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Current Horticultural Crop Production Technologies in Ethiopia: A Comprehensive Review

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Systematic Review

Keywords: adoption, climate-smart agriculture, Ethiopia, horticulture, ICT

Posted Date: May 15th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9716817/v1

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Additional Declarations: The authors declare no competing interests.

Abstract

Horticultural crop production is central to Ethiopia's agricultural transformation, contributing to food and nutrition security, employment, diversification and exports. Although the country has favourable agro-ecological conditions and expanding markets, the sector faces persistent constraints, including weak seed systems, climate variability, limited irrigation access, postharvest losses, certification barriers, digital infrastructure gaps, and gender disparities. This review provides a comprehensive synthesis of horticultural production technologies in Ethiopia based on peer-reviewed studies published between 2000 and 2024. It examines improvements in seed and planting materials, climate-resilient practices, soil and nutrient management, integrated pest management, protected cultivation, information communication technology–based solutions, quality standards, and value addition systems. Based on the literature, improvements in varieties, drip irrigation, greenhouse production, and integrated pest management enhance yields, water-use efficiency, and product quality. However, there has been uneven adoption due to high investment costs, limited extension services, low digital literacy, infrastructure deficits, and compliance expenses. There are gaps in linking technology adoption to long-term productivity, income stability, and export competitiveness. There is the need for coordinated, gender-responsive, and context specific strategies to strengthen innovation systems and promote sustainable, inclusive horticultural development in Ethiopia.

INTRODUCTION

Agriculture is the backbone of Ethiopia's economy, contributing substantially to the gross domestic product (GDP), employment, and foreign exchange earnings. The sector employs nearly three-quarters of the labour force and supports the livelihoods of the majority of the rural population. However, Ethiopian agriculture is predominantly based on smallholders and characterised by rain-fed production systems, low input use, limited mechanisation, and high vulnerability to climate variability, all of which constrain productivity and food security outcomes (Abate et al., 2016; Gebrehiwot and van der Veen, 2013). Given these structural challenges, agricultural diversification and technological advancement are needed to enhance resilience and to ensure sustainable growth.

Horticulture is particularly important to Ethiopia's agricultural sector, as it contributes to the country's food security and provides livelihoods for the rural population (FAO, 2021). The diverse agro-ecological zones and fertile soils of Ethiopia offer favourable conditions for cultivating fruits, vegetables, flowers, spices, roots, and tubers.

In recent years, there has been a notable surge in horticultural crop production in the country, driven by growing domestic demand and more export opportunities. Horticultural crops provide essential vitamins, minerals, antioxidants, and dietary fibre necessary for a balanced diet, improving food and nutrition security and reducing micronutrient deficiencies (Ruel *et al*., 2005). Compared with staple cereals, horticultural crops generally generate higher returns per unit area, contributing to income diversification, poverty reduction, and livelihood resilience among smallholder farmers (Bellemare and Novak, 2017).

The horticulture sector is an important driver of both employment and export revenue. The rapid growth of floriculture, for example, has established Ethiopia as a leading exporter of cut flowers, highlighting how targeted investment, adoption of new technologies, and integration into global markets can support structural changes in agriculture (Gebreeyesus and Iizuka, 2010).

However, the sector continues to face challenges, including gaps in productivity, pest and disease pressures, postharvest losses, limited irrigation, and weak coordination along the value chain. Overcoming these issues through improved farming techniques, integrated pest management, expanded irrigation, and stronger postharvest systems is key to unlocking the full potential of Ethiopia's horticultural industry.

In recent decades, Ethiopia has experienced a gradual transition from subsistence-oriented production towards greater commercialisation and market integration. Historically, smallholder farmers primarily produced staple crops for household consumption and had limited interaction with output markets. However, as the population has increased and the country has become more urbanised, policy reforms have influenced stronger market participation among smallholders (Barrett, 2008; Carletto et al., 2017).

Agricultural commercialisation is widely recognised as a key pathway for improving farm productivity, raising rural incomes, and enhancing economic transformation, particularly in sub-Saharan Africa (Pingali, 2012). In Ethiopia, commercialisation has been closely associated with the expansion of high-value crops, particularly horticultural commodities. The rapid growth of Ethiopia's floriculture and export-oriented vegetable sectors demonstrates how technological adoption, foreign investment, and institutional coordination can accelerate the shift towards commercial agriculture (Gebreeyesus and Iizuka, 2010). Nevertheless, commercialisation remains uneven throughout the country, as smallholders continue to face constraints related to access to irrigation, improved inputs, credit, extension services, and reliable market information. Therefore, it is crucial to strengthen horticultural production technologies and value chain integration to sustain Ethiopia's transition towards a more market-oriented and competitive agricultural system.

Knowledge gap

Despite Ethiopia's substantial potential in horticultural crop production, there are significant gaps in the knowledge and practical adoption of advanced technologies among both smallholders and commercial producers. Most existing studies tend to describe individual technologies – such as improved seed varieties, irrigation systems, integrated pest management, protected cultivation, and information and communications technology (ICT) applications – without providing a comprehensive, comparative, and context-specific analysis of their adoption, effectiveness, and limitations. There are key challenges that must be addressed, including inefficiencies in seed systems, limited access to climate-resilient varieties, postharvest losses, certification and quality compliance issues, inadequate infrastructure, low digital literacy, gender disparities, and weak market linkages.

Moreover, most previous research has not measured the impacts of technology adoption on yield stability, resource use efficiency, income generation, or export performance, and has rarely examined trade-offs, scalability, or readiness for implementation. There is also a lack of integrated studies connecting climate-resilient practices, ICT adoption, value addition, and market diversification across Ethiopia's diverse agro-ecological zones. Without this information, policymakers, researchers, and practitioners are limited in their ability to design evidence-based, technically feasible, economically viable, and socially inclusive interventions.

Consequently, a comprehensive, analytical, and context-sensitive review is urgently needed. It should describe the current technologies; evaluate adoption constraints; and identify practical strategies for smallholders, commercial producers, and policymakers. This effort would help bridge research-to-practice gaps and support the sustainable development of Ethiopia's horticultural sector.

Objective

The objective of this review is to critically examine horticultural crop production technologies in Ethiopia and to evaluate how they contribute to enhance productivity, commercialisation, and sustainable agricultural development.

Specifically, the review identifies and synthesises major horticultural crop production technologies currently practiced in Ethiopia, including improved varieties, irrigation systems, nutrient management, integrated pest and disease management (IPM), protected cultivation, and postharvest handling techniques; evaluates the reported impacts of these technologies on yield performance, production efficiency, income generation, and export competitiveness based on available empirical studies; assesses existing constraints and adoption gaps limiting the effective implementation of horticultural technologies among smallholder farmers; and highlights research gaps and future directions for enhancing technological innovation, sustainability, and commercialisation.

MATERIALS AND METHODS

Data sources and search strategy

This review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 guidelines (Snyder, 2019). Scopus, Web of Science, ScienceDirect, and Google Scholar were searched using combinations of keywords related to horticultural production technologies, including "horticultural crops" and "Ethiopia"; "production technologies" and "horticulture"; "Ethiopia", "irrigation systems", and "horticulture"; "Ethiopia", "integrated pest management", and "horticulture"; "Ethiopia", "postharvest handling", and "vegetables"; "Ethiopia" and "protected cultivation"; and "greenhouse production" and "Ethiopia" Boolean operators (and, or) were used to refine and expand the search results. Articles were screened for relevance to Ethiopia's horticultural sector, production technologies, commercialisation, and challenges. Two published reviews and sector syntheses – those by Ashine *et al*.

(2019) and Zigene (2023) – guided the search strategy. These articles reviewed horticultural research and development, horticultural constraints and opportunities, and sector growth in Ethiopia.

Inclusion and exclusion criteria

Table 1 describes the inclusion and exclusion criteria used to select the studies included in the review.

Screening and selection process

Table 2 summarizes the study selection process. Initially, 330 records were identified, of which 46 duplicates were removed. This left 284 records for screening based on titles and abstracts. Subsequently, 148 records that did not meet the inclusion criteria were excluded. After full-text assessment, 136 full-text articles were assessed for eligibility and 60 studies were included in the qualitative synthesis.

Figure 1 shows the PRISMA flowchart for study selection. The final studies were grouped into six thematic categories for further analysis: varietal improvement, irrigation technologies, IPM, protected cultivation, postharvest technologies, and commercialisation/ value chains.

Thematic categorisation of technologies

The 60 included studies were organised thematically to allow a comparative evaluation of performance, adoption constraints, and context-specific effectiveness across Ethiopia's horticultural production systems. *Table 3* summarises the six themes and lists the number of studies for each theme.

Table 1 – Inclusion and exclusion criteria used for this review

Category	Inclusion criteria	Exclusion criteria
Type of publication	Peer-reviewed journal articles, review papers, and research articles indexed in Scopus or Web of Science	Editorials, opinion papers, newsletters, unpublished theses (unless highly relevant), and non-peer-reviewed sources
Geographical scope	Studies conducted in Ethiopia or directly addressing Ethiopian horticultural systems	Studies conducted outside Ethiopia without clear relevance to Ethiopian horticulture
Subject focus	Research addressing horticultural crops (fruits, vegetables, spices, ornamentals, and root and tuber crops) and related production technologies	Studies focusing solely on non-horticultural crops without linkage to horticulture
Thematic coverage	Studies on improved varieties, irrigation systems, nutrient management, integrated pest and disease management, protected cultivation, postharvest handling, value chains, and commercialisation	Articles not addressing production technologies, adoption, productivity, sustainability, or commercialisation aspects
Time frame	Publications from 2000 to 2024	Publications before 2000 unless considered foundational or highly cited
Language	Articles published in English	Articles published in other languages without an accessible English translation
Methodological quality	Studies with clearly defined objectives, transparent methodology, and scientifically sound analysis	Studies lacking methodological clarity, insufficient data, or unclear analytical procedures
Accessibility	Full-text articles accessible through institutional or public databases	Abstract-only articles without accessible full text

Source: Snyder (2019)

Comparative performance of horticultural technologies

Effectiveness is context-dependent: technologies with lower capital requirements and simpler management are more widely adopted. On the other hand, high-input technologies are usually limited to commercial farms. *Table 4* presents a comparison of horticultural technologies.

Adoption determinants and constraints

Adoption of horticultural technologies in Ethiopia is influenced by financial issues, including high input costs and limited access to credit (Abate *et al.*, 2015; Ashine *et al.*, 2019). Moreover, a lack of extension services reduces adoption of IPM and protected cultivation (Ashine *et al.*, 2019; Zigene, 2023). Other factors that affect horticulture in Ethiopia include infrastructure limitations such as inadequate irrigation networks, storage, and transport (Ashine *et al.*, 2019; Zigene, 2023); socio-economic elements, including

farm size, risk aversion, and market access (Lemma *et al.*, 2015; Tadele, 2017); and institutional barriers, namely fragmented value chains and weak coordination (Abate *et al.*, 2015; Tadele, 2017).

Table 2 – Study inclusion based on the Preferred Reporting Items for

Systematic reviews and Meta-Analyses (PRISMA) 2020 guidelines

PRISMA step	Description	Number of records	Notes/reasons
Identification	Records identified through searching Scopus, Web of Science, ScienceDirect, and Google Scholar	312	Comprehensive searches using predefined keywords and Boolean operators
	Additional records identified through other sources	18	Reference lists of key review articles and related studies
	Total records identified	330	Combined database and manual searches
	Duplicate records removed	46	Duplicates across databases
	Records after duplicates removed	284	Records forwarded to the screening stage
Screening	Records screened based on title and abstract	284	Screening based on relevance to Ethiopian horticulture and production technologies
	Records excluded	148	Not relevant to Ethiopia, non-horticultural focus, or lacking technological aspect
	Records retained for full-text assessment	136	Met initial screening criteria
Eligibility	Full-text articles assessed for eligibility	136	Evaluated using predefined inclusion and exclusion criteria
	Full-text articles excluded	76	See reasons below
	Not focused on production technologies	32	Did not address core thematic areas
	Outside geographical scope (not the Ethiopian context)	21	Studies conducted outside Ethiopia
	Insufficient methodological quality	14	Lack of clear methods or weak analysis
	Full text not accessible	9	Abstract-only or inaccessible sources
	Total excluded	76	Based on strict application of the criteria
Included	Studies included in qualitative synthesis	60	Final studies used for thematic analysis

Source: Adapted from Snyder (2019) and Page *et al*. (2021)

Technologies that require small investments and simpler management are more readily adopted, particularly among smallholder farmers.

Research gaps and future directions

This systematic review revealed several research gaps: a lack of long-term and large-scale studies to assess sustainability and scalability (Snyder, 2019); limited integration of agronomic, economic, and social analyses (Abate *et al.*, 2015; Ashine *et al.*, 2019; Lemma *et al.*, 2015); insufficient cost–benefit evaluations for adoption potential (Ashine *et al.*, 2019; Zigene, 2023); understudied policy and institutional factors influencing adoption (Abate *et al.*, 2015; Tadele, 2017); and the need for context-specific technology adaptation across agro-ecological zones (Gebremeskel *et al.*, 2019; Lemma *et al.*, 2015; Zigene, 2023). Addressing these gaps is critical for improving the adoption, impact, and sustainability of horticultural technologies in Ethiopia.

Table 3 – The six thematic areas considered in this review

Theme	Focus	Number of studies	References
Varietal improvement	Improved varieties, yield, and pest resistance	12	Ashine *et al*. (2019); Lemma *et al*. (2015)
Irrigation technologies	Drip irrigation, surface irrigation, and water-use efficiency	10	Gebremeskel *et al*. (2019)
Integrated pest and disease management (IPM)	Pest control and environmental sustainability	8	Zigene (2023)
Protected cultivation	Greenhouses and high tunnels	7	Zigene (2023)
Postharvest technologies	Storage, handling, and packaging	9	Ashine *et al*. (2019); Zigene (2023)
Commercialisation and value chains	Market access and adoption determinants	14	Abate *et al*. (2015); Tadele (2017)

Table 4 – Comparative performance of horticultural technologies

Technology	Reported benefits	Limitations	Context-specific notes	References
Varietal improvement	Higher yield, pest resistance, better quality	Limited seed access and poor extension	Genotype × environment interactions; performance varies across agro-ecologies	Ashine *et al*. (2019); Lemma *et al*. (2015)
Irrigation technologies	Increased yield and cropping intensity	High cost, water scarcity, and management challenges	Most effective in arid/semi-arid zones	Gebremeskel *et al*. (2019)
Integrated pest and disease management (IPM)	Reduced chemical use and improved sustainability	Knowledge/training limitations, local pest variability	Adoption higher where there is extension support	Zigene (2023)
Protected cultivation	High yield and quality; off-season production possible	High capital and technical requirements	Mainly adopted by commercial/ peri-urban farms	Zigene (2023)
Postharvest technologies	Reduced losses (20%-40%) and better market value	Weak infrastructure and low awareness	High returns if markets accessible	Ashine *et al*. (2019); Zigene (2023)
Commercialisation and value chains	Improved profitability	Fragmented value chains and institutional weakness	Adoption constrained for smallholders	Abate *et al*. (2015); Tadele (2017)

Added value of the study

Systematic synthesis of evidence: Using a PRISMA-guided approach, 60 relevant studies were critically analysed across six thematic areas: varietal improvement, irrigation technologies, IPM, protected cultivation, postharvest technologies, and commercialisation/ value chains. This thematic organisation allows for comparative assessment of technology performance, adoption constraints, and context-specific effectiveness in Ethiopia.

Context-specific insights: Based on the included studies, the effectiveness of horticultural technologies is highly dependent on agro-ecological, socio-economic, and institutional contexts. For example, irrigation and protected cultivation technologies provide higher productivity under peri-urban and commercial settings, whereas smallholders more readily adopt practices that are low cost and simple to manage (Ashine *et al.*, 2019; Gebremeskel *et al.*, 2019; Zigene, 2023).

Identification of determinants and barriers: The analysis of adoption determinants (financial, technical, socio-economic, and institutional) provides actionable insights on why certain technologies succeed or fail in specific contexts, highlighting the interaction between technology, farmer capacity, and policy frameworks.

Research gaps and future directions: This review provides a structured assessment of gaps in long-term studies, cost–benefit analyses, integration of socio-economic factors, and policy research. This serves as guidance for future research priorities and policy interventions in Ethiopian horticulture.

Practical implications: The synthesis of the findings across the included studies provides stakeholders – including researchers, extension agents, policymakers, and farmers – with evidence-based guidance for selecting, adapting, and promoting horticultural production technologies in Ethiopia.

HORTICULTURAL CROP PRODUCTION TECHNOLOGIES

Ethiopia's horticultural sector is diverse, including fruits, vegetables, spices, herbs, and ornamental crops. This sector plays a key role in food security, income generation, employment, and foreign exchange. Adoption of modern technologies and improved agronomic practices has contributed to increased productivity, sustainability, and profitability (Asmare *et al.*, 2019; Girma *et al.*, 2021).

Status of and major types of horticultural crops in Ethiopia

Table 5 summaries the major horticultural crops cultivated in Ethiopia. Smallholder farmers dominate the production of fruits and vegetables for domestic markets, while large-scale commercial farms, particularly in floriculture, focus on export-oriented production. Recent trends, including urbanisation, rising domestic demand, and expansion of irrigation and investment, are accelerating growth in high-value horticultural crops.

Despite this potential, the horticultural sector faces challenges related to input supply, postharvest losses, market access, and technological adoption, highlighting the need for strengthened production technologies and institutional support mechanisms (Gebreeyesus and Iizuka, 2010; Minten *et al.*, 2014).

Spatial distribution and agroecological zones of major horticultural crops in Ethiopia

Horticultural crop production in Ethiopia varies widely across the country's diverse agro-ecological zones, which range from lowland arid areas to highland temperate regions (*Table 6*). Altitude, temperature, rainfall, and soil characteristics strongly influence crop suitability, growing seasons, pest and disease prevalence, and productivity levels. . In general, lowland areas (<1,500 m above sea level) favour tropical fruits and irrigated vegetable production, mid-altitude zones (1,500-2,300 m above sea level) support a broad range of vegetables and fruits, while highland areas (>2,300 m above sea level) are suitable for temperate fruits and cool-season vegetables.

Table 1 – A summary of the major horticultural crops in Ethiopia

Category	Major crops	Main producing regions	Production status	Primary use/market orientation
Fruits	Mango (*Mangifera indica*), banana (*Musa* spp.), avocado (*Persea americana*), papaya (*Carica papaya*), *Citrus* spp.	Oromia, SNNPR, Amhara, and Benishangul-Gumuz	Expanding production; increasing smallholder and commercial farms; increasing irrigation	Domestic consumption and growing export market
Vegetables	Tomato (*Solanum lycopersicum*), onion (*Allium cepa*), cabbage (*Brassica oleracea*), potato (*Solanum tuberosum*), pepper (*Capsicum spp.*), and carrot (*Daucus carota*)	Oromia (Rift Valley), Amhara, SNNPR, and Tigray	Widely cultivated by smallholders; rapid expansion under irrigation; increasing greenhouse production	Domestic markets and some export (fresh vegetables)
Root and tuber crops	Sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), yam (*Dioscorea* spp.), and enset (*Ensete ventricosum*)	SNNPR and Oromia	Important for food security; largely based on smallholders	Household consumption and local markets
Spices and herbs	Ginger (*Zingiber officinale*), turmeric (*Curcuma longa*), coriander (*Coriandrum sativum*), and garlic (*Allium sativum*)	SNNPR, Oromia, and Amhara	Increasing commercialisation; export potential	Domestic and export markets
Floriculture (ornamentals)	Cut roses, summer flowers, and cuttings	Oromia (around Addis Ababa) and Amhara	Highly commercialised; dominated by large-scale private investment; strong export growth	Export oriented, especially to the European and Middle Eastern markets

Abbreviation: SNNPR, Southern Nations, Nationalities, and Peoples' Region

Source: Gebreeyesus and Iizuka (2010)

Table 6 – Spatial distribution and agroecological zones of major horticultural crops in Ethiopia

Agro-ecological zone	Altitude (m above sea level)	Climate characteristics	Dominant soil types	Major horticultural crops	Main producing areas
Lowland (Kolla)	<1,500	High temperature (20-30°C); low to moderate rainfall; semi-arid to sub-humid	Fluvisols and Cambisols	Banana, mango, Papaya, tomato (irrigated), onion, and pepper	Afar, Somali, Rift Valley (Oromia), and Benishangul-Gumuz
Mid-altitude (Woina Dega)	1,500-2,300	Moderate temperature (15-22°C); moderate rainfall	Nitisols and Luvisols	Avocado, citrus, cabbage, carrot, potato, and spices (ginger and turmeric)	Oromia, Amhara, and SNNPR
Highland (Dega)	>2,300	Cool temperature (10-18°C); higher rainfall	Nitisols and Vertisols	Apple, pear, plum, garlic, shallot, and cool-season vegetables	Amhara Highlands, Oromia Highlands, and Tigray Highlands
Irrigated river basins (across zones)	Variable	Controlled water supply; year-round production potential	Alluvial soils (Fluvisols)	Tomato, onion, green beans, and cut flowers	Awash Basin, Rift Valley, and peri-urban areas of Addis Ababa

Abbreviation: SNNPR, Southern Nations, Nationalities, and Peoples' Region

Source: Hurni (1998)

Soil types such as Nitisols, Vertisols, and Fluvisols further affect crop adaptation and yield performance (Hurni, 1998; MoA, 2000).

Seed and planting materials

High-quality seed and planting materials are foundational to horticultural crop productivity because they strongly influence germination, seedling vigour, yield potential, and resilience to biotic and abiotic stresses. In Ethiopia, seed technologies range from certified open-pollinated varieties and hybrids developed for specific agro-ecological conditions to pre-sowing treatments such as priming, pelleting, and coating, which enhance germination rates and early vigour (Alemayehu *et al.*, 2015; Tesfaye *et al*., 2020).

Vegetative propagation methods – including cuttings, grafting, budding, and *in vitro* tissue culture – are widely employed for crops such as banana, avocado, and ornamentals to maintain genetic uniformity and quality (Bairu *et al*., 2011; Ghebrehiwot and Tesfaye, 2019). Recent research has also explored biotechnological approaches such as marker-assisted selection to accelerate the development of

varieties with desirable traits such as disease resistance, drought tolerance, and improved shelf life (Kebede *et al*., 2021).

Comparisons between improved and local varieties show that improved seeds generally have higher germination rates, uniform crop maturity, greater yield potential, and enhanced resistance to major pests and diseases. In contrast, local varieties are often genetically heterogeneous and less resilient (Alemayehu *et al*., 2015; Tesfaye *et al*., 2020). However, many smallholder farmers continue to rely on local varieties due to the high cost of certified seeds, limited access to improved planting materials, cultural preferences for specific organoleptic traits, and the perceived reliability of local ecotypes under traditional management practices.

Adoption of improved seed and planting material technologies in Ethiopia is further constrained by systemic inefficiencies in the seed supply chain. Formal seed production remains underdeveloped for most horticultural crops, with limited foundation seed from breeding programmes and weak linkages between research institutions and commercial multipliers (Gebremedhin *et al*., 2019; MoARD, 2017). Ineffective quality assurance and certification systems restrict the availability of high-quality planting materials at the farm level (Gebrekidan and Tadesse, 2020). Moreover, distribution networks are often unreliable, particularly in remote areas, so farmers often depend on informal seed sources that may lack varietal purity and vigour.

Performance outcomes for adoption include the extent of varietal uptake, yield response, economic returns, and stability of performance across diverse agro-ecological conditions. Adoption rates are highest where extension support, credit access, and market integration are strong, resulting in measurable yield advantages and improved profitability (Alemayehu *et al*., 2015; Tesfaye *et al*., 2020). Conversely, in areas with limited technical support and weak seed system infrastructure, local varieties continue to predominate despite their lower productivity metrics.

Uses of greenhouses in crop production

Greenhouse technology is increasingly adopted in Ethiopia to enhance horticultural crop production, particularly for high-value vegetables, flowers, and seedlings. By providing a controlled environment, greenhouses mitigate the adverse effects of climate variability – including temperature extremes, erratic rainfall, and pest and disease pressures – allowing for year-round production (Gebreeyesus and Iizuka, 2010). Greenhouses regulate temperature, humidity, and light, improving crop growth, yield, and quality while reducing water usage and exposure to pests. They are particularly valuable in peri-urban areas and regions with limited arable land, enabling intensive production on smaller plots.

Adoption is facilitated by the development of low-cost greenhouse models, training programmes for farmers, and support from the government and non-governmental organisations. However, high initial investment costs, limited technical knowledge, and insufficient access to quality greenhouse materials hinder wider uptake of greenhouses. Despite these constraints, greenhouse cultivation presents a

significant opportunity to increase productivity, to enhance food security, and to generate income through both domestic and export markets (Abebe and Alemu, 2020; Gebreeyesus and Iizuka, 2010).

Soil management

Soil health – encompassing physical, chemical, and biological properties that support plant growth, nutrient cycling, and water retention – is fundamental for productive and sustainable horticultural systems (Abera and Belay, 2020). In Ethiopia, soils face challenges such as degradation, nutrient depletion, acidity, and poor water management, which limit crop productivity (ATA, 2021; Tadesse, 2017; Teklu and Hailemariam, 2019).

Several sustainable soil management practices, including organic amendments, integrated nutrient management, crop rotation, cover cropping, conservation tillage, liming of acidic soils, and efficient irrigation and drainage systems, can enhance soil fertility, structure, and moisture retention while minimising environmental degradation (Abera and Belay, 2020; ATA, 2021; Tadesse, 2017; Teklu and Hailemariam, 2019). Adoption of these practices ensures long-term productivity, supports climate resilience, and improves crop quality.

Biological control and IPM

Pests and diseases are major threats to horticultural crops, reducing both yields and quality. Sustainable alternatives to chemical pesticides include biological control and IPM. Biological control utilises natural enemies – predators, parasitoids, and pathogens – to suppress pest populations (Bayeh and Bekele, 2018). IPM integrates biological, cultural, mechanical, and selective chemical control measures for effective monitoring, prevention, and ecosystem-based management (Alemu and Adamu, 2021; Kassa and Alemayehu, 2020).

Although there has been increased awareness of and research on IPM and biological control in Ethiopia, these techniques have not been widely adopted by smallholder farmers due to limited knowledge, a lack of training, and insufficient resources. Strengthening extension services and providing policy support are critical for scaling up these sustainable pest management practices (ATA, 2021; Kassa and Alemayehu, 2020).

Climate-resilient cultivation practices

Horticultural production in Ethiopia is highly sensitive to climate variability, including irregular rainfall patterns, rising temperatures, and an increased frequency of drought events, all of which negatively influence crop performance (Deressa *et al.*, 2011; Kassie *et al*., 2013). Based on a case study from the Central Rift Valley, erratic precipitation reduced yields of rain-fed vegetables by up to 30% over a 5-year period, highlighting the need for adaptive practices that stabilise production under changing climatic conditions (Molla *et al*., 2018).

The adoption of **improved irrigation technologies,** such as drip and sprinkler systems, enhance water-use efficiency (WUE) and yield. For example, on smallholder tomato farms in the Awash Basin, drip irrigation increased WUE by 40%-55% and increased marketable yields by 25%-35% compared with traditional furrow irrigation (Gebreyesus *et al*., 2017). **Rainwater harvesting systems**, including micro-ponds and rooftop catchments, are being employed in semi-arid zones to provide supplemental irrigation during dry spells, increasing seasonal crop survival by up to 20% (Worku and Dessalegn, 2019).

Soil management and crop diversification also contribute to climate resilience. Conservation tillage, mulching, and organic compost improve soil moisture retention and fertility. For example, mulched plots in the Ethiopian Highlands maintained 15%-20% more soil moisture and produced 18%-22% higher yields of leafy vegetables compared with non-mulched controls (Teklu and Hailemariam, 2019). **Crop rotation and intercropping systems** also contribute to resilience by reducing the incidence of pests and diseases and enhancing nutrient cycling. For example, incorporating legumes into rotation sequences improved subsequent vegetable yields by 12%-16% by enhancing soil nitrogen availability (Abera and Belay, 2020). The adoption of **drought-tolerant and heat-resistant varieties** has further improved stability, with trials of improved onion and cabbage cultivars showing a 20%-30% increase in yield over local varieties under water stress (Tesfaye *et al*., 2015).

P**rotected cultivation systems**, including low-cost greenhouses and shade nets, buffer crops against climate extremes, reduce heat and water stress, and extend production windows. In peri-urban zones, greenhouse-grown lettuce and peppers consistently achieved 1.5-2 times higher seasonal yields and more uniform quality (Abebe and Alemu, 2020; Gebreeyesus and Iizuka, 2010). Additionally, **climate information services**, such as seasonal forecasts and localised advisories disseminated through mobile platforms, help farmers plan planting, irrigation, and harvest schedules, improving yield stability and reducing risks (Kebede and Wondimagegnehu, 2021). Collectively, these climate-resilient enhance resource use efficiency and support sustained productivity in Ethiopia's variable environments.

Quality standards and certification

Quality standards and certification are essential for ensuring that horticultural products are safe, marketable, and internationally competitive. In Ethiopia, the Ethiopian Standards Agency (ESA) develops and enforces national standards for seed quality, pesticide use, postharvest handling, and grading, providing a regulatory framework for domestic and export markets (ESA, 2020). Producers targeting exports increasingly pursue international certification schemes, such as GlobalGAP and organic certification under the International Federation of Organic Agriculture Movements (IFOAM), which cover food safety, environmental sustainability, and labour welfare (GlobalGAP, 2022; IFOAM, 2021). Certification is administered through national institutions, such as the Ethiopian Conformity Assessment Enterprise (ECAE), as well as private agencies, including SGS and Control Union, which conduct inspections, testing, and audits (Control Union, 2022; ECAE, 2019; SGS, 2022).

Adherence to quality standards improves market access, consumer confidence, and sustainability, but implementation presents technical and economic challenges. **Certification costs** – including application

fees, inspections, laboratory testing, and compliance audits – are often prohibitively high for smallholder producers, limiting participation in formal schemes (World Bank, 2020). **Additional barriers,** such as complex documentation requirements, strict pesticide residue limits, and traceability protocols, further restrict uptake, particularly among farmers with limited technical knowledge and resources (Mebratu, 2022). Noncompliance or inadequate adherence can lead to **export rejection**, penalties, and reduced incomes, threatening producer livelihoods and national export earnings (Bekele and Tesfaye, 2019; FAO, 2021).

Addressing these challenges requires targeted training, technical support, and investment in inspection and testing infrastructure, along with policy coordination to streamline certification processes. Incentives such as cost-sharing mechanisms, group certification schemes, and market linkage programmes can reduce financial and operational burdens, enabling broader participation. Effective implementation of quality standards and certification ultimately safeguards export markets, reduces postharvest losses, promotes sustainable horticultural practices, and supports equitable participation across the horticultural value chain (Gebremedhin, 2018; Molla, 2020; USAID, 2019).

Current state of ICT and digital farming solutions

ICT and digital farming solutions are increasingly applied to enhance horticultural production in Ethiopia, although adoption remains uneven and limited (*Table 7*). Recent surveys indicate that only **15%-20% of smallholder horticultural farmers** use any form of digital technology to manage their crops, with adoption concentrated in peri-urban and better-connected regions (Abebe and Alemu, 2020; Kebede and Wondimagegnehu, 2021). Key technologies include **mobile applications, Geographic Information Systems (GIS), remote sensing, drones, and integrated data analytics platforms**. Mobile applications provide real-time advisory services on pest and disease management, weather forecasts, and market price information, improving **farmer decision-making and timely interventions by 20%-30%** compared with non-users (Yonas and Hailu, 2022). GIS and remote sensing support soil mapping, crop health monitoring, and resource allocation, enhancing **fertiliser and irrigation efficiency** by 10%-15% (Tekalign and Mekonnen, 2019). Drones allow precision monitoring of pests, water stress, and disease outbreaks, **reducing pesticide use by up to 25%** (Kebede and Wondimagegnehu, 2021). Data analytics platforms integrate multi-source information to optimise crop management decisions, enhancing overall yield performance and input-use efficiency.

Despite these benefits, widespread adoption is constrained by multiple factors. **P**oor internet connectivity, limited network coverage in rural areas, and unreliable electricity hinder consistent use of digital tools. In addition, **digital literacy** among smallholder farmers is low, with fewer than 30% able to use smartphone-based advisory applications effectively without external support (Abebe and Alemu, 2020). Financial barriers, including high initial device costs and subscription fees, further limit uptake. M**obile applications are the most widely used and accessible ICT tool**, while drones and GIS are largely restricted to research institutions, commercial farms, or development projects due to their cost and technical complexity (Tekalign and Mekonnen, 2019; Yonas and Hailu, 2022).

Scaling up digital adoption requires **capacity-building programmes**, government-led digital extension initiatives, and **public–private partnerships** that provide affordable access to technology, training, and technical support. Investments in rural digital infrastructure and tailored and user-friendly ICT platforms can increase adoption; promote data-driven horticultural management; and enhance productivity, resource use efficiency, and resilience of smallholder horticultural systems in Ethiopia.

Gender-inclusive approaches

Gender-inclusive approaches and women empowerment initiatives are essential for promoting equity, improving livelihoods, and enhancing the sustainability of horticultural value chains in Ethiopia (Admasu *et al*., 2018; Tilahun *et al*., 2022). Women represent a significant proportion of the horticultural workforce, contributing substantially to crop production, postharvest handling, and marketing. Despite their critical role, women often face **limited access to productive resources** – including land, credit, quality seeds, fertilisers, irrigation facilities, and extension services – which constrains their productivity and adoption of modern technologies (Gebremedhin and Swinton, 2003). Gender norms also influence household decision-making and labour allocation, affecting women's participation in innovative agricultural practices. Several interventions have aimed to reduce these disparities and to promote **gender-responsive horticultural development**. Training programmes targeting both men and women in modern horticultural techniques, pest and disease management, and postharvest handling have improved skill acquisition and adoption of improved technologies (Lemma, 2018). W**omen's access to technologies – including** digital advisory tools, drip irrigation, and greenhouse systems – is 25%-35% lower than men's, highlighting the need for gender-sensitive capacity-building (Tesfaye and Wood, 2015).

Table 2 – Information and communication technology and digital farming solutions in Ethiopian Horticulture

Tool	Adoption rate	Effectiveness	Key constraints
Mobile applications	15%-20% of farmers	20%-30% increase in decision-making and market access	Low digital literacy; weak network coverage; high subscription costs
Geographic Information Systems and remote Sensing	10%-12% of farmers	10%-15% improvement in input efficiency	High cost and complexity; limited technical skills
Drones	5%-8% of farmers	Up to a 25% reduction in pesticide use	Expensive equipment; regulatory barriers
Data Analytics Platforms	8%-10% of farmers	Enhanced yield and resource optimisation	Poor internet access; data integration issues

Source: Abebe and Alemu (2020); Kebede and Wondimagegn (2021);

Tekalign and Mekonnen (2019); Yonas and Hailu (2022)

Programmes facilitating women's access to inputs, land, and financial services have increased participation in horticultural production and boosted productivity by 10%-20% in some regions.

Gender integration also extends to **climate-smart and ICT-based technologies**. Equitable access to improved seed varieties, greenhouse farming, and efficient irrigation systems enhances labour efficiency and water-use efficiency, narrows productivity gaps, and improves yields (Tesfaye and Wood, 2015). Moreover, promoting women's involvement in value addition, such as processing, packaging, and market linkages, further increases income, economic empowerment, and household food security (UN Women Ethiopia, 2019). Incorporating **gender-disaggregated indicators** – such as access to inputs, training participation, technology adoption rates, and decision-making authority – into horticultural interventions is crucial to ensure equitable benefits and to inform evidence-based policies and programmes.

Government initiatives to promote the horticulture sector

The Government of Ethiopia has implemented strategic policies and institutional interventions to promote the horticulture sector as part of its broader agricultural transformation framework. Initiatives such as the Agricultural Growth Program (AGP) and the Agricultural Transformation Agenda emphasise crop diversification, commercialisation of smallholder farms, and strengthening value chains. Public investments have focused on expanding irrigation infrastructure, enhancing seed systems for high-quality planting materials, and supporting agricultural research and extension services tailored to horticultural crops (Minten *et al*., 2014; Negatu and Parvathamma, 2018).

The Ministry of Agriculture, in collaboration with regional agricultural bureaus, provides technical training on modern production technologies, IPM, postharvest handling, and market integration to increase productivity and reduce losses. Furthermore, policy frameworks encourage private sector participation through incentives, public–private partnerships, and certification systems that improve market access. These coordinated efforts reflect a shift from subsistence-oriented production towards a more market-oriented and commercially viable horticultural subsector that contributes to national economic growth and rural employment.

Expansion of agroprocessing industries linked to horticultural growth

The expansion of horticultural production in Ethiopia has stimulated growth in agroprocessing industries, which play a critical role in value addition, waste reduction, and enhancing competitiveness. Increased production of fruits, vegetables, spices, and herbs has encouraged investments in processing facilities such as fruit canning, juice and puree production, dried vegetables and spice processing units, and cold storage infrastructure (Assefa *et al*., 2020). These ventures are frequently located in peri-urban clusters that serve as hubs linking smallholder producers with processing enterprises, thereby generating rural employment and increasing farmers' incomes. In the floriculture subsector, grading and packing facilities have expanded significantly to meet export specifications, reinforcing Ethiopia's integration into international markets. Despite this progress, challenges such as limited access to finance, inadequate infrastructure, and logistical bottlenecks continue to limit the full realisation of

Ethiopia's agroprocessing potential. Addressing these issues requires enhanced investment incentives, improved transport and energy infrastructure, and stronger coordination between producers and processors.

Marketing opportunities in neighbouring countries and the Middle East

Ethiopia's horticultural products have considerable marketing potential in regional and international markets, owing to geographic proximity, rising demand for fresh produce, and efforts to improve trade logistics. According to data, horticultural commodities – particularly cut flowers, fruits, and vegetables – are increasingly exported to Djibouti and Somalia, which serve as accessible regional outlets due to shared border access and established trade linkages (Gebreeyesus and Sonobe, 2012). Additionally, the Middle East, notably the Gulf Cooperation Council (GCC) nations, represents an expanding market for Ethiopian horticultural exports, driven by demand for off-season produce and specialty crops that are not grown locally. Improvements in air and sea freight logistics, participation in regional trade agreements, and compliance with international quality standards such as GlobalGAP have facilitated access to these markets. Nonetheless, export growth faces challenges including stringent phytosanitary requirements, competition from other exporting countries, and infrastructural hurdles at border crossings. Strategic investments in cold chain systems, quality certification mechanisms, and bilateral trade agreements could enhance Ethiopia's competitive position and expand its horticultural market share in Djibouti, Somalia, and the Middle East.

Opportunities and challenges

The Ethiopian horticultural sector has substantial opportunities for growth due to high domestic demand, expanding export markets, the adoption of modern technologies, and the potential for climate-resilient practices. Research innovations, public–private partnerships, capacity-building programmes, and ICT solutions further enhance productivity and sustainability (Abebe and Alemu, 2020; Tesfaye and Abate, 2020). Nevertheless, challenges remain, including limited access to quality seeds and planting materials, poor infrastructure, fragmented supply chains, pests and diseases, high input costs, and low awareness of modern practices among smallholder farmers (Asmare *et al*., 2019; Girma *et al*., 2021; Tekalign and Mekonnen, 2019). Coordinated efforts by government, research institutions, non-governmental organisations, and private sector stakeholders are essential to develop context-specific solutions, to strengthen market linkages, to improve technical support, and to ensure the long-term sustainability of horticultural crop production in Ethiopia (Abera *et al*., 2017; Tesfaye and Abate, 2020).

CONCLUSIONS

This review provides a comprehensive assessment of the status, technological advancements, and challenges in horticultural production in Ethiopia. This sector plays a critical role in **food security, income generation, employment, and export earnings**, supported by the country's diverse agro-ecological conditions that enable the production of a wide range of crops, including fruits, vegetables, flowers, and spices.

Key technological interventions – including **improved seed and planting material technologies, modern nursery practices, vegetative propagation, and biotechnological tools** – contribute to improved productivity and crop quality. However, adoption remains constrained by **gaps in the seed supply chain, limited awareness of improved varieties, infrastructure gaps, and financial and knowledge barriers**, particularly among smallholder farmers. Although improved varieties consistently outperform local cultivars in yield and resilience, their uptake depends on availability, affordability, and technical capacity.

Quality standards and certification systems, such as GlobalGAP and organic certification, are increasingly important for market access and competitiveness. However, **high costs and complex compliance requirements limit participation by smallholder farmers** and increase the risk of exclusion from high-value markets. Similarly, **ICT and digital farming solutions**, including mobile applications, GIS, drones, and data analytics, have great potential to improve decision-making, resource use efficiency, and market linkages, but adoption remains limited due to digital literacy gaps, poor connectivity, and infrastructure constraints.

This review also highlights **important trade-offs across technologies**. Climate-resilient practices such as drip irrigation and greenhouse cultivation enhance water-use efficiency and yield stability but require higher initial investments and training. IPM reduces reliance on pesticides and chemical inputs but demands increased knowledge and labour. Gender-inclusive approaches are critical, as women play a central role in horticultural production yet face persistent **disparities in access to resources, training, and technologies**, which affect adoption and productivity.

Overall, sustainable development of Ethiopia's horticultural sector requires coordinated efforts across research, extension, policy, and institutional frameworks. Strengthening infrastructure, improving access to technologies and markets, promoting gender equity, and supporting smallholder inclusion will be essential to overcome adoption barriers and fully realise the sector's potential for economic growth, food security, and climate resilience.

FUTURE PROSPECTS

Ethiopia's horticultural sector faces persistent challenges, including climate stress, limited technology adoption, postharvest losses, market dependence, and knowledge gaps. Addressing these constraints requires integrated and forward-looking strategies that balance technological innovation with adoption feasibility. Advances in **climate-resilient cultivars,** particularly drought- and heat-tolerant varieties, can help stabilise yields, but their adoption depends on strengthening seed systems and expanding extension support. Similarly, **smart farming technologies**, including ICT tools, GIS, drones, and data analytics, are expected to play a growing role in improving productivity and resource use efficiency. Realising this potential will require investments in digital infrastructure, as well as targeted capacity-building programs to address gaps in digital literacy. Future growth in the sector will also depend on strengthening **value addition and marketing integration. Expansion of agroprocessing industries** and cold-chain infrastructure can reduce postharvest losses and increase income but will require substantial investment and improved coordination across value chains. **At the same time, diversification** into

regional and Middle Eastern markets presents opportunities to reduce export risks and increase competitiveness, contingent on improved compliance with quality standards and stronger production–market linkages. **Capacity-building and inclusive extension** systems will be central to these efforts. In particular, gender-responsive approaches that enhance women's access to resources, training, and technologies are critical for improving adoption rates and overall productivity.

Declarations

Funding: This research received no external funding.

Author Contributions: The author conceived and designed the study, developed the methodology, conducted the investigation, per-formed data curation and formal analysis, prepared the original draft, reviewed and edited the manuscript, and approved the final version of the manuscript. The author declares that he has read and approved the publication of the manuscript in this present form.

Data availability statement: The datasets generated and/or analyzed during the current study are publicly available in an open-access repository and can be accessed without restriction.

Conflicts of interest: The author declares no conflicts of interest.

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Figures

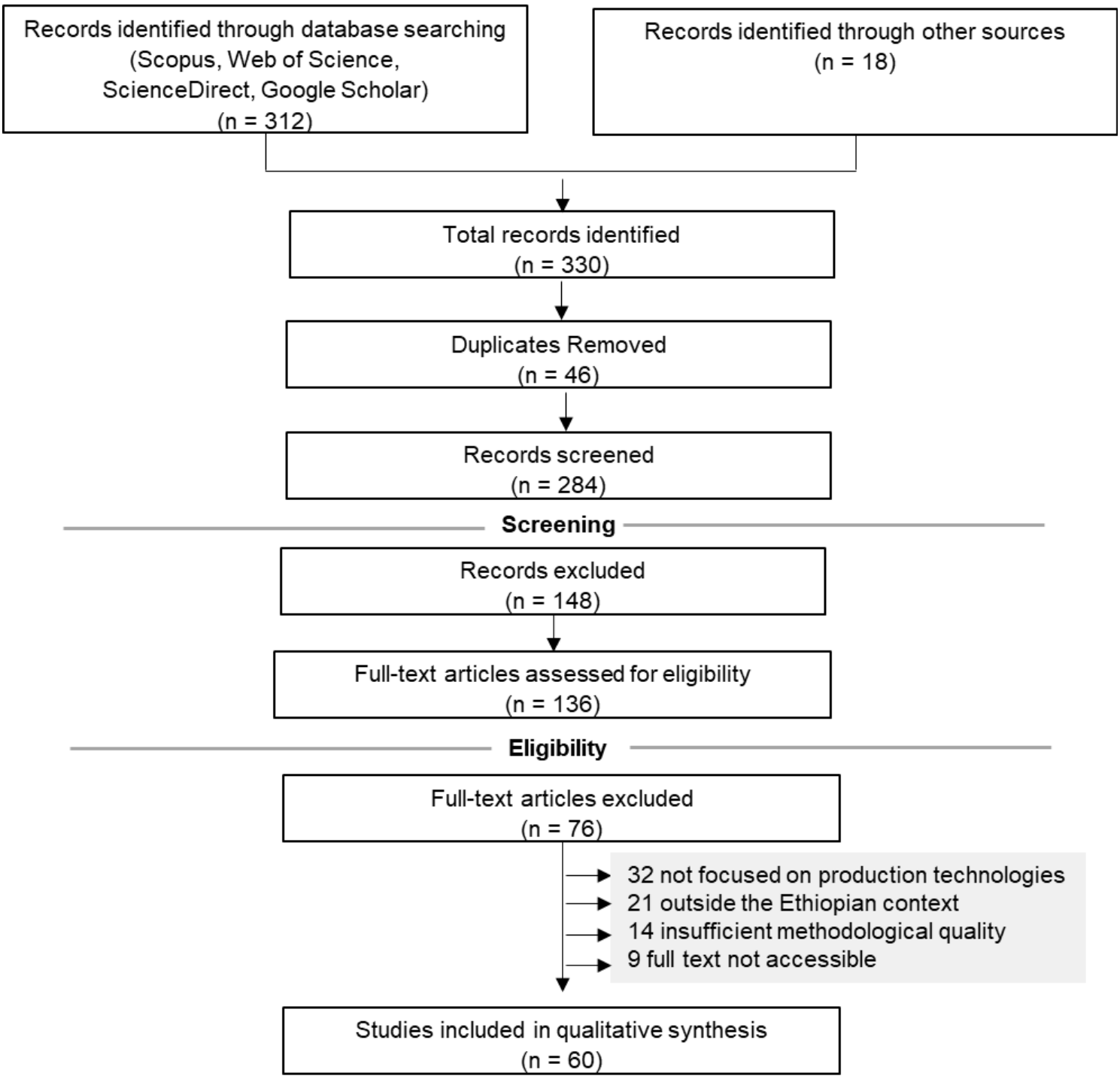


Figure 1

PRISMA 2020 Flow Diagram