metal silos, and cold chains remains low, particularly among smallholder farmers in remote regions[9,10]. Furthermore, comparative experiences from other developing countries, such as Kenya, Uganda, and India, reveal similar systemic challenges—fragmented policy, inadequate infrastructure, and weak market linkages—which underscore the universality of the problem[11,12].

Despite these insights, postharvest management in Ethiopia has remained fragmented, with weak inter-ministerial coordination, limited regulatory enforcement, and poor integration into national food security strategies[8,13]. Research also highlights that the lack of harmonized data and systematic monitoring of losses hinders the formulation of evidence-based policies, limiting the effectiveness of national strategies[7,14].

Given Ethiopia's commitment to achieving the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production), strengthening policy, governance, and regulatory frameworks is essential[15]. A comprehensive understanding of existing gaps, lessons from past interventions, global experiences in similar contexts, and opportunities for policy innovation will provide pathways to reducing food losses, improving resilience, and ensuring food security[16–18].

Problem statement

Despite the centrality of agriculture to Ethiopia's economy and rural livelihoods, postharvest losses remain a major bottleneck to achieving food and nutrition security. Agriculture accounts for a

significant share of the GDP and employs the majority of the population, yet millions of tons of food are lost annually due to inefficiencies along the supply chain[4,19]. Although various policies and programs—such as the Agricultural Growth Program (AGP), initiatives by the Ethiopian Agricultural Transformation Agency (ATA), and grain storage programs—have been introduced, they remain underfunded and inconsistently implemented across regions, with limited evidence of tangible reduction in losses at farm or market levels[8,13].

National agricultural and food security strategies largely emphasize production expansion, while postharvest management receives secondary attention. Consequently, systemic interventions such as improved storage, cold chain infrastructure, and market regulation are inadequately supported[4,8]. Furthermore, postharvest losses are highly heterogeneous across regions. For example, maize losses in Oromia and SNNPR often exceed 25%, whereas losses in Tigray are slightly lower (~18%) due to more structured cooperative storage practices; similarly, tomato and onion losses in Amhara and Oromia reach 40%–50% due to weak cold-chain adoption[7,20]. These regional disparities underscore the need for localized interventions.

Smallholder farmers, who constitute over 90% of production, face limited access to modern storage facilities, affordable packaging, and market linkages, while women—central to postharvest handling—are often excluded from decision-making processes[16,21]. Climate variability, including rising temperatures, erratic rainfall, and pest infestations such as Fall Armyworm, further aggravates losses and underscores the lack of climate-resilient postharvest strategies[22,23].

In light of these challenges, this study aims to critically review and analyze the policy, governance, and regulatory frameworks influencing postharvest management in Ethiopia. The overarching goal is to identify challenges, lessons, and opportunities for reducing food losses and enhancing food security. Specifically, the study seeks to assess the effectiveness of national policies, strategies, and programs, examine governance structures and institutional arrangements, and analyze regulatory frameworks and enforcement mechanisms that ensure food safety, quality, and market competitiveness. Additionally, it identifies technical, financial, institutional, and socioeconomic constraints that hinder sustainable postharvest management, documents lessons from successful initiatives, and explores opportunities for innovation, policy reform, and multi-stakeholder collaboration. Regional variations and local capacity are explicitly considered to ensure recommendations are context-sensitive and actionable. Ultimately, the study provides actionable recommendations for policymakers, development partners, and stakeholders to reduce postharvest losses, improve nutrition, strengthen rural livelihoods, and advance Ethiopia's Sustainable Development Goals.

Methodology

Review approach

This study employed a systematic literature review (SLR) approach to synthesize existing evidence on policy, governance, and regulatory frameworks for sustainable postharvest management in Ethiopia. The review integrated both qualitative and quantitative analyses to provide a comprehensive understanding of challenges, lessons, and opportunities in reducing postharvest losses and enhancing food security. Systematic reviews are widely recognized for their rigor in collecting, appraising, and synthesizing research findings to provide reliable conclusions[24,25]. The methodology followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure transparency, replicability, and methodological rigor[26].

Data sources and search strategy

A comprehensive search was conducted across multiple academic and institutional databases, including Scopus, Web of Science, PubMed, Google Scholar, and ScienceDirect, to capture peer-reviewed journal articles, policy reports, government documents, and institutional studies published between 2000 and 2025. To supplement these sources, additional grey literature was obtained from the Food and Agriculture Organization (FAO), the Ethiopian Agricultural Transformation Agency (ATA), the World Bank, the Ministry of Agriculture (MoA), and the Sustainable Development Solutions Network (SDSN).

The search strategy employed a combination of keywords and Boolean operators to ensure a wide scope of relevant literature. Key terms included: 'Sustainable Postharvest Management' OR 'Postharvest Losses,' 'Policy' OR 'Governance' OR 'Regulatory Framework', 'Ethiopia,' and 'Food Security' OR 'Nutrition'. This systematic approach ensured the inclusion of diverse sources that provide insights into the policy, governance, and regulatory frameworks shaping sustainable postharvest management in Ethiopia.

Inclusion and exclusion criteria

Studies were included if they focused on postharvest management policies, governance, or regulatory frameworks in Ethiopia; reported empirical evidence, quantitative estimates, or qualitative assessments of postharvest losses; were published in English between 2000 and 2025; and were peer-reviewed articles, government or institutional reports, or policy documents. Conversely, studies were excluded if they focused solely on other countries without comparative relevance to Ethiopia, were purely opinion pieces lacking empirical data, or did not address postharvest management or regulatory frameworks.

Screening and selection process

The initial search yielded 1,458 records. After removing duplicates (n = 318), 1,140 records remained for title and abstract screening. Following an independent review by two researchers, 502 articles were selected for full-text assessment. Of these, 178 studies met all inclusion criteria and were retained for qualitative and quantitative synthesis. The screening process adhered to PRISMA guidelines, and a PRISMA flow diagram was developed to illustrate the selection process.

Data extraction and analysis

For each included study, data were extracted on publication details (author, year, and institution), type of study (empirical, case study, review, and policy analysis), quantitative estimates of postharvest losses, policy frameworks, institutional arrangements, and regulatory mechanisms, as well as identified challenges, lessons, and opportunities.

Qualitative data were analyzed thematically, grouping findings into categories such as governance, policy coherence, regulatory enforcement, institutional capacity, and stakeholder collaboration[27]. Quantitative data, including estimates of postharvest losses and program impacts, were analyzed descriptively and synthesized into tables and figures to enable comparative analysis across crop types, regions, and policy interventions.

Reliability and validity

Two reviewers independently conducted screening, data extraction, and coding. Discrepancies were resolved through discussion, and inter-rater reliability was assessed using Kappa[28] ($\kappa = 0.83$), indicating substantial agreement. Triangulation of qualitative insights with quantitative data from national surveys, FAO reports, and peer-reviewed studies enhanced the validity of the findings.

Results and discussion

Postharvest losses in Ethiopia: an overview

Postharvest losses represent a critical constraint to food security in Ethiopia, undermining both rural livelihoods and national development goals. Agriculture accounts for over 30% of Ethiopia's GDP and employs more than 65% of the population[1]. Despite increased production efforts, losses along the supply chain significantly reduce the availability of food for consumption and market sale. Quantitative assessments indicate that losses vary across crop types and production systems, with cereals, pulses, tubers, and horticultural crops all affected[4,5].

The quantitative data (Table 1) highlight that postharvest losses in Ethiopia are both substantial and crop-specific, with a clear distinction between cereals, legumes, tubers, and perishable horticultural crops. Among cereals, maize experiences losses of 18%–25%, largely due to insect infestation, mold, and inadequate storage conditions[8]. Wheat and teff, two key staples, also incur losses ranging from 15%–20%, driven by moisture accumulation, pest infestations, and improper grain handling[4]. Sorghum, often stored in traditional granaries, shows even higher losses (22%–28%) due to pest activity and outdated storage methods[2]. These figures reflect systemic weaknesses in storage infrastructure, pest control, and postharvest management practices for cereals, which are critical for food security and market supply stability.

For legumes, such as chickpeas and lentils, losses are slightly lower but still significant, ranging from 15%–25%, primarily caused by inadequate storage, limited market access, and moisture-related deterioration[29]. These losses reduce both the availability of protein-rich foods and income opportunities for smallholder farmers, highlighting the need for targeted interventions in storage and market linkages.

Tubers and perishable horticultural crops face the highest losses. Potatoes lose 30%–35% postharvest due to poor storage and transport delays, while onions lose 25%–30% primarily from storage deterioration[5]. Tomatoes and general fruits suffer the most extreme losses, 40%–45% and 40%–50% respectively, largely because of a lack of cold chain infrastructure, inefficient transport, and spoilage during handling[4,30]. These high losses in perishable crops underscore the critical role of temperature-controlled storage, rapid market access, and improved handling practices to maintain both quality and food availability.

Table 1. Quantitative estimates of postharvest losses in Ethiopia by crop type.

Crop type	Estimated postharvest loss (%)	Primary causes
Maize	18–25	Insect infestation, mold, poor storage
Wheat	15–20	Moisture, pest infestation, storage conditions
Teff	15–20	Storage loss, grain handling
Sorghum	22–28	Traditional storage, pests
Chickpeas	15–20	Storage, market access
Lentils	20–25	Inadequate storage, moisture
Potato	30–35	Poor storage, delayed transport
Onion	25–30	Storage loss, spoilage
Tomato	40–45	Lack of cold chain, transport delays
Fruits (general)	40–50	Spoilage, poor handling

Source: synthesized from peer-reviewed secondary sources.

Regional variation in postharvest losses in Ethiopia is pronounced. Studies show that cereal losses are higher in the Oromia and Amhara regions (up to 28% for sorghum and maize) due to traditional storage methods, limited access to hermetic storage bags, and irregular extension support[7,31]. In contrast, losses in the Southern Nations, Nationalities, and Peoples' Region (SNNPR) for similar cereals are somewhat lower, averaging 18%–22%, due to slightly better adoption of improved storage facilities and more active extension services[20]. Horticultural crops display even more marked regional differences: losses of tomatoes and fruits in central and northern Ethiopia (Amhara, Oromia) reach 45%–50%, whereas in southern regions such as the Oromia zone around Addis Ababa and SNNPR, losses average 35%–40% owing to better access to urban markets and pilot cold chain facilities[30,32].

These regional differences are influenced by multiple factors, including climatic variability, access to postharvest technologies, infrastructure quality, market proximity, and institutional support. For instance, areas with poor road networks and limited electricity have higher losses due to delayed transport and lack of refrigeration[8,33]. Similarly, the presence of agricultural cooperatives and strong local extension networks significantly reduces losses by promoting the adoption of improved storage techniques and timely market sales[7,29].

These quantitative and regional patterns highlight that postharvest losses in Ethiopia are substantial, affect both food availability and economic returns for smallholder farmers, and are unevenly distributed across the country. Addressing these losses requires investment in modern storage facilities, cold chain development, and effective regulatory frameworks, training for farmers and handlers, and climate-resilient postharvest strategies. Reducing losses not only improves national food security but also enhances household incomes and contributes to achieving Sustainable Development Goals, particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production)[34].

Policy frameworks for postharvest management in Ethiopia

Ethiopia's agricultural sector continues to face substantial postharvest losses, which compromise food security, reduce farmers' incomes, and undermine economic stability[31,33]. To address these challenges, the government has developed and implemented a variety of policies, programs, and legal frameworks aimed at reducing losses, improving food safety, and promoting sustainable agricultural practices[1,4]. Table 2 provides a summary of the key policies, their lead institutions, objectives, roles, and measured implementation outcomes.

Overview of key policies and programs

Several national initiatives attempt to address postharvest challenges (Table 2). The National Postharvest Management Strategy (PHMSE, 2024–2030) represents the most recent and comprehensive effort, targeting loss reduction across key commodities. It emphasizes improved storage, market access, and extension services, aligning with international best practices[4,13]. While the strategy's integrated approach is promising, its implementation may be constrained by overlapping mandates among agricultural

Table 2. Policy frameworks for postharvest management in Ethiopia.

Policy/program	Year	Lead institution	Aim	Roles, contributions and implementation outcomes
National Postharvest Management Strategy (PHMSE)	2024–2030	Ministry of Agriculture	Reduce postharvest losses across key commodities	Provides a comprehensive framework for postharvest loss reduction; emphasizes improved storage facilities, market access, and extension services. Pilot interventions show reductions in maize losses from 22% → 15% in Oromia, and tomato spoilage from 45% → 30% in Amhara during 2024–25. Strategy is in early scaling-up, with regional variations in adoption.
Agricultural Growth Program (AGP)	2010–2020	Ministry of Agriculture	Increase agricultural productivity and commercialization	Supports infrastructure development, capacity building, and market linkages. Postharvest outcomes limited: only 20%–25% of targeted households benefited from storage improvements; losses in grains and vegetables remained high in several regions, indicating production-centric prioritization.
National Nutrition Program (NNP)	2016–2025	Ministry of Health (multi-sectoral)	Improve nutrition and food security	Recognizes the importance of reducing postharvest losses; integrates postharvest considerations into nutrition strategies. Empirical assessments show modest spoilage reduction in pilot districts; challenges persist due to weak inter-ministerial coordination and limited capacity at local levels.
Food Safety and Quality Proclamation No. 661/2009 (amended 2019)	2009 / 2019	Ethiopian Food and Drug Authority (EFDA)	Set standards for food safety, storage, and transport	Establishes regulations for postharvest handling, storage, and transportation. Implementation is uneven: market inspections remain low, especially in informal settings; losses for fruits and vegetables in Toke Kutaye District remain high.
Integrated Agro-Industrial Parks (IAIPs)	Ongoing	Ministry of Industry/ATA coordination	Promote agro-processing and value addition	Develops infrastructure for agro-processing; creates markets for surplus produce, reducing postharvest losses. Pilot parks show improved aggregation and reduced spoilage, though smallholder inclusion remains limited.
Climate-Resilient Green Economy (CRGE) Strategy	2011	Ministry of Environment, Forest & Climate Change	Enhance resilience of the agricultural sector	Implements measures to improve infrastructure; improves agricultural practices to indirectly support postharvest management. Early-stage benefits observed in climate-smart storage adoption; scaling inconsistent across regions.

Source: synthesized from peer-reviewed secondary sources.

institutions and limited coordination mechanisms, risking fragmented execution at regional and local levels[19]. Importantly, this strategy was officially launched in 2024/25, and emerging empirical data show reductions in maize losses from 22% → 15% in Oromia and tomato spoilage from 45% → 30% in Amhara during pilot implementations[19,35].

Earlier initiatives, such as the Agricultural Growth Program (AGP, 2010–2020), aimed to enhance overall agricultural productivity and commercialization, incorporating postharvest interventions through infrastructure development and capacity-building components[1,8]. Despite improvements in storage and transport infrastructure, AGP's postharvest focus remained secondary to production objectives — a pattern demonstrating systemic under-prioritization of postharvest management in Ethiopia (Table 2)[8].

The National Nutrition Program (NNP, 2016–2025) integrates postharvest considerations within nutrition strategies, emphasizing the link between food losses and nutritional outcomes[21,36]. While multisectoral coordination is encouraged, limited inter-ministerial collaboration and weak institutional communication hinder the program's effectiveness in reducing postharvest losses (Table 2)[37].

Legal frameworks, such as the Food Safety and Quality Proclamation No. 661/2009, establish standards for postharvest handling, storage, and transportation[1,38]. Enforcement remains inconsistent, particularly at local and informal markets, reflecting broader challenges including insufficient resources, overlapping mandates, and unclear accountability (Table 2)[39].

Emerging initiatives, such as Integrated Agro-Industrial Parks (IAIPs) and the Climate-Resilient Green Economy (CRGE) Strategy, illustrate potential avenues for enhancing postharvest management. IAIPs provide agro-processing infrastructure, creating markets for surplus produce and directly reducing losses[13]. The CRGE strategy addresses climate-related risks, indirectly supporting postharvest outcomes by promoting resilience[40]. Their success depends on coherent policy alignment, coordinated institutional action, and adequate investment in climate-resilient infrastructure, areas where Ethiopian postharvest governance has historically been weak (Table 2)[41].

Moreover, recent developments related to global and domestic shocks—including the COVID-19 pandemic, supply-chain disruptions, and conflict-related logistic constraints—have placed additional strain on Ethiopia's postharvest systems, reinforcing the need for agile policy frameworks. For example, a 2025 multilevel analysis found significant regional variation in food insecurity during COVID-19 linked to supply chain disruptions[33]. Similarly, the FAO and Ethiopian Ministry of Agriculture reported in June 2024 that nationwide scaling up of postharvest handling technologies, including metal silos and hermetic bags, was underway to mitigate these risks[19].

Systemic challenges in policy implementation

Analysis of Table 2 highlights persistent systemic weaknesses in Ethiopia's postharvest policy landscape[19,31]. Institutional fragmentation is a key challenge. Multiple ministries—including agriculture, health, industry, and environment—manage overlapping aspects of postharvest management, creating unclear roles and diluting accountability[41]. This fragmentation often leads to duplication of functions, gaps in implementation, and inconsistent support to producers and value-chain actors[19].

Weak enforcement of regulations is another major challenge. Legal frameworks such as the Food Safety and Quality Proclamation No. 661/2009 exist but are inconsistently applied, especially at the regional and local levels[7]. Inadequate monitoring, limited technical capacity, and insufficient resources compromise compliance, leading to persistent postharvest losses. For instance, fruit and vegetable losses remain high due to improper handling and storage practices, particularly among women- and men-managed farms in Toke Kutaye District[23,42,43].

Underinvestment in infrastructure further constrains policy effectiveness. While national strategies highlight storage, processing, and market access, financial and technological resources for

climate-resilient facilities remain insufficient[31,7]. Traditional storage methods continue to dominate, and modern solutions such as hermetic bags or cold chains are not widely accessible[44]. Per recent data, teff losses in 2022 were estimated at 12.6%[45]. These gaps disproportionately affect perishable and high-value commodities, limiting long-term improvement in postharvest management.

Limited cross-sectoral coordination also weakens the impact of postharvest initiatives. Although policy documents recognize multi-sectoral approaches involving agriculture, nutrition, industry, and environment, in practice, coordination remains weak[37,19]. Siloed institutional structures reduce policy coherence and hinder the effectiveness of integrated programs such as IAIPs and climate-resilient strategies. Recent empirical studies, including Fekadu & Andarege[46] confirmed that over half of fruit and vegetable retailers in Addis Ababa experienced moderate food insecurity due to postharvest losses, highlighting the urgency of implementing PHMSE effectively.

Addressing these systemic challenges requires integrated policy execution with clear roles and accountability across ministries; strengthened regulatory enforcement at regional and local levels; and targeted investment in climate-resilient storage, processing, and distribution infrastructure[7,19,31]. Active cross-sectoral collaboration is essential to link postharvest loss reduction with nutrition, industrial development, and climate resilience[37].

Governance and institutional arrangements

The governance architecture for postharvest loss (PHL) management in Ethiopia is multi-layered, involving federal agencies (MoA, EIAR, EFDA, ESA), regional bureaus, cooperatives, farmers' organizations, and private-sector actors. Ethiopia's PHMSE (2024–2030) envisions a multi-stakeholder approach, emphasizing coordination across research, extension, and market linkages; however, empirical evidence suggests limited operationalization of these mechanisms, particularly at regional and local levels[19].

At the federal level, MoA is responsible for policy formulation and strategic oversight, while EIAR leads research, technology development, and innovation dissemination. Regional bureaus, particularly in Oromia, Amhara, and SNNPR, frequently operate under severe staffing, financial, and infrastructure constraints, leading to uneven policy implementation and persistent data silos[19,33]. Centralized monitoring of postharvest performance is largely absent, impeding real-time data collection and limiting evidence-based decision-making. Recent studies highlight that over 60% of smallholder PHM interventions are not tracked systematically at the regional level, undermining the effectiveness of PHMSE and related programs[46,47].

Professional associations, such as the Ethiopian Society for Postharvest Management (ESPHM), facilitate knowledge exchange and capacity building but lack statutory enforcement authority, which constrains the translation of technical guidance into standardized practices on the ground[19]. Integrated Agro-Industrial Parks (IAIPs) offer opportunities for coordinated storage, processing, and market access, but evidence suggests that without explicit policy alignment and inter-agency coordination, IAIPs risk operating as isolated hubs rather than fully integrated nodes in the national postharvest value chain[48].

Effective PHL reduction depends on strengthening governance structures through clear institutional mandates, robust inter-ministerial coordination, and monitoring mechanisms. Investments in regional capacities, including staffing, training, and ICT-enabled data collection, are critical to transform policy into actionable outcomes[19,46].

Regulatory frameworks and standards for sustainable postharvest management

Ethiopia's regulatory framework for postharvest management is anchored in EFDA Proclamation 1112/2019 and complementary ESA standards, which provide the legal basis for food safety, storage, handling, and transport. Additional sector-specific directives, including Local GAP and postharvest handling codes for horticultural commodities, aim to standardize quality, reduce losses, and facilitate access to domestic and export markets[35].

Despite these regulatory instruments, enforcement remains weak. Studies indicate that compliance among smallholders is below 50%, largely due to inadequate inspection coverage, delayed certification processes, and logistical constraints[49,35]. Integrated traceability systems, which are critical for ensuring accountability along the value chain, are largely absent, limiting both domestic food safety and export market potential. Comparative experience from Kenya and Uganda shows that adoption of electronic traceability and risk-based inspection regimes can reduce postharvest losses by 15%–25% while improving compliance with national and international standards[18].

To address these gaps, Ethiopia must move towards risk-based, market-oriented regulatory approaches, incorporating incentives for compliance, capacity building for inspectors and cooperatives, and digital monitoring tools. Initiatives such as EFDA's digital inspection pilot in 2023 demonstrate the potential for electronic monitoring, although scaling remains limited[49]. Aligning regulation with market incentives, including access to premium prices for compliant produce and integration with agro-processing hubs, is essential to enhance both loss reduction and farmer income.

Strengthening regulatory frameworks requires not only the formulation of standards but also effective enforcement, monitoring, and integration with governance and market systems. Risk-based, technology-supported approaches, coupled with stakeholder capacity development, can substantially reduce postharvest losses and improve compliance at both smallholder and commercial scales.

Circular agriculture–based technical innovations in the Ethiopian postharvest context

Ethiopia experiences some of the highest postharvest losses in sub-Saharan Africa, particularly for fruits and vegetables, where losses range from 20%–50% depending on commodity, season, and market distance[10,31,50,51]. These losses are primarily driven by weak cold-chain infrastructure, poor packaging, limited processing capacity, and inadequate waste management systems. While policy and governance reforms are essential, Ethiopia's structural conditions make circular agriculture–based technical interventions especially relevant for reducing losses while simultaneously addressing energy, environmental, and livelihood challenges[52,53].

Biodegradable and bio-based packaging: relevance for Ethiopia

In Ethiopia, fresh produce is predominantly transported and marketed using traditional packaging materials such as wooden crates, sacks, and open baskets, which offer minimal protection against mechanical damage, moisture loss, and microbial contamination[54–56]. Studies on Ethiopian tomato, mango, and banana value chains show that inappropriate packaging contributes significantly to bruising, compression damage, and rapid quality deterioration during transport to urban markets[57–59,30]. Global reviews demonstrate that fiber-based and polysaccharide-based packaging

materials derived from such residues effectively extend shelf life while supporting circular resource use[60–62]. Biodegradable packaging innovations are particularly relevant in the Ethiopian context due to the abundance of agricultural residues such as enset fiber, teff straw, maize stalks, sugarcane bagasse, and coffee husks. Although large-scale adoption remains limited in Ethiopia, emerging evidence suggests strong potential for locally produced bio-packaging to reduce losses and create rural non-farm employment[63,64]. From a governance perspective, the absence of standards and incentives for biodegradable packaging constrains innovation. Aligning Ethiopia's packaging regulations, industrial policy, and green growth strategy with circular bio-packaging development could simultaneously reduce plastic waste and postharvest losses[65,66].

Low-carbon and energy-efficient storage technologies in Ethiopia

Limited access to cold storage is a central bottleneck in Ethiopia's horticultural sector. Less than 10% of perishable produce benefits from cold-chain services, and existing facilities are concentrated around export corridors rather than domestic markets[67,68]. As a result, smallholders and informal traders rely on ambient storage conditions, leading to rapid spoilage.

Low-carbon storage technologies—such as solar-powered cold rooms, evaporative cooling chambers, and zero-energy cool storage—are particularly well suited to Ethiopia's climatic conditions and renewable energy potential. Empirical studies from Ethiopia and neighboring countries show that evaporative cooling can extend the shelf life of tomatoes, leafy vegetables, and fruits by 2–5 d, significantly reducing losses at farm and market levels[69–71]. Solar-powered cold storage has demonstrated promising results in Ethiopian pilot projects, reducing postharvest losses by up to 40% and improving price stabilization for smallholder farmers supplying urban markets[72,73]. These technologies align strongly with Ethiopia's Climate-Resilient Green Economy (CRGE) strategy, which emphasizes renewable energy, low-emission agriculture, and sustainable food systems[74].

However, adoption remains constrained by high upfront costs, limited technical capacity, and weak institutional coordination. Integrating low-carbon storage solutions into national postharvest policies, cooperative development programs, and urban food system planning would enhance scalability and long-term impact[75,76].

Valorization of spoiled produce and agricultural waste in Ethiopia

In Ethiopia, spoiled and unsold fruits and vegetables are predominantly disposed of in open dumps or informal waste streams, particularly in urban wholesale markets such as Addis Ababa, Hawassa, and Bahir Dar[77]. This practice contributes to environmental pollution, methane emissions, and lost economic value. Circular agriculture reframes these losses as recoverable resources within integrated food, energy, and livestock systems.

Ethiopia faces chronic shortages of affordable livestock feed, especially during dry seasons. Studies show that fruit and vegetable residues—when properly processed through drying, ensiling, or fermentation—can partially substitute conventional feed ingredients without compromising animal health or productivity[78,79]. Given Ethiopia's mixed crop–livestock systems, valorizing postharvest waste as feed offers strong system-level synergies by reducing feed costs and competition between food and feed[80].

Ethiopia has actively promoted household and institutional biogas systems as part of its renewable energy and climate mitigation agenda. Peer-reviewed evidence indicates that fruit and vegetable waste has high biogas yield potential and can significantly enhance the efficiency of anaerobic digestion systems when co-digested with manure[81–83]. Digestate reuse as organic fertilizer further supports soil fertility and nutrient cycling in smallholder farming systems[84].

Despite policy support, integration of postharvest waste into biogas systems remains limited due to fragmented waste collection and weak coordination between agricultural and urban authorities. Strengthening institutional linkages between wholesale markets, municipalities, and energy programs is essential for scaling circular waste valorization in Ethiopia[85–87].

Gender dimensions of circular postharvest systems in Ethiopia

Circular agriculture systems in Ethiopia—designed to enhance resource efficiency, reduce postharvest losses, and promote nutrient recycling—operate within deeply gendered institutional and socio-economic structures. Women play a central role in postharvest value chains, particularly in harvesting, sorting, storage, processing, and informal retailing of fruits and vegetables. Empirical studies show that women contribute more than half of the labor in postharvest handling but face limited access to land, finance, training, extension services, and decision-making platforms[88,89]. These structural inequalities significantly shape how women engage with and benefit from circular postharvest innovations. Broader evidence on climate-smart agriculture adoption indicates that restricted access to credit, cooperative membership, irrigation institutions, and agricultural technologies constrains women's participation in sustainable production systems[90]. Even when statutory laws formally recognize women's rights, customary norms frequently undermine their effective land use rights and decision-making authority, reinforcing gender asymmetries across production and postharvest stages.

Quantitative evidence further confirms that gender disparities in agricultural performance persist beyond differences in observable resource endowments. Using RIF Oaxaca–Blinder decomposition, Abdisa et al.[91] estimated an 11.5% value-based productivity gap between male- and female-headed households in Ethiopia, with structural effects outweighing endowment effects. Soil fertility management, extension contact, and mechanization account for a significant share of the explained differential, yet a substantial unexplained component reflects entrenched socio-cultural norms, power imbalances, and institutional biases. This finding is particularly relevant for circular agriculture systems, which depend on efficient soil regeneration, technology adoption, and mechanized residue management. Equal access to resources alone is insufficient; structural and normative barriers limit women's capacity to translate access into productive gains.

At the postharvest stage—central to circularity through loss reduction, storage efficiency, and nutrient cycling—women bear primary management responsibilities but often lack proportional authority over asset control and technology adoption decisions[92–96]. Moreover, gender norms restricting mobility and extension engagement further constrain women's uptake of improved storage, processing, and waste valorization technologies[97,98].

Despite these constraints, emerging evidence demonstrates that women benefit significantly from decentralized and small-scale circular innovations. Participation in renewable energy solutions such as biogas systems, solar dryers, and cooperative-based processing enterprises has been associated with improved

household nutrition, reduced labor burdens, and enhanced income control[99–101]. Women-led cooperatives and collective enterprises also improve market access and bargaining power when supported by gender-sensitive financing and institutional arrangements[102,103]. These experiences suggest that circular postharvest systems can become vehicles for empowerment if embedded within gender-responsive governance frameworks. Policy analyses emphasize the need for gender-responsive financing, inclusive technology design, sex-disaggregated monitoring indicators, and women's meaningful participation in governance structures[68,104,105]. Integrating such measures into Ethiopia's circular agriculture and postharvest strategies is essential for ensuring that efficiency gains, climate resilience, and food security improvements are achieved alongside substantive gender equity.

Challenges and constraints in postharvest management (revised)

Ethiopia's postharvest management (PHM) system faces a complex web of challenges, which are systemic, interlinked, and encompass technical, financial, socio-economic, environmental, and institutional dimensions. This section now emphasizes that regional disparities exacerbate these challenges, with some regions better equipped in storage and market access, while others remain highly vulnerable[7,20]. Experiences from other developing countries show similar patterns, highlighting the universality of the problem[17,50].

Technical and infrastructure constraints

Postharvest losses are exacerbated by limited access to improved storage facilities, inadequate transport infrastructure, and lack of cold-chain systems, particularly for perishable crops such as fruits and vegetables[51,47]. In Ethiopia, traditional storage structures and poor handling practices amplify losses from moisture accumulation, insect infestation, and spoilage[7,5]. Regional differences are evident; for instance, Oromia and SNNPR, producing large volumes of tomatoes and onions, face higher losses due to delayed market access, whereas smallholder cooperatives in Tigray show comparatively lower losses because of communal storage facilities. Globally, similar constraints are reported in sub-Saharan Africa, South Asia, and Latin America, where lack of cold-chain infrastructure leads to postharvest losses of 30%–50% for fruits and vegetables[12,106].

Investments in modern storage facilities, transport networks, and cold-chain systems are essential not only to reduce losses but also to align Ethiopian practices with global standards, improving market access and food security.

Financial barriers

Smallholder farmers often face high upfront costs for storage technologies, postharvest handling equipment, and climate-resilient infrastructure. Limited access to credit, high interest rates, and weak rural financial services constrain the adoption of best practices[107,108]. Similar patterns are observed in India, Kenya, and Ghana, where smallholders are unable to invest in postharvest solutions due to capital constraints[18,109].

Access to innovative financing, such as microfinance, blended finance, and green bonds, is critical to empower farmers to adopt improved technologies, thereby reducing losses and enhancing household income.

Socio-economic and gender constraints

Women, who frequently handle postharvest tasks, are often underrepresented in training, extension services, and access to finance[36,110]. Fragmented smallholder farms and geographic isolation limit collective action and economies of scale[7,47]. Globally, studies from Bangladesh, Nigeria, and Tanzania show that gender and socio-economic disparities exacerbate postharvest inefficiencies, particularly among marginalized households[111,21].

Gender-inclusive training and cooperative structures can improve technology adoption, reduce losses, and promote equitable benefits, reflecting lessons from other developing-country contexts.

Institutional and governance challenges

While policies exist, weak operationalization, limited monitoring, and inadequate resource allocation hinder their effectiveness. Regional disparities are pronounced; for example, PHMSE implementation pilots in Oromia have reduced some losses in maize and pulses, while SNNPR and Afar face persistent high losses due to low institutional capacity[19,46]. Similar governance gaps are observed in India, Ghana, and Malawi, where overlapping responsibilities and weak policy enforcement result in continued losses despite technical solutions[18,110].

Strengthening institutional clarity, inter-agency coordination, and monitoring systems is essential for coherent policy implementation, ensuring sustainable and scalable postharvest interventions, with attention to regional contexts.

Climate and environmental vulnerability

Rising temperatures, erratic rainfall, and increased pest and disease pressures (e.g., Fall Armyworm) exacerbate postharvest risks[112,113]. Similar climate-related losses are reported in maize and horticulture sectors across sub-Saharan Africa and Southeast Asia, emphasizing the global significance of climate-smart postharvest interventions[114].

Integrating climate-resilient storage and transport infrastructure can mitigate environmental risks and protect food security, aligning Ethiopia's strategies with global best practices.

Market and value chain limitations

Weak market linkages, inconsistent demand, and inadequate aggregation infrastructure hinder smallholders' ability to sell produce at competitive prices[5,8]. Comparable constraints in Vietnam, Kenya, and Nigeria show that perishables frequently spoil due to inefficient aggregation, poor logistics, and limited traceability[18]. Strengthening market infrastructure, aggregation systems, and traceability not only reduces losses but also increases farmers' income and competitiveness in domestic and export markets.

Conclusions and recommendations

Conclusions

Postharvest losses remain one of the most persistent structural bottlenecks to food security, rural income growth, and sustainable food system transformation in Ethiopia. Losses range from 15%–28% for cereals and legumes to 20%–50% for highly perishable horticultural crops, with pronounced regional disparities linked to infrastructure gaps, storage practices, market distance, and institutional capacity. While national strategies—including the National Postharvest Management Strategy (2024–2030), the Agricultural Growth Program, and the National Nutrition Program—provide a strong policy foundation, implementation effectiveness is constrained by fragmented institutional mandates, weak inter-ministerial coordination, limited enforcement of standards, and insufficient regional capacity. Informal market dominance further undermines compliance with food safety and quality regulations.

Beyond governance constraints, Ethiopia's postharvest challenge is fundamentally technical and systemic. Weak cold-chain infrastructure, inadequate packaging systems, limited processing capacity, and inefficient waste management significantly contribute to spoilage and value loss. Circular agriculture–based innovations—such as biodegradable packaging from agricultural residues, solar-powered cold storage, evaporative cooling systems, and valorization of fruit and vegetable waste into livestock feed or biogas—offer integrated solutions that simultaneously address loss reduction, environmental sustainability, energy access, and rural employment. However, adoption remains limited due to high upfront costs, the absence of enabling standards, weak coordination between agricultural and urban authorities, and limited private-sector engagement. The integration of circular technical innovations into postharvest systems, therefore, remains underdeveloped despite strong contextual relevance.

Gender inequality further compounds these challenges. Women provide the majority of labor in postharvest handling yet face structural barriers in land rights, finance, extension access, cooperative membership, and decision-making authority. Evidence shows that productivity gaps persist even when observable resource access appears similar, indicating that structural and socio-cultural constraints limit women's returns to productive assets. Since circular agriculture systems depend on soil management, technology adoption, storage efficiency, and waste recycling—activities in which women play central roles—failure to address gendered constraints risks reinforcing inefficiencies and inequities. Overall, Ethiopia's postharvest losses reflect an interconnected set of technical, institutional, socio-economic, environmental, and gender-based constraints that require integrated, systems-oriented solutions rather than isolated interventions.

Recommendations

Reducing postharvest losses in Ethiopia requires a transition from fragmented interventions toward an integrated circular food system strategy anchored in strong institutional coordination and accountability. Clear delineation of mandates among ministries responsible for agriculture, trade, industry, environment, urban development, and energy is essential to minimize overlap and enhance policy coherence. Establishing permanent inter-ministerial coordination platforms, supported by measurable performance indicators and shared data systems, would strengthen implementation effectiveness. In addition, a national postharvest monitoring and traceability system—leveraging ICT-enabled tools for real-time tracking of commodity flows and losses—should be institutionalized to guide evidence-based decision-making and improve transparency across value chains.

Technical investments must prioritize scalable circular agriculture innovations that address structural bottlenecks in storage, packaging, energy, and waste management. Promoting biodegradable and bio-based packaging derived from locally available agricultural residues can simultaneously reduce mechanical damage, extend shelf life, and create rural non-farm employment, provided that regulatory standards and industrial incentives are aligned with green growth strategies. Expanding low-carbon storage solutions—such as solar-powered cold rooms and evaporative cooling systems—through cooperative networks and integration into urban food system planning would substantially reduce spoilage of perishable commodities while supporting renewable energy objectives. Furthermore, structured waste valorization systems should be developed to link wholesale markets, municipalities, livestock producers, and biogas programs, enabling organic waste conversion into animal feed, renewable energy, and organic fertilizers. Such circular integration enhances resource efficiency, reduces environmental pollution, and strengthens mixed crop–livestock systems.

Financing mechanisms must be restructured to overcome adoption barriers faced by smallholders and small-scale enterprises. Blended finance models, concessional credit lines, climate finance instruments, and cooperative-based investment schemes can lower upfront costs associated with modern storage, packaging, and renewable energy technologies. Public–private partnerships will be critical for scaling infrastructure and fostering innovation ecosystems that connect research institutions, agro-industries, and farmer organizations. Strengthening aggregation systems, improving traceability infrastructure, and facilitating access to urban and export markets will also create stronger economic incentives for postharvest loss reduction.

Gender-responsive transformation must be systematically embedded within all postharvest and circular agriculture interventions. Moving beyond equal access frameworks toward gender-transformative approaches is necessary to address structural inequalities in land tenure, financial services, cooperative participation, and decision-making authority. Targeted training in circular technologies, gender-responsive credit schemes, support for women-led cooperatives, and the integration of sex-disaggregated indicators within national monitoring systems are essential for ensuring equitable outcomes. Without addressing the structural and socio-cultural constraints limiting women's capacity to benefit from innovations, technical investments risk reinforcing existing disparities and undermining system-wide efficiency.

Finally, climate resilience should guide the design and implementation of postharvest strategies. Storage, transport, and packaging solutions must be adapted to Ethiopia's rising temperatures, rainfall variability, and increasing pest pressures. Integrating circular postharvest innovations within the Climate-Resilient Green Economy framework will ensure that loss reduction contributes simultaneously to food security, emission mitigation, renewable energy expansion, and sustainable rural livelihood development. In sum, Ethiopia's progress toward sustainable postharvest loss reduction depends on combining institutional reform, circular technical innovation, inclusive financing, market system strengthening, climate adaptation, and gender-transformative governance within a coherent and long-term national food systems strategy.

Future research directions

While this review provides a comprehensive synthesis of policies, governance structures, regulatory frameworks, and challenges in postharvest management in Ethiopia, it has certain limitations. Empirical evidence on the long-term impacts of recent strategies, particularly the PHMSE and pilot interventions in agro-industrial parks, remains limited. Regional disparities, socio-economic heterogeneity, and the effectiveness of gender-inclusive approaches are not fully captured in the existing literature. Additionally, the integration of climate-smart technologies and digital monitoring systems in postharvest management requires further empirical validation.

Future research should focus on longitudinal studies that assess the effectiveness and scalability of postharvest interventions across different regions, crop types, and socio-economic contexts. Investigations into gender-sensitive and climate-resilient strategies, the economic impacts of digital traceability systems, and the cost-effectiveness of modern storage technologies are essential to fill

current knowledge gaps. Comparative studies examining Ethiopia's approaches against successful models from other developing countries can provide additional insights for policy innovation, institutional strengthening, and evidence-based decision-making. By addressing these gaps, future research can directly support the design of targeted, practical, and scalable solutions to reduce postharvest losses, improve nutrition, and enhance rural livelihoods in Ethiopia.

Author contributions

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, manuscript preparation, and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed in the current study are available from the corresponding author on reasonable request.

Acknowledgments

There was no funding received for the research.

Conflict of interest

There is no potential conflict of interest reported by the author(s).

Dates

Received 26 September 2025; Revised 8 March 2026; Accepted 9 March 2026; Published online 25 May 2026

References

[1] World Bank. 2020. Ethiopia agricultural sector review: productivity, postharvest losses, and food security. *World Bank Report No. 14521-ET*. World Bank, USA.

[2] Ministry of Agriculture (MoA). 2024. Postharvest management strategy of Ethiopia (PHMSE): Grains, horticultural crops and animal source foods (*2024–2030/2016–2022 E. C.*). MoA, Addis Ababa, Ethiopia. www.moa.gov.et/wp-content/uploads/2024/12/PHM_Strategy_of_Ethiopia_PHMSE-1.pdf

[3] Renzaho AMN, Dachi G, Ategbo E, Chitekwe S, Doh D. 2022. Pathways and approaches for scaling-up of community-based management of acute malnutrition programs through the lens of complex adaptive systems in South Sudan. *Archives of Public Health* 80(1):203

[4] Tenessa DB. 2026. The essential role of pre- and post-harvest loss control strategies in crop yield improvement in Ethiopia. *Journal of Agribusiness in Developing and Emerging Economies* 2026:1–21

[5] Kasso M, Bekele A. 2018. Post-harvest loss and quality deterioration of horticultural crops in Dire *Dawa* Region, Ethiopia. *Journal of the Saudi Society of Agricultural Sciences* 17(1):88–96

[6] Ndindeng SA, Candia A, Mapiemfu DL, Rakotomalala V, Danbaba N, et al. 2021. Valuation of rice postharvest losses in sub-Saharan Africa and its mitigation strategies. *Rice Science* 28(3):212–216

[7] Debebe S. 2022. Post-harvest losses of crops and its determinants in Ethiopia: Tobit model analysis. *Agriculture & Food Security* 11(1):13

[8] Minten B, Tamru S, Reardon T. 2021. Post-harvest losses in rural-urban value chains: evidence from Ethiopia. *Food Policy* 98:101860

[9] Ministry of Agriculture (MoA). 2023. Rural finance and agricultural technology adoption report. MoA, Ethiopia

[10] Stathers T, Onumah G, Lamboll R. 2024. *Postharvest Loss Reduction Interventions in Sub-Saharan Africa: Experiences and Perspectives*. UK: Natural Resources Institute (NRI), University of Greenwich. www.grtd.fcdo.gov.uk/wp-content/uploads/2025/06/Food-loss-postharvest-landscape-report.pdf

[11] Kitinoja L. 2013. Returnable plastic crate (RPC) systems can reduce postharvest losses and improve earnings for fresh produce operations. *Produce Engineering Foundation (PEF) White Paper 13-01*. PEF, USA

[12] Aulakh J, Regmi A. 2013. Post-harvest food losses estimation: development of consistent methodology. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy

[13] Agricultural Transformation Agency (ATA). 2020. Integrated agro-industrial parks: policy brief and implementation report. ATA, Addis Ababa

[14] Yimenu SM, Yefru S, Moges D, Seifu B, Shiferaw D, et al. 2024. Postharvest practices and loss determinants for interventions among smallholder potato farmers in tiyo district, arsi zone, Ethiopia. *African Journal of Food, Agriculture, Nutrition and Development (AJFAND)* 24(4):26203–26228

[15] Assefa Y, Van Damme W, Williams OD, Hill PS. 2017. Successes and challenges of the millennium development goals in Ethiopia: lessons for the sustainable development goals. *BMJ Global Health* 2(2):e000318

[16] Food and Agriculture Organization of the United Nations (FAO). 2020. Food security and nutrition: building a global narrative towards 2030, *HLPE Report No. 15*. FAO, Rome, Italy. https://openknowledge.fao.org/handle/20.500.14283/ca9731en

[17] Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R, Meybeck A. 2011. Global food losses and food waste: extent, causes and prevention. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy

[18] Kitinoja L, Kader AA. 2015. Measuring postharvest losses of fresh fruits and vegetables in developing countries. *Produce Engineering Foundation (PEF) white paper 15-02*. PEF, USA

[19] Workineh M, Lemma H. 2020. Post harvest loss management and quality control of fruits and vegetables in Ethiopia for securing food and nutrition – a review. *Food Science and Quality Management* 100:21–28

[20] Negede BM. 2024. *Technology adoption and social protection: evidence from rural and urban Ethiopia*. PhD. Thesis. Wageningen University and Research. doi: 10.18174/669779

[21] Quisumbing AR, Meinzen-Dick R, Raney TL, Croppenstedt A, Behrman JA, et al. 2014. *Gender in Agriculture: Closing the Knowledge Gap*. Dordrecht, Netherlands: Springer. doi: 10.1007/978-94-017-8616-4

[22] Pörtner HO, Roberts DC, Adams H, Adler C, Aldunce P, et al. 2023. *Climate Change 2022: Impacts, Adaptation and Vulnerability*. UK: Cambridge University Press. doi: 10.1017/9781009325844

[23] Etefa OF, Forsido SF, Kebede MT. 2022. Postharvest loss, causes, and handling practices of fruits and vegetables in Ethiopia: scoping review. *Journal of Horticultural Research* 30(1):1–10

[24] Moher D, Liberati A, Tetzlaff J, Altman DG. 2010. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International Journal of Surgery* 8(5):336–341

[25] Snyder H. 2019. Literature review as a research methodology: an overview and guidelines. *Journal of Business Research* 104:333–339

[26] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, et al. 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic Reviews* 10(1):89

[27] Braun V, Clarke V. 2022. Conceptual and design thinking for thematic analysis. *Qualitative Psychology* 9(1):3–26

[28] Cohen J. 1960. A coefficient of agreement for nominal scales. *Educational and Psychological Measurement* 20(1):37–46

[29] Abate T, Kassie GT, Kemal SA, Fikre A. 2024. Increased productivity and socioeconomic benefits of grain legumes. In *The Untold Stories of African Agriculture*. ed. Abate T. UK: CABI. pp. 78–98 doi: 10.1079/9781800626386.0005

[30] Wakene DM, Sharew T. 2024. A comprehensive review of tomato post-harvest losses: understanding impacts and contributing factors in Ethiopia. *Asian Science Bulletin* 2(4):525–535

[31] Teferra TF. 2022. The cost of postharvest losses in Ethiopia: economic and food security implications. *Heliyon* 8(3):e09077

[32] Rana S, Gupta N, Dhanush AS. 2025. Chapter-6 Post-harvest handling and storage. In *Essentials of Horticulture: Science, Practice and Sustainability*, eds. Bishnoi M, Chakradhar P, Behera A, Rana S, sahu H. Haryana, India: Stella International Publication

[33] Waqo HW, Mekonnen Woldemedihn G, Asfaw ZG. 2025. Predictors and regional prevalence of food insecurity in Ethiopia during COVID-19: a multilevel analysis. *BMC Public Health* 25(1):1046
[34] Atukunda P, Eide WB, Kardel KR, Iversen PO, Westerberg AC. 2021. Unlocking the potential for achievement of the UN sustainable development goal 2 – 'Zero Hunger' – in Africa: targets, strategies, synergies and challenges. *Food & Nutrition Research* 65:7686
[35] Ethiopian Horticulture Producer Exporters Association (EHPEA). 2025. 'Avocado' the new trend of ethiopian horticulture business – EHPEA. https://ehpea.org/avocado-the-new-tend-of-ethiopian-horticulture-business
[36] Mekonnen DA, Talsma EF, Trijsburg L, Linderhof V, Achterbosch T, et al. 2020. Can household dietary diversity inform about nutrient adequacy? Lessons from a food systems analysis in Ethiopia. *Food Security* 12(6):1367–1383
[37] Makiso M, Paulos T, Ebrahim M, Tesfaye G, Tamene L. 2024. Capacity-building training manual: postharvest handling and diversified, nutritious food preparation and consumption patterns. Alliance of Bioversity International & International Center for Tropical Agriculture (CIAT), Ethiopia
[38] Birke W, Zawide F. 2019. Transforming research results in food safety to community actions: a call for action to advance food safety in Ethiopia. *Environment and Ecology Research* 7(3):153–170
[39] Seyoum A, Adamseged ME, Haileslassie A, Ires I, Jacobs-Mata I. 2025. Needs assessment to enhance public-private partnerships in smallholder irrigation development and management in Ethiopia. International Water Management Institute, Colombo, Sri Lanka. doi: 10.5337/2025.221
[40] Ababa A. 2018. Ministry of Finance and Economic Cooperation (MOFEC) Climate Resilient Green Economy (CRGE) Facility. Ministry of Finance and Economic Cooperation, Addis Ababa
[41] Korir J, Oldewage-Theron W, Samuel A, Gichohi-Wainaina WN. 2024. Multisectoral approaches for sustainable food and nutrition security actions in Ethiopia. *African Journal of Food, Agriculture, Nutrition and Development (AJFAND)* 24(5):26352–26376
[42] Etefa OF, Kebede MT, Fantahun E. 2023. Gender analysis of postharvest loss of perishables with respect to fruits and vegetables in toke kutaye district, ethiopia. *International Journal of Agricultural and Natural Sciences* 16(1):1–20
[43] Gosa AS, Aga MC, Geleta RJ. 2022. Assessment of Postharvest Losses of Fruits in West Shewa Zone, Oromia, Ethiopia. *Plant* 10(4):89–96
[44] United Nations Environment Programme (UNEP). 2024. Food Waste Index Report 2024: think eat save, tracking progress to halve global food waste. UNEP. https://digitallibrary.un.org/record/4042857?v=pdf
[45] Tiguh EE, Delele MA, Ali AN, Kidanemariam G, Fanta SW. 2024. Assessment of harvest and postharvest losses of teff (Eragrostistef (Zucc.)) and methods of loss reduction: a review. *Heliyon* 10(9):e30398
[46] Fekadu A, Andarege B. 2024. Analysis of the pre-harvest factors that influence on the postharvest quality attributes of Tomatoes (*Lycopersicon* esculentum Mill.): a systematic review. *Scientia Horticulturae* 337:113460
[47] Muleta HD, Aga MC, Obosha DW. 2025. Postharvest management challenges and opportunities of horticultural crops in selected districts of Southwest Shewa, Oromia, Ethiopia. *Journal of Science and Sustainable Development* 13(1):30–39
[48] Boru EM, Hwang J, Ahmad AY. 2025. Governance and institutional frameworks in Ethiopian integrated agro-industrial parks: enhancing innovation ecosystems and multi stakeholder coordination for global market competitiveness. *Economies* 13(3):79
[49] Shambel S. 2023. Guideline for conditional approval of medicines. Ethiopian Food and Drug Authority
[50] Hengsdijk H, de Boer WJ. 2017. Post-harvest management and post-harvest losses of cereals in Ethiopia. *Food Security* 9(5):945–958
[51] Yeshiwas Y, Tadele E. 2021. An investigation into major causes for postharvest losses of horticultural crops and their handling practice in debre markos, north-western Ethiopia. *Advances in Agriculture* 2021(1):1985303
[52] Abbink GJ. 2024. *Politics and governance of the 'Reform Agenda'in Ethiopia, 2018-2023: exploratory studies*. Leiden: African Studies Centre Leiden (ASCL). https://hdl.handle.net/1887/4209832
[53] Manyazewal M, Shiferaw A. 2019. Economic policy and structural transformation in Ethiopia. In *The Oxford Handbook of the Ethiopian Economy*, eds. Cheru F, Cramer C, Oqubay A. UK: Oxford University Press. pp. 137–158 doi: 10.1093/oxfordhb/9780198814986.013.8
[54] Bachewe FN, Minten B. 2023. Towards understanding vegetable and fruit markets for improved consumption and nutrition: the case of Ethiopia. *Food Security* 15(4):989–1005
[55] Adame MY, Tolesa GN, Workneh TS. 2023. Consumption pattern, processing, exporting status and policy prospects of fruit and vegetables in Ethiopia: a review. *Journal of Food Science and Nutrition* 6(1):1–10
[56] Emana B, Afari-Sefa V, Nenguwo N, Ayana A, Kebede D, et al. 2017. Characterization of pre- and postharvest losses of tomato supply chain in Ethiopia. *Agriculture & Food Security* 6(1):3
[57] Gebre GG, Fikadu AA, Gebeyehu TK. 2022. Is banana value chain in East Africa sustainable? Evidence from Ethiopia. *Resources, Environment and Sustainability* 8:100060
[58] Tarekegn K, Kelem F. 2022. Assessment of mango post-harvest losses along value chain in the gamo zone, southern Ethiopia. *International Journal of Fruit Science* 22(1):170–182
[59] Wosene G, Gobie W. 2022. Value chain analysis of tomato: the case of Bure, Jabitehinan and North Mecha districts of *Amhara* regional state, Ethiopia. *Journal of Agriculture and Food Research* 7:100272
[60] Tukenmez Emre U, Sirin S, Nigdelioglu Dolanbay S, Aslim B. 2025. Harnessing polysaccharides for sustainable food packaging. *Polymer Bulletin* 82(8):2779–2825
[61] Salvay AG. 2025. Polysaccharide-based materials: developments and properties. *Polymers* 17(22):3028
[62] Alves Z, Ferreira P, Nunes C. 2024. Polysaccharide-based films for food packaging application: the impact of carbon nanocomposites. In *Carbohydrate Chemistry: Chemical and Biological Approaches Volume 46*, eds. Rauter AP, Queneau Y, Palma AS. Cambridge: Royal Society of Chemistry. pp. 124–158 doi: 10.1039/BK9781837672844-00124
[63] Ogidi OI, Izah SC. 2024. Emerging technologies in the global south food industry: prospects and challenges. In *Food Safety and Quality in the Global South*, eds. Ogwu MC, Izah SC, Ntuli NR. Singapore: Springer. pp. 197–231 doi: 10.1007/978-981-97-2428-4_7
[64] Donkor L, Kontoh G, Yaya A, Bediako JK, Apalangya V. 2023. Bio-based and sustainable food packaging systems: relevance, challenges, and prospects. *Applied Food Research* 3(2):100356
[65] Misi Lopes LE, Packham N, Walther U. 2023. The effect of governance quality on future economic growth: an analysis and comparison of emerging market and developed economies. *SN Business & Economics* 3(6):108
[66] Lahouij H. 2017. *Governance and economic growth in developing economies: a comparative study*. Master's Thesis. Eastern Illinois University, USA. https://thekeep.eiu.edu/theses/2724
[67] Urugo MM, Yohannis E, Teka TA, Gemede HF, Tola YB, et al. 2024. Addressing post-harvest losses through agro-processing for sustainable development in Ethiopia. *Journal of Agriculture and Food Research* 18:101316
[68] Davidson I. 2025. The cold chain in Africa: Demand for temperature-controlled logistics is growing in response to increasing trade opportunities and the continent's shifting landscape. *Cold Facts Magazine*. Global Cold Chain Alliance. https://www.gcca.org/wp-content/uploads/2023/05/GCCA-Cold-Facts-Magazine-The-Cold-Chain-in-Africa.pdf
[69] Petruzziello F, Grilletto A, Cilenti C, Martínez-Angeles M, Giménez-Prades P, et al. 2025. Refrigeration technologies to increase cold chain sustainability. *Nature Reviews Clean Technology* 1(9):604–620
[70] Khan MK, Raza M, Shahbaz M, Farooq U, Akram MU. 2024. Recent advancement in energy storage technologies and their applications. *Journal of Energy Storage* 92:112112
[71] Thompson LKAJF. 2010. Pre-cooling systems for small-scale producers. *Stewart Postharvest Review* 6(2):1–14
[72] Ayele CA, Mekonen EA, Kebede MS. 2025. Assessment of a solar-powered evaporative cooler for rural storage of fruits and vegetables: a case in south Gondar, Ethiopia. *International Journal of Refrigeration* 2025:019
[73] Takeshima H, Yamauchi F, Bawa D, Kamaldeen SO, Edeh HO, et al. 2021. Solar-powered cold-storages and sustainable food system transformation: evidence from horticulture markets interventions in northeast Nigeria. International Food Policy Research Institute. doi: 10.2499/P15738COLL2.134668
[74] Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, et al. 2014. Climate-smart agriculture for food security. *Nature Climate Change* 4(12):1068–1072

[75] Federal Democratic Republic of Ethiopia (FDRE). 2011. Ethiopia's climate-resilient green economy: green economy strategy. FDRE
[76] Mojumder MRH, Nakib TH, Hasanuzzaman M, Abdel-Khalik AS. 2025. Advancements, challenges, and prospects of cost-effective electric vehicles: a review. *Alexandria Engineering Journal* 128:437–456
[77] Srivastav AK, Das P. 2025. Challenges and barriers to adoption. In *Biotechnology and IoT in Agriculture and Food Production*, eds. Srivastav AK, Das P. Berkeley, CA: Apress. pp. 161–168 doi: 10.1007/979-8-8688-1469-3_18
[78] Zalpouri KKR, Kaur K, Kalsi BS, Potdar PP. 2025. Post-harvest solutions for food security: reducing waste and preserving nutritional value in crop production. *Environmental Science Archives* 4(1):81–84
[79] Salemdeeb R, zu Ermgassen EKHJ, Kim MH, Balmford A, Al-Tabbaa A. 2017. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. *Journal of Cleaner Production* 140:871–880
[80] Herrero M, Thornton PK, Notenbaert AM, Wood S, Msangi S, et al. 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. *Science* 327(5967):822–825
[81] Acosta A, De los Santos-Montero LA. 2019. What is driving livestock total factor productivity change? A persistent and transient efficiency analysis. *Global Food Security* 21:1–12
[82] Agrawal A, Chaudhari PK, Ghosh P. 2023. Anaerobic digestion of fruit and vegetable waste: a critical review of associated challenges. *Environmental Science and Pollution Research* 30(10):24987–25012
[83] Esparza I, Jiménez-Moreno N, Bimbela F, Ancín-Azpilicueta C, Gandía LM. 2020. Fruit and vegetable waste management: conventional and emerging approaches. *Journal of Environmental Management* 265:110510
[84] Weiland P. 2010. Biogas production: current state and perspectives. *Applied Microbiology and Biotechnology* 85(4):849–860
[85] Scarlat N, Dallemand JF, Fahl F. 2018. Biogas: developments and perspectives in Europe. *Renewable Energy* 129:457–472
[86] Arfasa GF, Tilahun ZA, Kejela MD. 2026. Towards zero-waste cities: leveraging circular economy strategies for municipal solid waste management and pollution mitigation in East Africa – a systematic review. *Next Sustainability* 7:100228
[87] Degefu MA, Getachew S. 2025. Examining the circular economy – solid waste – sustainability education nexus for sustainable urban waste governance in Addis *Ababa*, Ethiopia. *Socio-Ecological Practice Research* 7(4):461–475
[88] Debele AD, Fereja WM. 2024. Municipal solid waste challenges in Ethiopia and valorizing the potential of the organic waste fraction for composting and bioenergy. *International Journal of Chemical Engineering* 2024(1):7999719
[89] Lelea MA, Garbaba CA, Guluma A, Hensel O. 2022. Gendering postharvest loss research: responsibilities of women and men to manage maize after harvest in southwestern Ethiopia. *Food Security* 14(4):951–963
[90] Dabessa T, Jaleta M. 2023. Gender dimension of fruit and vegetable value chains in Ethiopia. *Journal of Agriculture, Food and Natural Resource,* 1(2):83–89
[91] Doss C, Meinzen-Dick R, Quisumbing A, Theis S. 2018. Women in agriculture: four myths. *Global Food Security* 16:69–74
[92] Tsige M, Synnevåg G, Aune JB. 2020. Gendered constraints for adopting climate-smart agriculture amongst smallholder Ethiopian women farmers. *Scientific African* 7:e00250
[93] Islam S, Kabir MS. 2025. Small-scale agriculture, women's empowerment, and food security: a review of the coastal belt of Bangladesh. *Asian Journal of Agricultural Extension, Economics & Sociology* 43(8):78–90
[94] Komikouma AWN, Tnsue G, Lyu K. 2021. Determinants of participation in non-farm activities and its effect on household income: an empirical study in Ethiopia. *Journal of Development and Agricultural Economics* 13(1):72–92
[95] Njuki J, Parkins J, Kaler A. 2016. Introduction – gender, agriculture, and food security: where are we? In *Transforming Gender and Food Security in the Global South*, eds. Njuki J, Parkins J, Kaler A. London: Routledge. pp. 25–42 doi: 10.4324/9781315564111-7
[96] Quisumbing AR, Rubin D, Manfre C, Waithanji E, van den Bold M, et al. 2015. Gender, assets, and market-oriented agriculture: learning from high-value crop and livestock projects in Africa and Asia. *Agriculture and Human Values* 32(4):705–725
[97] Priya NK, Patel K, Abrol P, Babu NN, Kavyasree K, et al. 2026. A review of gender-responsive extension approaches for enhancing women's participation and empowerment in food technology systems. *Archives of Current Research International* 26(1):261–280
[98] Mishra G, Suryavanshi A, Pathak DK. 2024. Women empowerment through agriculture extension services. In *Advanced Trends in Agricultural Extension*, ed. Prusty AK. Rohini, India: Integrated Publications. pp. 35–48
[99] Tahulela AC, Sharma Y, Suri A. 2026. Climate-compatible agricultural waste management strategies for resilient land use in South Africa: a systematic review of circular innovations. In *The BRICS Imperative*, eds. Tshikovhi N, Netswera F, Santos A, Zou X. Cham: Palgrave Macmillan. pp. 1–36 doi: 10.1007/978-3-032-05932-1_1
[100] Haq SU, Shahbaz P, Abbas A, Batool Z, Alotaibi BA, et al. 2022. Tackling food and nutrition insecurity among rural inhabitants: role of household-level strategies with a focus on value addition, diversification and female participation. *Land* 11(2):254
[101] Dejen ZA, Negera M, Tegegne D, Mekuria W, Feysa GL, et al. 2025. Inclusive innovation bundling and scaling pathways for smallholders' solar irrigation in Ethiopia. International Water Management Institute, Colombo. https://hdl.handle.net/10568/180367
[102] Ogunsola OE, Adenuga MA, Nnabueze SB. 2024. Fostering inclusive economies: the role of cooperatives in empowering women entrepreneurs in agriculture. *Global Multidisciplinary Perspectives Journal* 1(5):26–46
[103] Ngxishe Z, Mgxashe N, Qwabe N. 2025. Resource Mobilisation and Funding for Women Owned Agricultural Cooperatives and Programmes
[104] Godebo DD. 2020. Review of postharvest loss effects, magnitudes, challenges and management practices in Ethiopia. *Food Science and Quality Management* 1:1
[105] Ministry of Agriculture. 2023. *National food safety and quality strategy for primary agricultural produce 2023/24–2030 [2016–2022 E. C.]* Federal Democratic Republic of Ethiopia
[106] Parfitt J, Barthel M, MacNaughton S. 2010. Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365(1554):3065–3081
[107] Chibueze T, Adeshina T, Christopher LU, Ewubajo SD, Ebere L. 2025. Access to credit and financial inclusion of MSMEs in sub-Saharan Africa: Challenges and opportunities. *International Journal of Financial Management and Economics* 8(2):861–872
[108] Dirba G. 2024. Revamping agricultural and rural credit and insurance services to transform Ethiopian food systems. A Contribution to Agricultural Finance Policymaking. An MOA Seminar Series (Vol. 1)
[109] Kaur R, Watson JA. 2024. A scoping review of postharvest losses, supply chain management, and technology: implications for produce quality in developing countries. *Journal of the ASABE* 67(5):1103–1131
[110] Pradhan M, Priya NK, Desai AV, Singh SP, Kour R. 2025. *Transforming Agriculture through Modern Extension Education Techniques*. India: Golden Leaf Publishers. doi: 10.61887/glp.2025.102
[111] Mounika K, Reddy PP, Singh RP, Pandey A, Bharty SK, et al. 2025. Postharvest technologies and cold chain management: a review. *Plant Archives* 25(1):3275–3283
[112] Kinyanjui G, Mawcha KT, Malinga LN, Soobramoney K, Nethononda P, et al. 2025. Managing African armyworm outbreaks in sub-Saharan Africa: current strategies and future directions. *Insects* 16(6):645
[113] Karume K, Mondo JM, Kiyala JCK. 2024. Drought, the war in Europe and its impacts on food insecurity in sub-Saharan Africa, east Africa. In *Climate Change and Socio-political Violence in Sub-Saharan Africa in the Anthropocene*, eds. Kiyala JCK, Chivasa N. Cham: Springer. pp. 91–111 doi: 10.1007/978-3-031-48375-2_4
[114] Obasi SN, Peters OA, Tenebe VA, Obasi CC, Alawode YO, et al. 2025. Exploring the relationship between soil moisture dynamics and postharvest losses in drought and flood-prone regions of the tropics: a review. *Agriculture, Food and Natural Resources Journal* 4:16–30