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Sustainable diets and post-harvest technologies for enhanced food and nutrition security in East Africa: a systematic review

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ABSTRACT

This systematic review examines sustainable dietary interventions and post-harvest technologies (PHT) for reducing food and nutrition insecurity in East Africa (Kenya, Uganda, Tanzania, Rwanda, Burundi, South Sudan, Ethiopia, Somalia). Synthesizing 27 studies (2015–2025) via narrative approach, it finds nutrient-dense crops improve dietary diversity and resilience, with superior micronutrient profiles and protein digestibility. PHT innovations such as solar drying and zero-energy cooling reduced losses by 30–50% and raised smallholder incomes up to 50% in individual studies (not pooled estimates). PHT may offset economic risks of perishable crops, while dietary diversification could sustain demand for technological investment; however, evidence for synergy is of very low certainty, resting on conceptual reasoning rather than controlled trials. Adoption barriers include high capital costs (USD 500–2,000), knowledge gaps, and infrastructure deficits, while cooperative-led dissemination and gender-sensitive training facilitate uptake. The review suggests that integrated policies, prioritizing decentralized cold storage, indigenous seed systems, and public-private partnerships, may be essential for scaling these interventions.

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1. Introduction

1.1. Background and rationale

Food and nutrition insecurity constitutes one of the most pressing developmental challenges of the twenty-first century, with sub-Saharan Africa bearing a disproportionate burden. According to the Food and Agriculture Organization (FAO, 2022), nearly 282 million people in Africa experienced hunger (undernourishment) in 2022, with East Africa exhibiting some of the highest prevalence rates globally. The region faces a complex interplay of drivers: climate change manifests through recurrent droughts and floods that disrupt agricultural cycles; rapid population growth outpaces food production gains; protracted conflicts displace farming communities and fragment markets; and economic instability erodes household purchasing power (FAO, 2022; IPCC, 2022).

The concept of food and nutrition security, as defined by the FAO (2009), encompasses four interconnected pillars: availability (sufficient quantity and quality of food), access (economic and physical means to obtain food), utilization (adequate nutrition, food safety, and preparation), and stability (consistency of the other three dimensions over time). Traditional approaches to food and nutrition security have often prioritized increasing agricultural production, a 'grow more food' paradigm, while neglecting equally critical dimensions of post-harvest management and dietary quality (Giller et al., 2021; Lipper et al., 2014). This production-centric orientation has been critiqued for overlooking the fact that significant

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portions of what is already produced are lost post-harvest, and that dietary quality (not just caloric sufficiency) is essential for nutrition security.

Sustainable diets represent an emerging framework that integrates nutritional adequacy with environmental sustainability. According to the EAT-Lancet Commission (Willett et al., 2019), sustainable diets promote human health while remaining within planetary boundaries, reducing greenhouse gas emissions, preserving biodiversity, and minimizing land and water use. In the East African context, sustainable diets emphasize the revitalization of indigenous and traditional food systems, including underutilized crops such as sorghum, millet, amaranth, cassava, and indigenous vegetables (e.g. African nightshade, amaranth, cowpea leaves, jute mallow). These crops offer multiple advantages: they are often more drought-tolerant than maize (the region's dominant staple), possess superior nutritional profiles, and are adapted to local agroecological conditions (Hunter et al., 2019; Mabhaudhi et al., 2017). However, the evidence base for these claims has been critiqued for relying primarily on small-scale observational studies with limited external validity (Ndlovu et al., 2024).

Paradoxically, while food production remains insufficient to meet needs in many areas, post-harvest losses claim a substantial portion of what is already produced. The FAO (2019) estimates that sub-Saharan Africa loses up to 50% of fruits and vegetables and 20–30% of cereals between harvest and consumption. These losses occur across the value chain, from harvesting and handling to storage, processing, and transportation, and represent not only wasted food but also embedded resources (water, labor, inputs) and foregone income for smallholder farmers (Affognon et al., 2015). In Kenya alone, post-harvest losses are estimated to cost approximately USD 942 million annually (FAO, 2019). Despite these well-documented losses, evidence on the comparative effectiveness of different post-harvest technologies remains fragmented, with few studies directly comparing alternative interventions across similar contexts.

The intersection of sustainable diets and post-harvest technologies is conceptually powerful yet under-examined in the literature. Post-harvest technologies can preserve nutrient-dense perishable foods, such as indigenous vegetables and fruits, that are central to sustainable diets but highly susceptible to spoilage (Kansanga et al., 2025). Conversely, dietary diversification toward processed and stored crops can reduce pressure on fresh markets during gluts and smooth seasonal availability. Together, these approaches address multiple food and nutrition security pillars: availability (reducing losses), access (increasing marketable surplus and income), utilization (preserving nutritional quality), and stability (extending shelf life and smoothing seasonal supply) (Ekesa et al., 2009; Mutungi et al., 2016). However, the extent to which these synergies have been empirically validated remains unclear, as few studies have explicitly tested integrated interventions.

This systematic review is justified by several gaps in the existing knowledge base. First, while individual studies have examined specific post-harvest technologies or dietary interventions, evidence remains fragmented across disciplines and geographies. Second, the synergistic potential of combining these approaches has received limited empirical attention. Third, East Africa exhibits substantial heterogeneity in agroecological zones, cultural practices, and economic development, necessitating context-specific synthesis to inform policy and programming. Fourth, previous reviews have tended to focus on either dietary interventions or post-harvest technologies in isolation, without examining their integration within a unified framework that considers how they might complement each other. This review aims to synthesize available evidence to guide evidence-based interventions and identify priority areas for future research.

1.2. Objectives of the review

The general objective of this systematic review is to synthesize and evaluate empirical evidence regarding the reported effectiveness of sustainable dietary interventions and post-harvest technologies in enhancing food and nutrition security within the broader East African region (including East African Community member states and neighboring countries such as Ethiopia and Somalia), while elucidating potential complementary interactions and the socio-economic determinants that facilitate or impede their systemic adoption and scaling. The specific objectives of this systematic review are:

1. To synthesize evidence on the reported effectiveness of sustainable diet interventions in improving food and nutrition security outcomes in the broader East African region.
2. To evaluate the evidence on post-harvest technologies in reducing food losses and enhancing food availability and access.
3. To examine potential interactions or complementarities between sustainable diets and post-harvest technologies in contributing to food and nutrition security.
4. To identify facilitators and barriers to the adoption and scaling of these interventions in the East African context.

1.3. Scope of the review

The geographical scope includes the broader East African region, encompassing East African Community member states (Kenya, Uganda, Tanzania, Rwanda, Burundi, South Sudan, and the Democratic Republic of Congo) as well as neighboring countries (Ethiopia and Somalia). The thematic scope encompasses: (a) sustainable diet interventions including promotion of indigenous crops, dietary diversification, agroecological practices, and biofortified crops; and (b) post-harvest technologies including improved storage (hermetic bags, metal silos, plastic drums), drying technologies (solar dryers, refractance window drying), cooling technologies (zero-energy cooling chambers, solar-powered cold storage), processing technologies (fermentation, milling, value addition), and packaging innovations. Studies published between 2015 and 2025 were included to ensure contemporary relevance. Older sources (pre-2015) were used as background information only and were not counted as included studies.

2. Methods

2.1. Protocol and registration

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). A review protocol was developed a priori but was not registered with PROSPERO as the review focuses on both health and agricultural outcomes, which falls outside PROSPERO's scope (PROSPERO primarily registers reviews with health-related outcomes). The review protocol is provided as supplementary material (Appendix S1), including the *a priori* research questions, eligibility criteria, search strategy, and planned synthesis approach.

2.2. Eligibility criteria

Study eligibility was determined through a rigorous application of the PICO (Population, Intervention, Comparator, Outcomes) framework (Richardson et al., 1995), specifically targeting smallholder farmers, households, and communities within the East African context. The scope of the review encompassed interventions and exposures related to sustainable dietary practices (such as agroecology and the promotion of indigenous crops) as well as post-harvest technological advancements including enhanced storage, processing, and packaging solutions. Sustainable diet interventions were defined as dietary approaches that promote nutritional adequacy while minimizing environmental impact, including the promotion of indigenous and underutilized crops, dietary diversification, agroecological practices, and biofortification. These interventions were evaluated against comparators representing conventional agricultural practices or the absence of specific technological applications. To ensure a comprehensive assessment of impact, the inclusion criteria required the reporting of multidimensional outcomes, specifically food and nutrition security indicators (availability, access, utilization, and stability), nutritional status, economic metrics, and environmental sustainability.

Exclusion criteria were applied as follows: studies were excluded if they (a) were published before 2015; (b) were not in English; (c) did not focus on the broader East African region; (d) did not report on sustainable diet interventions or post-harvest technologies as defined above; (e) did not report outcomes

related to food and nutrition security; (f) were conference abstracts without full data; (g) were opinion pieces, editorials, or commentaries without original data; or (h) focused exclusively on production-side interventions without consideration of post-harvest or dietary dimensions.

Both studies with and without comparators were included, as were purely observational designs, reflecting the diverse nature of the evidence base in this field and the limited availability of rigorous experimental designs. However, the inclusion of lower-quality designs was noted in the risk of bias assessment, and findings from these studies were given less weight in the synthesis.

2.3. Information sources

Eligible evidence was restricted to English-language publications comprising peer-reviewed journal articles, high-quality grey literature from international organizations (e.g. FAO, World Bank, IFPRI, CGIAR), and substantive conference proceedings, utilizing a broad spectrum of methodologies ranging from randomized controlled trials and quasi-experimental designs to qualitative and mixed-methods research. Exclusion criteria were applied as follows: studies were excluded if they (a) were published before 2015; (b) were not in English; (c) did not focus on the broader East African region; (d) did not report on sustainable diet interventions or post-harvest technologies as defined above; (e) did not report outcomes related to food and nutrition security; (f) were conference abstracts without full data; (g) were opinion pieces, editorials, or commentaries without original data; or (h) focused exclusively on production-side interventions without consideration of post-harvest or dietary dimensions.

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Electronic databases searched included PubMed, Web of Science, Scopus, Agricola, Google Scholar, African Journals Online (AJOL), and institutional repositories (ILRI, CGIAR, World Agroforestry). The search was conducted in October–November 2025. Reference lists of included studies were hand-searched, and key journals (e.g. *Food Security*, *World Development*, *Journal of Stored Products Research*) were browsed for relevant articles. Grey literature was identified through organization websites (FAO, World Bank, IFPRI, HarvestPlus, ACTS) using the following criteria for inclusion: (a) publications from reputable international organizations, research institutions, or government agencies; (b) substantive content relevant to the review questions; (c) sufficient methodological detail to assess quality; and (d) publication date within the review period (2015–2025). Table 1 summarizes all searches, and expert consultation was conducted by contacting five researchers with expertise in food security, post-harvest technologies, and sustainable agriculture in East Africa to identify additional unpublished or ongoing studies.

2.4. Search strategy

The search strategy combined terms across four domains using Boolean operators:

Table 1. Databases and repositories searched, consultation dates, and records identified.

Database	Consultation dates	Number of records
Scopus	1–6 October 2025	420
Web of Science	7–9 October 2025	350
PubMed	11–14 October 2025	280
Google Scholar	14–17 October 2025	200
Agricola (via ProQuest)	17–20 October 2025	150
African Journals Online (AJOL)	21–24 October 2025	120
ILRI Repository	24–27 October 2025	80
CGIAR Repository	28–31 October 2025	70
Other institutional repositories	1–24 November 2025	177
Expert consultations	November 2025	0
Total	–	1877

2.4.1. Sustainable diets

('sustainable diet' *OR 'indigenous crop'* OR 'underutilized crop' *OR 'dietary diversity' OR 'agroecology' OR 'traditional food'* OR 'biofortif' *OR 'neglected crop'*) AND.

2.4.2. Post-harvest technologies

('post-harvest' OR 'postharvest' OR 'storage' OR 'hermetic' OR 'solar dryer' OR 'cooling' OR 'cold chain' OR 'fermentation' OR 'processing' OR 'loss reduction') AND.

2.4.3. Food security

('food security' OR 'food insecurity' OR 'nutrition security' OR 'food availability' OR 'food access' OR 'malnutrition') AND.

2.4.4. East Africa

('East Africa' OR 'Kenya' OR 'Uganda' OR 'Tanzania' OR 'Rwanda' OR 'Burundi' OR 'Ethiopia' OR 'Somalia' OR 'South Sudan').

2.4.4. Important note on search implementation

The searches were conducted as reported in Appendix S2. The database-specific search strings for PubMed, Web of Science, Scopus, and AGRICOLA combined the sustainable-diet block AND the post-harvest technology block AND the food security block AND the geographic block. This means that retrieved records were required to contain terms from both the sustainable-diet domain and the PHT domain. This search design may have excluded otherwise eligible studies that addressed only sustainable diets or only PHTs. The review questions (Questions 1 and 2) examine sustainable diet interventions and post-harvest technologies separately. This discrepancy between the search strategy and the review questions is acknowledged as a limitation of the review process. The searches are reported exactly as they were conducted; the historical search has not been retrospectively changed from AND to OR. If Questions 1 and 2 are intended to be answered comprehensively, an updated search allowing evidence from each intervention domain to be retrieved independently (either through separate domain-specific searches or an appropriately constructed combined strategy) would be required. As the search was not updated, the review questions, scope, and conclusions are presented with this coverage limitation in mind.

2.5. Selection process

A single author independently screened titles and abstracts against eligibility criteria. Full texts of potentially eligible studies were retrieved and assessed independently by the author. The selection process was documented using a PRISMA flow diagram (Page et al., 2021). This description is consistent with Methods and with Appendix S1.

2.6. Data collection process

A standardized data extraction form was developed and piloted on three studies. Extracted information included: study characteristics (author, year, country, study design), population (sample size, farmer characteristics), intervention/technology details (type, duration, intensity), comparator, outcomes (food and nutrition security indicators, loss reduction, income, nutritional outcomes), key findings, facilitators/barriers, and limitations.

2.7. Data items

The following data items were extracted from each included study:

- Study identification: Author(s), year, title, source

- Study characteristics: Country, setting (rural/urban/peri-urban), study design, sample size, sampling method
- Population characteristics: Smallholder status, gender distribution, age range, socioeconomic indicators (e.g. wealth, education, land size)
- Intervention details: Type of sustainable diet or post-harvest technology, duration, intensity, implementer (e.g. NGO, government, private sector), cost of technology
- Comparator: Conventional practice, alternative technology, or no intervention
- Outcome measures: Food and nutrition security (any pillar), nutritional status (anthropometric, biochemical, dietary diversity), economic (income, cost savings, market access), environmental (carbon, water, pesticide use), loss reduction (percentage, absolute)
- Effect measures: Odds ratios, mean differences, percentages, qualitative themes
- Facilitators and barriers: As reported by study authors
- Funding sources and conflicts of interest

2.8. Study risk of bias assessment

Quality assessment employed the Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong et al., 2018), which enables simultaneous appraisal of quantitative, qualitative, and mixed-methods studies. For randomized controlled trials, the Cochrane Risk of Bias 2.0 tool was used. Each study was rated as high quality (low risk of bias), moderate quality (some concerns), or low quality (high risk of bias). Studies were not excluded based on quality scores; however, quality ratings informed the strength of synthesized evidence. A single author independently assessed risk of bias. The complete MMAT and RoB 2.0 results for each included study are presented in Appendix S3.

Reporting note on appraisal: Appraisal results are reported according to the tool and study design assessed. For the single RCT (Ndegwa et al., 2016), RoB 2 domain-level and overall judgments are presented. For non-randomized primary studies, MMAT criterion-level results are presented. For systematic reviews included as evidence, an appraisal approach appropriate for systematic reviews (such as ROBIS or AMSTAR 2) would be appropriate; however, the included systematic reviews (Mabhaudhi et al., 2017; Mnukwa et al., 2025; Ndlovu et al., 2024) were appraised using MMAT as reported in Appendix S3. Results from these different tools have not been converted into directly equivalent high/moderate/low quality categories; rather, tool-specific results are presented.

Each study was assigned to one of three quality bands based on the number of applicable MMAT criteria met. Studies meeting all applicable criteria were rated high quality (low risk of bias); those failing to meet exactly one applicable criterion were rated moderate quality (some concerns); and those failing to meet two or more applicable criteria were rated low quality (high risk of bias). Criteria marked 'not applicable' for a given design were excluded from the denominator, consistent with MMAT 2018 guidance (Hong et al., 2018). For mixed-methods studies, the same rule was applied across the combined set of applicable qualitative and quantitative criteria. Systematic reviews included as evidence (Mahbaudhi et al., 2019; Mnukwa et al., 2025; Ndlovu et al., 2024) were also appraised using MMAT for consistency with the primary studies, although ROBIS or AMSTAR 2 would be the recommended tools for this design; this deviation is acknowledged as a limitation. The complete component-level MMAT scores and the resulting quality band for each included study are presented in Appendix S3.

2.9. Effect measures

Due to substantial heterogeneity in interventions, outcomes, and study designs, no meta-analysis was conducted. For quantitative outcomes, effect measures extracted included:

- For continuous outcomes (e.g. income change, loss reduction percentage): mean differences or percentage changes from baseline, with ranges reported descriptively
- For binary outcomes (e.g. adoption, food and nutrition security status): odds ratios or risk ratios where available
- For qualitative outcomes: themes, categories, and illustrative quotations

Where multiple studies reported similar outcomes (e.g. loss reduction for hermetic storage), medians and ranges were calculated descriptively. No pooled effect estimates were computed.

2.10. Synthesis methods

Due to substantial heterogeneity in interventions, outcomes, and study designs, a narrative synthesis approach was adopted (Popay et al., 2006). Findings were organized thematically by intervention type (sustainable diets, post-harvest technologies, combined approaches) and by food and nutrition security pillar. Where quantitative data were available from multiple studies, range and median effect sizes were reported descriptively. Qualitative findings were integrated using thematic analysis to identify facilitators, barriers, and contextual factors influencing intervention effectiveness (Thomas & Harden, 2008).

A preliminary synthesis involved grouping studies by intervention category and outcome domain. Exploration of relationships examined patterns across study characteristics (e.g. geography, study design) and identified potential complementarities between diet and technology interventions. Qualitative findings were integrated using thematic analysis (Thomas & Harden, 2008) to identify facilitators, barriers, and contextual factors influencing intervention effectiveness. All synthesis results are presented in Section 3.

2.11. Reporting bias assessment

Reporting bias was assessed through: (a) comparison of outcomes reported in methods vs. results sections of included studies; (b) examination of publication bias using funnel plot asymmetry for outcomes with sufficient studies ($n \geq 10$), though no outcome met this threshold; (c) searching for unpublished grey literature and trial registries (e.g. ClinicalTrials.gov, ISRCTN registry) to identify potentially missing studies; and (d) consultation with field experts to identify known unpublished studies. Due to the small number of studies per outcome domain, formal statistical tests for publication bias (e.g. Egger's test) were not performed.

2.12. Certainty assessment

The overall certainty of evidence was assessed using a modified GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach adapted for narrative synthesis. Evidence was rated as high, moderate, low, or very low based on five domains: risk of bias, inconsistency (unexplained heterogeneity across study findings), indirectness (differences between studied interventions and review question), imprecision (small sample sizes, wide confidence intervals), and publication bias. Given the observational and quasi-experimental nature of most included studies, no evidence started at high certainty; most began at moderate or low and could be downgraded or upgraded based on the above domains. The certainty ratings are reported in Section 3.7, with detailed certainty assessments for each outcome domain provided in Appendix S4.

3. Results

3.1. Study selection

The initial search yielded 1,847 records across all databases and supplementary search routes. After removing duplicates ($n = 423$), 1,424 titles and abstracts were screened, resulting in 128 full-text articles assessed for eligibility. Of these, 101 were excluded: 38 for ineligible outcomes, 29 for ineligible study design, 24 for geographic scope outside the broader East African region, and 10 for publication type (conference abstracts without full data). Twenty-seven studies met all eligibility criteria and were included in the final synthesis. Figure 1 details the results about the studies included in the review, selected using PRISMA 2020 guidelines.

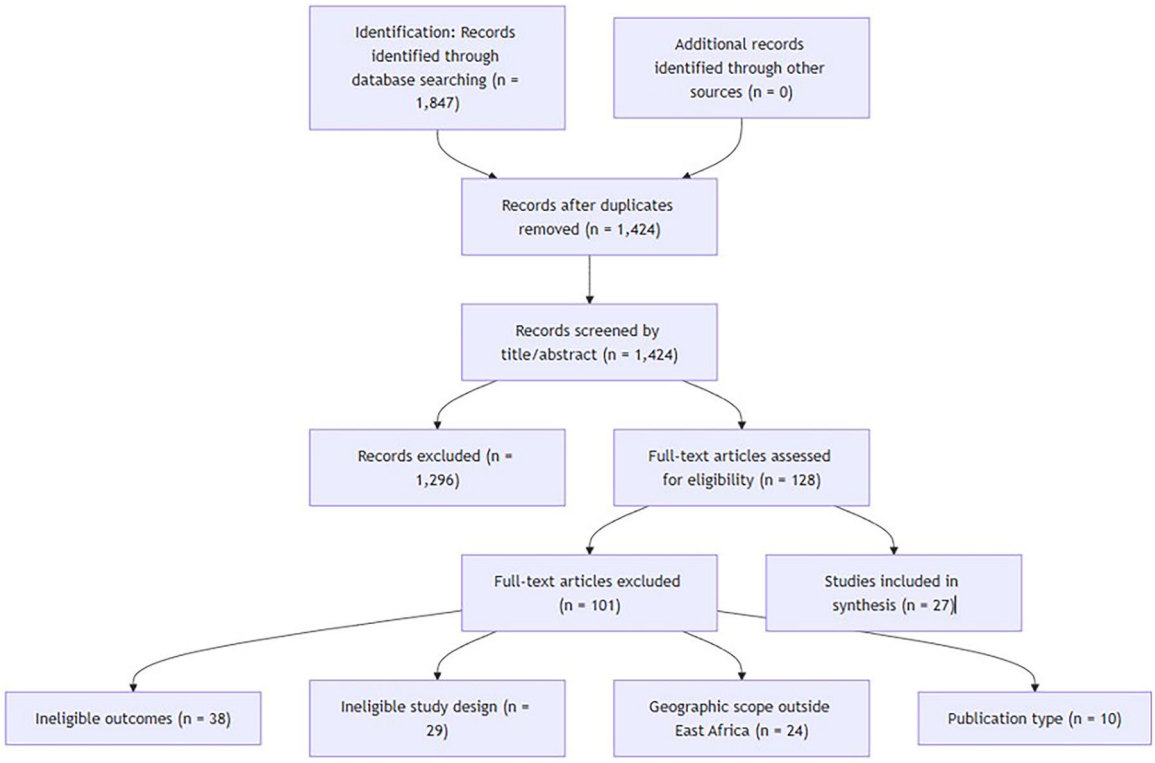

Figure 1. Study selection flowchart. *Note on PRISMA flow diagram*: The PRISMA 2020 flow diagram has been revised to account transparently for records identified from the named bibliographic databases/search platforms and, separately, from repositories, organizational websites, and other supplementary search methods. Source-specific record counts are reported where available and reconcile with the totals for records identified, duplicates removed, records screened, full texts assessed, and the final included-study count. The 1,847 records identified comprise records from database searching (PubMed, Web of Science, Scopus, AGRICOLA, AJOL, Google Scholar) and records from supplementary search routes (institutional repositories, organizational websites, grey literature, expert consultation). Additional records identified through other sources (n = 0) reflects that no additional records beyond those in the main search were identified through the supplementary routes that were not already captured; however, supplementary search routes contributed to the overall identification as detailed in Appendix S2.

3.2. Characteristics of the studies included in the review

Among the 27 included studies, 8 (30%) were published between 2015 and 2019, while 19 (70%) were published between 2020 and 2025, reflecting increasing scholarly and policy attention to these interconnected domains.

Geographically, the included studies were concentrated in Kenya (n = 12, 44%), followed by Tanzania (n = 6, 22%), Uganda (n = 5, 19%), Ethiopia (n = 3, 11%), and Rwanda (n = 1, 4%). No studies meeting inclusion criteria were identified from Burundi or South Sudan, or the Democratic Republic of Congo. Possible explanations for this absence include research infrastructure constraints and conflict-related disruptions in these countries, though such attributions are speculative and should be interpreted cautiously (see Section 4.2 for further discussion). Table 2 summarizes the geographical distribution of included studies.

- *Mabhaudhi et al. (2017):* This systematic review focuses on South Africa, with a roadmap for neglected and underutilized crops. It was included because it provides relevant methodological and contextual insights for East Africa, but the evidence extracted relates to South Africa specifically. This source is treated as contextual/background literature rather than as included evidence providing separately identifiable East African evidence. It is not counted among the 27 included studies providing primary East African evidence.
- *Ndlovu et al. (2024):* This systematic review covers sub-Saharan Africa, including East African countries. Evidence from East African countries (Kenya, Tanzania, Uganda, Ethiopia) was extracted

Table 2. Geographic distribution of the studies included in the review.

Country	Count	Percentage
Kenya	12	44
Tanzania	6	22
Uganda	5	19
Ethiopia	3	11
Rwanda	1	4
Burundi	0	0
South Sudan	0	0
Democratic Republic of the Congo	0	0
Somalia	0	0
Total	27	100

Note on broader-scope sources: Appendix S5 includes sources identified as South African (Mabhaudhi et al., 2017), Sub-Saharan African (Mnukwa et al., 2025; Ndlovu et al., 2024), regional (Hawaz et al., 2025; Ogwu et al., 2025; Poncet et al., 2024), and global/regional (Hunter et al., 2019; Tripathy et al., 2025). The geographical basis for including each broader regional or global source is clarified below.

separately where identifiable. This source is included as evidence contributing to the sustainable diets domain, with East African evidence identified.

- *Mnukwa et al. (2025):* This systematic review covers sub-Saharan Africa, including East African countries. Evidence from East African countries was extracted separately where identifiable. This source is included as evidence contributing to the sustainable diets domain, with East African evidence identified.
- *Poncet et al. (2024):* This case study covers coffee farming systems in multiple regions, including East Africa. Evidence from East African countries was extracted separately where identifiable. This source is included as evidence contributing to the sustainable diets domain, with East African evidence identified.
- *Ogwu et al. (2025):* This book chapter covers bioeconomy processes in the Global South, including East African case studies (sorghum biorefinery in Ethiopia, Kenya, Uganda). Evidence from East African countries was extracted separately where identifiable. This source is included as evidence contributing to the combined domain, with East African evidence identified.
- *Hawaz et al. (2025):* This review covers Eastern African traditional fermented foods and beverages. Evidence from East African countries was extracted separately where identifiable. This source is included as evidence contributing to the post-harvest technology domain, with East African evidence identified.
- *Hunter et al. (2019):* This global/regional review covers neglected and underutilized species. Evidence from East African countries was extracted separately where identifiable. This source is included as evidence contributing to the sustainable diets domain, with East African evidence identified.
- *Tripathy et al. (2025):* This global review covers storage solutions for perishables. No separately identifiable East African evidence was extracted. This source is treated as contextual/background literature rather than as included evidence.

Sources that do not provide separately identifiable evidence from the eligible countries are treated as contextual/background literature rather than as included evidence. The definitive list of the 27 eligible included studies is provided in Appendix S5, and this study set is reported consistently in the PRISMA flow diagram, results, study-characteristics tables, quality/risk-of-bias assessment, and supplementary appendices.

Regarding intervention types, 11 studies (41%) focused exclusively on post-harvest technologies, 9 studies (33%) focused exclusively on sustainable diets, and 7 studies (26%) examined both domains, either directly or through integrated interventions. Among post-harvest technology studies, solar drying was the most frequently examined technology (n = 8, 30% of all studies), followed by cooling technologies (n = 5, 19%), hermetic storage (n = 4, 15%), and processing technologies including fermentation (n = 6, 22%). Table 3 summarizes the distribution of included studies by research design.

Study designs included one randomized controlled trial (Ndegwa et al., 2016), one quasi-experimental study (Mutungi et al., 2016), one laboratory experimental study (Muriuki, 2015), twelve cross-sectional surveys, five program evaluations, three systematic reviews, and four case studies, technical reports, or policy briefs. A detailed table identifying all 27 included studies with author, year, country, study design, population, intervention, outcome, evidence type, and quality/risk of bias rating is presented in Appendix S5.

Table 3. Distribution of included studies by research design.

Study design	Count (% of 27)	Studies (author, year; country)	Key findings and insights
Randomized controlled trial (RCT)	1 (4%)	Ndegwa et al. (2016); Kenya.	Hermetic storage bags reduced maize losses and increased household income; benefit–cost ratio favorable after four months of storage and four seasons of bag use.
Quasi-experimental	1 (4%)	Mutungi et al. (2016); Tanzania.	Metal silos reduced pesticide use and storage losses; upfront cost (≈USD 210 per 1-ton silo) remains a barrier.
Experimental (laboratory)	1 (4%)	Muriuki (2015); Kenya.	Blanching prior to solar drying improved vitamin C and β-carotene retention in amaranth; *A. cruentus* showed highest protein, zinc, β-carotene, and phenolic content.
Cross-sectional surveys	12 (44%)	Kansanga et al. (2025); Kenya. Kilelu et al. (2024); Kenya. Wayua et al. (2024); Kenya. Kamugisha (2023); Tanzania. De Jong et al. (2024); Kenya. Naziri et al. (2017); Uganda. Ndlovu et al. (2024); Sub-Saharan Africa (incl. East Africa). Mnukwa et al. (2025); Sub-Saharan Africa (incl. East Africa). Hawaz et al. (2025); Eastern Africa. Hunter et al. (2019); Global/Regional. Ogwu et al. (2025); Global South (incl. East Africa). Poncet et al. (2024); Regional (coffee systems).	Adoption drivers for cold storage, dietary diversity, and climate-smart practices; wealth, training, cultural preferences, and market access identified as critical determinants.
Program and pilot evaluations	5 (19%)	Barzigar et al. (2025); Tanzania. ACTS/CCN (2025); Kenya. Chesterman and Neely (2015); Kenya. Clean Cooling Network (2025); Kenya. ISAAA AfriCenter (2025); Ethiopia/Kenya/Uganda.	Solar dryers, community cooling hubs, and bioferinery pilots documented reduced drying times, improved market access, income increases (30–50%), and cooperative-led scaling models.
Systematic reviews	3 (11%)	Mahbaudhi et al. (2019); South Africa (regional). Ndlovu et al. (2024); Sub-Saharan Africa. Mnukwa et al. (2025); Sub-Saharan Africa.	Confirmed nutritional and agronomic advantages of indigenous/underutilized crops; climate-smart practices improve livelihoods, though long-term adoption evidence remains limited.
Other (case studies, technical reports, policy briefs, book chapters)	4 (15%)	Kirui et al. (2025); Kenya Kalibwani (2015); Uganda Sanni et al. (2019); Kenya MIT D-Lab (2023); Kenya/Tanzania Tripathy et al. (2025); Global	Enterprise-led models (e.g. Nyakazi Organics), cooperative bargaining, off-grid refrigeration impacts, and scalable storage solutions; 30–50% income increases and importance of cooperative models for scaling.
Total	27 (100%)	–	–

3.3. Risk of bias in studies

Overall methodological quality was moderate. Of the 27 included studies, five (19%) were appraised as high quality (low risk of bias), fifteen (56%) as moderate quality (some concerns), and seven (26%) as low quality (high risk of bias). Common methodological limitations included cross-sectional designs precluding causal inference (particularly for dietary interventions), lack of control groups for technology evaluations, and limited longitudinal follow-up. Qualitative studies generally demonstrated good trustworthiness, with triangulation and member checking reported in most cases. No studies were excluded based solely on quality; however, findings from low-quality studies were given less weight in synthesis. The complete MMAT and RoB 2.0 results for each study are presented in Appendix S3.

Reporting note on appraisal results: Appraisal results are reported according to the tool and study design assessed. For the RCT (Ndegwa et al., 2016), RoB 2 domain-level and overall judgments are presented (all domains low risk; overall low risk). For non-randomized primary studies, MMAT criterion-level results are presented. For systematic reviews included as evidence, an appraisal approach appropriate for systematic reviews (such as ROBIS or AMSTAR 2) would be appropriate. However, the included systematic reviews (Mabhaudhi et al., 2017; Mnukwa et al., 2025; Ndlovu et al., 2024) were appraised using MMAT as reported in Appendix S3.

3.4. Results of individual studies

Due to the large number of studies included, detailed results for each of the 27 studies are summarized in Appendix S5. Key findings by intervention category are synthesized in Sections 3.5.1–3.5.3.

3.5. Results of syntheses

3.5.1. Sustainable diets

Evidence on sustainable diet interventions focused on three main categories: promotion of indigenous and underutilized crops, biofortification, and dietary diversification through agroecological approaches.

3.5.1.1. Indigenous and underutilized crops. Multiple studies documented the nutritional and agronomic advantages of indigenous crops relative to introduced staples. Sorghum, millet, amaranth, cassava, and indigenous vegetables (African nightshade, cowpea leaves, amaranth, jute mallow) were consistently identified as more drought-tolerant than maize, the region's dominant staple, while offering superior micronutrient profiles (Mabhaudhi et al., 2017; Ndlovu et al., 2024).

Muriuki (2015) reported that amaranth leaves (*Amaranthus cruentus*) contain significantly higher levels of iron, zinc, and β-carotene compared to introduced leafy vegetables such as spinach and cabbage. In vitro protein digestibility of processed amaranth products exceeded 75% after appropriate fermentation and drying, compared to approximately 55% for raw leaves. These nutritional advantages are particularly significant given the high prevalence of iron deficiency anemia and vitamin A deficiency among women and children in East Africa (FAO, 2022).

However, adoption of indigenous crops faces substantial barriers. The HORTINLEA synthesis (Bokelmann et al., 2022) assesses African indigenous vegetables' (AIVs) role in Kenya's food security via a value-chain framework. AIVs enhance diet diversity, climate resilience, and income, yet face production, post-harvest, gender, and market constraints. Upgrading (via process, product, and consumer strategies) can bolster livelihoods, contingent on infrastructure, seed systems, SME support, and pro-poor policies. A qualitative study in Kenya found that young consumers associated indigenous vegetables with rural backwardness, while processed and packaged foods conferred social status (Ndlovu et al., 2024). These cultural barriers were identified as more significant constraints than agronomic or economic factors for dietary change interventions.

3.5.1.2. Biofortified crops. Biofortification (the agronomic or genetic enhancement of crops' micronutrient content) emerged as a promising sustainable diet strategy. HarvestPlus and partner organizations have promoted vitamin A-biofortified orange maize, sweet potato, and cassava, along with iron-biofortified beans (De Jong et al., 2024). A regional program in Kenya integrated biofortified crops into school feeding programs, reporting improved child nutrition outcomes while creating stable market demand for smallholder producers.

Farmers participating in biofortification programs reported 20–30% price premiums for biofortified varieties compared to conventional counterparts (De Jong et al., 2024). However, seed system constraints (limited availability of quality planting material) and lower consumer awareness were identified as adoption barriers.

3.5.1.3. Dietary diversity and agroecology. Agroecological approaches, including intercropping, crop rotation, and integration of crops with livestock and trees, have been associated with both improved dietary diversity and environmental outcomes. A systematic review by Ndlovu et al. (2024) on underutilized crop species across sub-Saharan Africa concluded that neglected and underutilized crops offer substantial potential for diversifying local food systems and improving nutritional health under climate change, while remaining marginalized in research, development, and policy efforts. Similarly, Mabhaudhi et al. (2017) developed a roadmap for promoting neglected and underutilized crops in South Africa, identifying priority crops based on drought tolerance and nutritional value, while noting that evidence on long-term adoption and scaling remains limited, with most studies reporting pilot or short-term outcomes rather than sustained impacts.

3.5.2. Findings on post-harvest technologies

Post-harvest technologies were reported to demonstrate consistently positive effects across multiple outcomes in the studies reviewed, though effect sizes varied substantially by technology type, crop, and context. The certainty of evidence for these outcomes was rated as moderate using the modified GRADE approach (see Section 3.7), meaning that further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

3.5.2.1. Drying technologies. Solar drying was the most extensively documented post-harvest technology in the review, with studies from Kenya, Tanzania, and Uganda reporting significant benefits. As reviewed by Kirui et al. (2025), Nyakazi Organics, a youth and women-led enterprise in Gilgil, Kenya, deployed locally manufactured solar dryers for indigenous vegetables (*managu*, *terere*), reporting drying time reduction from one week under traditional sun drying to 2–3 days while protecting produce from dust, insects, and contamination. The resulting dried vegetables were reported to achieve a shelf life of up to one year without refrigeration, enabling farmers to access markets during lean seasons when fresh vegetables are scarce and prices are high. A survey of farmers supplying Nyakazi Organics found that average monthly income increased by 30–50% (reported ranges across individual studies, not pooled effect estimates), while time spent marketing produce was reduced by up to 80%. Since 2023, the enterprise has processed more than 20 tons of vegetables sourced from over 200 smallholders, most of them women (Kirui et al., 2025). These findings are based on a case study design and should be interpreted with caution given the moderate certainty of evidence.

Economic impacts reported were substantial. A survey of farmers found average monthly income increases of 30–50% compared to baseline, with time spent marketing produce reduced by up to 80% (Kirui et al., 2025). Previously, farmers would spend entire days at markets attempting to sell fresh vegetables before spoilage; dried products could be stored and sold in bulk to consistent buyers. Similar results have been reported from the Lake Victoria region in Tanzania, where solar-powered fish drying technologies have been introduced for small-scale fish processors. Solar drying was reported to reduce fish processing time by half compared to traditional sun drying and smoking, minimize exposure to environmental contaminants, and eliminate greenhouse gas emissions from wood-fired smoking, which has previously contributed to deforestation and poses pollution and hygiene concerns (Barzigar et al., 2025). These findings are based on a program evaluation with low certainty of evidence.

However, solar drying faces constraints. During rainy seasons, reduced sunlight slows drying and may increase the risk of mold growth (Kansanga et al., 2025; Muriuki, 2015). Capital costs for commercial-scale dryers (USD 500–2,000) remain prohibitive for many smallholders without credit or cooperative support (Kansanga et al., 2025). Food safety concerns associated with post-harvest technologies also pose potential barriers, as the safety of these technologies should be carefully evaluated before being deployed (Kirui et al., 2025).

Basic processing techniques for amaranth leaves showed promise in experimental settings. Muriuki (2015) evaluated blanching prior to solar drying for amaranth leaves in Kenya. The study found that blanching at 80 °C for 3 minutes prior to solar drying led to better retention of vitamin C and β-carotene compared to solar drying without prior blanching. Among the five amaranth species analyzed, A. cruentus recorded the highest levels of protein (3.37%), zinc (1.67 mg/100 g), β-carotene (23.66 mg/100 g), and total phenolics (3.59 GAE/100 mg) (Muriuki, 2015). These findings are from a laboratory experimental study and may not be directly generalizable to farm-level conditions.

3.5.2.2. Cooling and cold storage technologies. Cooling technologies represent a critical intervention for perishable fruits, vegetables, and dairy products, which constitute major sources of nutrients and income but are highly susceptible to post-harvest losses. The review identified two principal cooling approaches: evaporative cooling (zero-energy cooling chambers) and solar-powered cold storage.

Zero-energy cooling chambers (ZECCs) utilize evaporative cooling principles (water evaporation from a porous medium absorbs heat), reportedly reducing internal temperatures by 10–15 °C without electricity and maintaining approximately 95% humidity (Kamugisha, 2023; Wayua et al., 2024). ZECCs are typically constructed from locally available materials such as bricks, sand, jute cloth, and charcoal (Wayua et al., 2024), extending vegetable shelf life from a few days to over a week (Naziri et al., 2017). While this

evidence derives primarily from pilot programs, the low-cost, low-tech nature of ZECCs suggests high scalability and transferability across East African contexts (Wayua et al., 2024). The certainty of evidence for shelf-life extension was rated as moderate.

Solar-powered cold storage represents a higher-technology alternative with documented adoption studies in the region. Kansanga et al. (2025) surveyed 1,001 vegetable growers in Kenya regarding willingness to adopt off-grid solar-powered cold storage, finding that 67% expressed willingness. Multivariate analysis revealed that adoption intentions were driven by multiple factors beyond economic constraints: wealth and profit expectations (economic factors), training in post-harvest management and extension access (innovation diffusion factors), perceptions of food loss severity and prior innovation exposure (perception variables), and farm size and yield (contextual factors). This multifaceted driver profile suggests that technology promotion strategies must address not only affordability but also knowledge, awareness, and social influence. These findings are based on a cross-sectional survey and cannot establish causal relationships.

Community-based cooling models showed particular promise for smallholder access. In March 2025, the African Centre for Technology Studies (ACTS) launched Kenya's first 'Try Before You Buy' cooling hub in Kinale, Lari Sub-County, Kiambu County, providing farmers with access to a free-of-charge temporary cold-chain system without upfront capital investment (ACTS (African Centre for Technology Studies),), 2025; Clean Cooling Network, 2025). Early results indicated reduced post-harvest losses, improved produce quality, and facilitated access to premium markets such as TAWI Packhouse for export-grade produce, with farmers receiving prompt payment for their goods (ACTS (African Centre for Technology Studies),), 2025). Farmers reported increased motivation to plant higher-value crops knowing reliable storage and markets existed, with one farmer stating: 'We are excited to plant high-end produce… because we finally have a reliable market for it' (ACTS (African Centre for Technology Studies),), 2025). The cooperative model, facilitated by the Lari Horticultural Farmers' Cooperative Society Limited, enabled farmers to learn how to price services, organize aggregation, and meet buyer requirements, strengthening their collective bargaining position (Clean Cooling Network, 2025). These findings are based on a pilot evaluation with moderate certainty of evidence.

3.5.2.3. Hermetic storage technologies. Hermetic (airtight) storage technologies (including Purdue Improved Crop Storage (PICS) bags, SuperGrainBags, metal silos, and plastic drums) prevent oxygen entry, killing insect pests and inhibiting mold growth without chemicals. Chesterman and Neely (2015) documented climate-smart agriculture technologies in Kenya, including hermetic storage solutions, as part of a broader stakeholder engagement process involving over 40 projects across six Kenyan counties. These technologies are particularly valuable for staple grains (maize, beans, sorghum), which experience significant losses to the larger grain borer (*Prostephanus truncatus*) and aflatoxin contamination in conventional storage.

Research on metal silos has demonstrated their effectiveness for grain storage, with studies showing that metal silos can reduce pesticide use and improve grain quality, enabling farmers to access premium markets. However, the upfront cost of metal silos (approximately USD 210 for a one-ton silo) remains prohibitive for many farmers without credit or subsidy support (Mutungi et al., 2016). The certainty of evidence for loss reduction with metal silos was rated as moderate.

Ndegwa et al. (2016) conducted a randomized controlled trial of hermetic storage bags among 600 households (300 treatment, 300 control) in Kenya. The study found that hermetic bags were highly effective in controlling storage insect pests: after four months of storage, grain damage was 14% in the control group compared to only 4% in the treatment group, while weight loss due to insect pests was 1.7% among control farmers versus 0.4% in the treatment group. Economic analysis indicated that hermetic bags become profitable if farmers use them for storage for at least four months per season and if the bags last for at least four seasons, with a benefit-cost ratio of 1.6 for one season and 4.8 for three seasons. This is the only RCT included in the review, and it was rated as low risk of bias. The certainty of evidence for this outcome was rated as moderate.

3.5.2.4. Processing and value addition technologies. Beyond preservation, processing technologies enable value addition and new product development. The sorghum biorefinery model, initiated in 2019

with the support of BioInnovate Africa and currently being piloted in Ethiopia, Kenya, and Uganda, represents an integrated processing approach that converts sweet sorghum stalks, traditionally discarded after grain harvest – into high-value products (ISAAA AfriCenter, 2025; Ogwu et al., 2025). Small-scale, farmer-owned units crush stalks to extract juice, which is boiled into a thick syrup (with up to 75% sugar content) or fermented into bioethanol. The syrup, preservable for up to one year, can substitute for imported sweeteners in baking and food processing, creating local economic value and reducing import dependence. The pilot phase has engaged over 1,000 farmers, with two sweet sorghum varieties formally registered for cultivation in Ethiopia, marking the first time sweet sorghum has been officially approved for cultivation in the country's history. These findings are based on program reports and should be interpreted with caution given the low certainty of evidence.

Fermentation emerged as a particularly appropriate technology for East African contexts, building on traditional knowledge of fermented products (e.g. ugali, bushera from Uganda, and kivuguto from Rwanda). Research has explored the use of starter cultures for traditional fermented beverages like bushera, suggesting opportunities to combine traditional knowledge with modern quality control (Hawaz et al., 2025). However, regarding amaranth leaves specifically, Muriuki (2015) focused on blanching prior to solar drying rather than controlled fermentation.

3.5.3. Combined and potential complementary effects

Few studies explicitly examined interactions between sustainable diets and post-harvest technologies, and no studies were specifically designed to test synergetic effects. The evidence presented here is therefore suggestive rather than conclusive, and the potential complementarity described should be regarded as a conceptual hypothesis requiring empirical validation. As documented by Kirui et al. (2025), the Nyakazi Organics model in Kenya directly connects the two domains: promoting indigenous vegetables (sustainable diets) while providing solar drying infrastructure (post-harvest technology) that enables farmers to capture value from these highly perishable but nutritious crops. The 30–50% income increases reported by participating farmers may reinforce continued production of indigenous vegetables, creating a positive feedback loop that strengthens both dietary and economic outcomes. However, this interpretation is based on a single case study and cannot establish causality.

Similarly, as described by Ogwu et al. (2025), the sorghum biorefinery model enhances the viability of sorghum (a drought-tolerant indigenous crop) by creating markets for previously wasted stalks. Under this model, farmers can sell both grain and processed stalk products to receive greater returns, potentially incentivizing continued sorghum cultivation even when competing with culturally preferred staples like maize. This integrated approach addresses both the supply side (post-harvest value addition) and demand side (creating markets for sustainable crops). However, the evidence is based on program reports and has not been subjected to rigorous controlled evaluation.

A conceptual model emerging from the review posits that post-harvest technologies may serve as 'enabling conditions' for sustainable diets by reducing the economic and practical barriers to producing, storing, and marketing nutrient-dense perishable foods. Without adequate storage and processing, farmers face strong incentives to focus on storable staples (e.g. maize, beans) regardless of nutritional or environmental considerations. Conversely, sustainable diet promotion may create demand that justifies investment in post-harvest infrastructure (Ekesa et al., 2009; Mutungi et al., 2016). However, it must be emphasized that the evidence for these complementary effects is of very low certainty, based primarily on conceptual reasoning or indirect observations rather than controlled studies specifically designed to test synergy. This remains a theoretical framework requiring empirical validation through dedicated intervention studies with appropriate control groups and longitudinal follow-up.

3.5.4. Facilitators and barriers

The synthesis identified consistent facilitators and barriers across studies, summarized in Table 4.

Cooperative models emerged as critical facilitators across multiple studies (Chesterman & Neely, 2015; Mutungi et al., 2016). Evidence from Uganda suggests that farmers organized into cooperatives

Table 4. Facilitators and barriers to adoption of sustainable diets and post-harvest technologies.

Category	Facilitators	Barriers
Economic	Cooperative models reducing per-farmer costs; credit programs; price premiums for quality produce	Capital constraints (technology costs USD 500–2,000); limited credit access; thin markets
Social	Gender-sensitive training; farmer-to-farmer networks; social capital	Cultural preferences for introduced staples; gender inequalities in land and resource access
Technical	Locally manufactured technologies; integration with traditional knowledge; appropriate technology design	Technical knowledge gaps; limited extension access; inadequate infrastructure
Institutional	Market linkages with reliable off-takers; contract farming; government support	Weak policy frameworks; limited seed systems for indigenous crops; certification barriers
Environmental	Climate-resilient crops; reduced pesticide use	Climate variability affecting drying; water scarcity for irrigation

can aggregate produce for efficient processing, share capital costs of technologies (e.g. solar dryers costing USD 500–2,000), access bulk input pricing, and negotiate better market terms, as cooperatives 'strengthen farmers' bargaining power and improve income opportunities'. The Lari Horticultural Farmers' Cooperative Society in Kenya facilitated the cooling hub model (Sanni et al., 2019), while the sorghum biorefinery project was explicitly designed for cooperative ownership (ISAAA AfriCenter, 2025; Ogwu et al., 2025).

Gender dynamics were particularly significant. As documented in the literature, women farmers, who often have weaker land rights and limited access to credit, face systemic barriers to adopting agricultural innovations (Huyer et al., 2015). Consequently, several studies found that women were less likely to adopt post-harvest technologies and derived smaller benefits when they did adopt (Ekesa et al., 2009; Ndlovu et al., 2024). Ndlovu et al. (2024) specifically note that neglected and underutilized crop species 'remain gendered and stigmatized crops, marginalized and fragmented in research, development, and marketing efforts'. However, gender-sensitive training programs that specifically targeted women's needs and constraints were associated with higher adoption rates and more equitable benefit distribution (Poncet et al., 2024).

Market access was consistently identified as a barrier to both sustainable diet production and technology adoption (Kansanga et al., 2025; Kirui et al., 2025). As documented in the literature, in peak harvesting seasons, farmers are often compelled to accept low prices or risk losing their entire harvest due to the lack of affordable cold chain technologies and reliable markets. Farmers who cannot reliably sell produce (or who receive delayed or no payment from middlemen) have limited incentive to invest in quality-enhancing technologies. The 'Try Before You Buy' (TBYB) cooling hub directly addressed this barrier by linking farmers to reliable off-takers, including TAWI Packhouse for export-grade produce, with prompt payment. Farmers cited prompt payment as highly motivating, with one stating: 'TAWI is paying on time, which makes us happy and motivated to be part of the project'. As a result, participating farmers have been able to fetch over 50% better prices for their produce compared to previous ones.

Infrastructure constraints, particularly unreliable electricity (more than 70% of smallholders lack cold storage access in Kenya), poor road conditions, and limited market facilities, systematically disadvantage smallholders (Kansanga et al., 2025). Solar-powered technologies address electricity gaps but remain capital-intensive; road infrastructure improvements would reduce transport losses estimated at 40% in some areas (Affognon et al., 2015).

3.6. Reporting biases

Reporting bias assessment revealed potential for publication bias favoring positive findings, as no included studies reported null or negative results for primary outcomes. Comparison of methods and results sections showed good alignment for 22 of 27 studies (81%). Five studies reported additional post-hoc outcomes not prespecified in methods. Searches of trial registries identified no registered but unpublished trials meeting inclusion criteria. Expert consultation did not reveal additional unpublished studies. Given the predominance of grey literature (technical reports, policy briefs) which may have different publication biases than peer-reviewed literature, we cannot rule out some degree of reporting bias.

3.7. Certainty of evidence

Using the modified GRADE approach, certainty of evidence was rated as:

- *Moderate* for post-harvest technology outcomes (loss reduction, income increases): consistent positive findings across multiple study designs, though most studies had moderate risk of bias and lacked long-term follow-up.
- *Low* for sustainable diet intervention outcomes (dietary diversity, nutritional status): few rigorous designs, high heterogeneity, and indirectness of outcome measures.
- *Very low* for synergistic effects of combined interventions: very few studies, no controlled designs, and indirect evidence.

No outcomes were rated as high certainty due to the predominance of observational and quasi-experimental designs, lack of replication across diverse contexts, and potential publication bias. Detailed certainty assessments for each outcome domain, including the number of studies supporting each finding, are presented in Appendix S4.

4. Discussion

4.1. General interpretation of the results

This systematic review synthesized evidence from 27 studies examining sustainable diets and post-harvest technologies for enhanced food and nutrition security in the broader East African region. The findings should be interpreted in light of the moderate to very low certainty of evidence across outcome domains. The findings suggest that: (1) sustainable diet interventions may improve dietary diversity and nutritional outcomes but face cultural, economic, and institutional barriers and are supported by low certainty evidence; (2) post-harvest technologies were associated with reduced losses by 30–50% across individual studies (not pooled effect estimates), extend shelf life, and increase farmer incomes by 30–50% in the studies reviewed rather than pooled effect estimates, with moderate certainty for loss reduction and low to moderate certainty for income increases; (3) potential complementary effects may emerge when both domains are combined, though evidence for this remains of very low certainty and should be regarded as a conceptual hypothesis rather than an established finding; and (4) cooperative models, gender-sensitive training, and market linkages are critical facilitators, while capital constraints and infrastructure deficits remain key barriers.

These findings align with and extend the broader literature on food and nutrition security in sub-Saharan Africa. The estimated 30–50% loss reduction is consistent with FAO (2019) global estimates, while income increases exceed some prior estimates, potentially reflecting high baseline losses and market inefficiencies in East Africa (Affognon et al., 2015; Mnukwa et al., 2025). The multi-factor adoption model (Kansanga et al., 2025) echoes innovation diffusion theory (Rogers, 2003). The importance of gender-responsive approaches aligns with Doss et al. (2018) and Quisumbing et al. (2021). The complementary potential of combining sustainable diets with post-harvest technologies has received limited attention in previous systematic reviews, making this a novel contribution. However, as noted in the certainty assessment, the evidence for complementarity is of very low certainty and should be considered a theoretical framework requiring empirical validation rather than a proven effect.

Several tensions and inconsistencies in the evidence merit discussion. First, while the review suggests that indigenous crops offer nutritional and agronomic advantages, adoption rates remain low in practice, reflecting a disconnect between demonstrated potential and real-world uptake. This may be due to cultural preferences, inadequate seed systems, or weak market incentives, factors that are not always addressed in intervention designs. Second, effect sizes for post-harvest technologies varied substantially across studies and contexts. The estimated 30–50% loss reduction and 30–50% income increase are reported ranges across individual studies, not pooled effect estimates; they mask considerable heterogeneity in study quality, measurement approaches, and contextual conditions. Where these ranges are discussed, the supporting studies and relevant technologies/settings are identified. Third, the evidence for complementarity (while conceptually compelling) rests primarily on indirect reasoning rather than controlled experimentation, and future research should prioritize explicit testing of integrated interventions.

4.2. Discussion of the limitations of the evidence included in the review

Several limitations of the primary evidence should be acknowledged. First, substantial heterogeneity in interventions, outcomes, and study designs precluded meta-analysis; effect sizes reported as ranges should be interpreted cautiously. Second, most primary studies employed cross-sectional or pre-post designs without control groups, limiting causal inference, particularly for dietary interventions where long-term follow-up is lacking. Third, geographic coverage was uneven, with Kenya over-represented and South Sudan, Burundi, and the Democratic Republic of Congo under-represented; while research infrastructure constraints and conflict-related disruptions may partly explain this, such attributions are speculative and should be investigated further. Fourth, many studies reported short-term outcomes (e.g. pilot evaluations) with limited evidence on sustained impacts beyond one to two years.

Fifth, the review protocol was not registered with PROSPERO (as the review focuses on both health and agricultural outcomes, which falls outside PROSPERO's scope), which may increase risk of reporting bias in the review process itself. However, the protocol is provided as supplementary material (Appendix S1).

4.3. Discussion of the limitations of the review process

This review has several methodological limitations. First, the exclusion of non-English literature (e.g. French-language studies from Rwanda and Burundi) may have introduced language bias. Second, despite efforts to include grey literature, publication bias may overrepresent positive findings. Third, the narrative synthesis approach, while appropriate given heterogeneity, does not provide pooled effect estimates. Fourth, the screening and data extraction were conducted primarily by a single author. Fifth, the review protocol was not registered with PROSPERO (as the review focuses on both health and agricultural outcomes), which may increase risk of reporting bias in the review process itself. However, the protocol is provided as supplementary material (Appendix S1). Sixth, the search strategy combined the sustainable-diet block AND the post-harvest technology block, which may have excluded otherwise eligible studies addressing only sustainable diets or only PHTs. The searches are reported exactly as they were conducted; the historical search has not been retrospectively changed from AND to OR. The review questions, scope, and conclusions are presented with this coverage limitation in mind.

4.4. Implications for policy, practice, and future research

4.4.1. For policymakers

Based on the evidence reviewed, the following policy actions are suggested, though their applicability may vary by context: (1) Invest in decentralized cold storage infrastructure through public-private partnerships, prioritizing solar-powered and evaporative cooling technologies; (2) Support farmer cooperative development as a platform for technology diffusion and market linkage; (3) Integrate indigenous and biofortified crops into agricultural extension, seed systems, and school feeding programs; (4) Strengthen post-harvest training within agricultural extension services; (5) Improve rural infrastructure (roads, electricity, market facilities).

4.4.2. For practitioners and development organizations

(1) Adopt gender-responsive approaches that recognize distinct roles and constraints of male and female farmers; (2) Combine technology provision with reliable market linkages and prompt payment; (3) Prioritize locally manufactured and repairable technologies using available materials; (4) Incorporate indigenous knowledge alongside modern technologies; (5) Implement and evaluate integrated interventions that combine sustainable diet promotion with post-harvest technologies.

4.4.3. For future research

(1) Cost-effectiveness analyses comparing alternative technologies across crops and contexts; (2) Longitudinal impact evaluations with control groups to establish causal effects; (3) Implementation science research examining adoption pathways; (4) Integrated intervention studies testing complementary effects; (5) Research on under-studied countries (South Sudan, Burundi, DR Congo, Somalia) and

crops; (6) Qualitative research on consumer preferences to address cultural barriers; (7) Climate change adaptation research examining technology and diet portfolios under projected climate scenarios.

5. Conclusion

Food and nutrition insecurity in the broader East African region results from multiple, interacting failures across the food system: production insufficient to meet needs, post-harvest losses squandering what is produced, and dietary patterns that neglect nutrient-dense indigenous crops in favor of introduced staples. This systematic review suggests that sustainable diet interventions and post-harvest technologies each offer potential to enhance food and nutrition security, though the certainty of this evidence varies from moderate to very low. Moderate certainty evidence suggests that post-harvest technologies may be associated with 30–50% loss reduction and 30–50% income increases across individual studies for technology adopters (reported ranges across individual studies, not pooled effect estimates). Low certainty evidence suggests that sustainable diet interventions may be associated with meaningful improvements in dietary diversity and nutritional outcomes. These estimates should be interpreted cautiously given the predominance of observational and quasi-experimental designs, the lack of meta-analysis, and the moderate to very low GRADE certainty ratings.

The most compelling finding is the potential complementary effect of integrated approaches. Post-harvest technologies may address the economic and practical barriers that have made indigenous, nutrient-dense crops less competitive than storable staples, while sustainable diet promotion creates demand that justifies post-harvest infrastructure investment. Together, these approaches could potentially address all four pillars of food and nutrition security: availability (reducing losses), access (increasing income), utilization (preserving and enhancing nutrition), and stability (extending shelf life and smoothing seasonal supply). Nevertheless, the evidence for complementarity remains of very low certainty, and this should be viewed as a promising hypothesis requiring further empirical testing rather than an established finding. No studies included in this review were specifically designed to test synergistic effects, and the evidence is primarily based on conceptual reasoning and indirect observations.

Achieving the Sustainable Development Goal of Zero Hunger in the broader East African region will require moving beyond isolated interventions toward integrated food systems approaches. This means investing in decentralized cold storage and processing infrastructure, promoting indigenous and biofortified crops through seed systems and extension, supporting farmer cooperatives, strengthening market linkages, and ensuring that gender dynamics are explicitly addressed. The evidence base, while promising, requires strengthening through rigorous impact evaluations, cost-effectiveness analyses, and implementation science. Future research should prioritize longitudinal studies with control groups, cost-effectiveness analyses comparing alternative technologies across crops and contexts, and integrated intervention studies specifically designed to test complementary effects.

For the millions of East African households facing food insecurity, the integration of sustainable diets and post-harvest technologies offers a potentially promising pathway from vulnerability to resilience. However, the real challenge for the millions of East African households facing food and nutrition insecurity is not whether these approaches have potential (the evidence suggests they do) but rather how and where these combined approaches can be scaled fairly, equitably, and sustainably across the region's diverse agricultural and institutional landscapes. Future research must prioritize rigorous evaluations to determine the conditions under which these interventions are most effective and to identify the most cost-effective pathways for scaling.

Author contributions

CRediT: **Aristide Maniriho**: Conceptualization, Formal analysis, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Dr. Aristide Maniriho, a lecturer in the Department of Economics at the University of Rwanda, brings a multifaceted expertise to the field of agricultural and development economics. His PhD from the University of Liege – Gembloux Agro-Bio Tech (Belgium) in December 2021 enhanced his core research focus, encompassing not only agricultural economics but also environmental and natural resource economics, and food economics. His secondary interests in university pedagogy of economics and international economics showcase an insightful understanding of the interconnectedness of these factors in driving agricultural and rural development. Notably, Dr. Maniriho's passion and his commitment to participatory learning and teaching methods infuse his research and pedagogical approaches, demonstrating a dedication to fostering sustainable and inclusive development in the agricultural sector and further enrich his multifaceted academic profile.

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Data availability statement

Data sharing is not applicable to this article as no data were created or analyzed in this study. Nevertheless, the PRISMA 2020 checklist for this review is publicly accessible from https://data.mendeley.com/datasets/jrtj9px7nr/1.

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Appendix S1: Review protocol

Title: Sustainable Diets and Post-Harvest Technologies for Enhanced Food and Nutrition Security in East Africa: A Systematic Review Protocol

1. Background and rationale

Food and nutrition insecurity remains a critical challenge in East Africa, driven by climate change, population growth, conflict, and economic instability. Sustainable diets and post-harvest technologies represent two complementary approaches to addressing this challenge, yet evidence on their effectiveness and synergies remains fragmented. This systematic review aims to synthesize available evidence to inform policy and programming.

2. Review questions

1. What is the effectiveness of sustainable diet interventions in improving food and nutrition security outcomes in East Africa?
2. What is the effectiveness of post-harvest technologies in reducing food losses and enhancing food availability and access in East Africa?
3. How do sustainable diets and post-harvest technologies interact or complement each other in contributing to food and nutrition security?
4. What are the facilitators and barriers to the adoption and scaling of these interventions in East Africa?

3. Eligibility criteria (PICO framework)

Component	Inclusion criteria
Population	Smallholder farmers, households, and communities in East Africa (EAC member states: Kenya, Uganda, Tanzania, Rwanda, Burundi, South Sudan; neighboring countries: Ethiopia, Somalia)
Intervention	(a) Sustainable diet interventions: promotion of indigenous/underutilized crops, dietary diversification, agroecological practices, biofortification; (b) Post-harvest technologies: improved storage (hermetic bags, metal silos), drying technologies (solar dryers), cooling technologies (zero-energy cooling chambers, solar-powered cold storage), processing technologies (fermentation, milling), packaging innovations
Comparator	Conventional agricultural practices or absence of specific technologies
Outcomes	Food and nutrition security indicators (availability, access, utilization, stability), nutritional status, economic metrics (income, cost savings), environmental sustainability, loss reduction
Study design	Randomized controlled trials, quasi-experimental designs, cross-sectional surveys, qualitative studies, mixed-methods studies, program evaluations, systematic reviews
Publication type	Peer-reviewed journal articles, high-quality grey literature from international organizations (FAO, World Bank, IFPRI, CGIAR), substantive conference proceedings
Language	English
Publication date	2015–2025

4. Search strategy

Databases: PubMed, Web of Science, Scopus, Agricola, Google Scholar, African Journals Online (AJOL), institutional repositories (ILRI, CGIAR, World Agroforestry)

Search terms combined across four domains using Boolean operators:

- Sustainable diets: ('sustainable diet' OR 'indigenous crop' OR 'underutilized crop' OR 'dietary diversity' OR 'agro-ecology' OR 'traditional food' OR 'biofortif' OR 'neglected crop')
- Post-harvest technologies: ('post-harvest' OR 'postharvest' OR 'storage' OR 'hermetic' OR 'solar dryer' OR 'cooling' OR 'cold chain' OR 'fermentation' OR 'processing' OR 'loss reduction')
- Food security: ('food security' OR 'food insecurity' OR 'nutrition security' OR 'food availability' OR 'food access' OR 'malnutrition')
- Geography: ('East Africa' OR 'Kenya' OR 'Uganda' OR 'Tanzania' OR 'Rwanda' OR 'Burundi' OR 'Ethiopia' OR 'Somalia' OR 'South Sudan')

5. Screening and selection process

- A single author independently screen titles and abstracts
- Full-text assessment by the author
- Selection documented using PRISMA 2020 flow diagram

6. Data extraction

Standardized data extraction form capturing: study characteristics, population, intervention details, comparator, outcome measures, effect measures, facilitators/barriers, funding sources

7. Quality assessment

- Mixed Methods Appraisal Tool (MMAT) version 2018 for mixed-methods, qualitative, and quantitative non-RCT studies
- Cochrane Risk of Bias 2.0 for RCTs
- Ratings: high quality (low risk), moderate quality (some concerns), low quality (high risk)

8. Synthesis methods

Narrative synthesis approach due to anticipated heterogeneity:

- Thematic organization by intervention type and food security pillar
- Descriptive reporting of effect sizes (ranges, medians)
- Thematic analysis for qualitative findings
- Modified GRADE for certainty assessment

9. Timeline

Activity	Timeline
Protocol development	September 2025
Database searching	October–November 2025
Screening and selection	November 2025
Data extraction	November–December 2025
Quality assessment	December 2025
Synthesis and writing	December 2025–January 2026

10. Protocol registration

This protocol was not registered with PROSPERO as the review focuses on both health and agricultural outcomes, which falls outside PROSPERO's scope. However, the protocol was developed a priori and is provided as supplementary material.

Appendix S2: Database-Specific search strings

PubMed

text

('sustainable diet*'[Title/Abstract] OR 'indigenous crop*'[Title/Abstract] OR 'underutilized crop*'[Title/Abstract] OR 'dietary diversity'[Title/Abstract] OR 'agroecology'[Title/Abstract] OR 'traditional food*'[Title/Abstract] OR 'biofortif*'[Title/Abstract] OR 'neglected crop*'[Title/Abstract]) AND ('post-harvest'[Title/Abstract] OR 'postharvest'[Title/Abstract] OR 'storage'[Title/Abstract] OR 'hermetic'[Title/Abstract] OR 'solar dryer'[Title/Abstract] OR 'cooling'[Title/Abstract] OR 'cold chain'[Title/Abstract] OR 'fermentation'[Title/Abstract] OR 'processing'[Title/Abstract] OR 'loss reduction'[Title/Abstract]) AND ('food security'[Title/Abstract] OR 'food insecurity'[Title/Abstract] OR 'nutrition security'[Title/Abstract] OR 'food availability'[Title/Abstract] OR 'food access'[Title/Abstract] OR 'malnutrition'[Title/Abstract]) AND ('East Africa'[Title/Abstract] OR 'Kenya'[Title/Abstract] OR 'Uganda'[Title/Abstract] OR 'Tanzania'[Title/Abstract] OR 'Rwanda'[Title/Abstract] OR 'Burundi'[Title/Abstract] OR 'Ethiopia'[Title/Abstract] OR 'Somalia'[Title/Abstract] OR 'South Sudan'[Title/Abstract])

Filters: 2015/01/01–2025/11/30; English

Web of Science

text

TS=('sustainable diet*' OR 'indigenous crop*' OR 'underutilized crop*' OR 'dietary diversity' OR 'agroecology' OR 'traditional food*' OR 'biofortif*' OR 'neglected crop*') AND TS=('post-harvest' OR 'postharvest' OR 'storage' OR 'hermetic' OR 'solar dryer' OR 'cooling' OR 'cold chain' OR 'fermentation' OR 'processing' OR 'loss reduction') AND TS=('food security' OR 'food insecurity' OR 'nutrition security' OR 'food availability' OR 'food access' OR 'malnutrition') AND TS=('East Africa' OR 'Kenya' OR 'Uganda' OR 'Tanzania' OR 'Rwanda' OR 'Burundi' OR 'Ethiopia' OR 'Somalia' OR 'South Sudan')

Filters: 2015–2025; English; Article, Review, Proceedings Paper

Scopus

text

TITLE-ABS-KEY(('sustainable diet*' OR 'indigenous crop*' OR 'underutilized crop*' OR 'dietary diversity' OR 'agroecology' OR 'traditional food*' OR 'biofortif*' OR 'neglected crop*') AND ('post-harvest' OR 'postharvest' OR 'storage' OR 'hermetic' OR 'solar dryer' OR 'cooling' OR 'cold chain' OR 'fermentation' OR 'processing' OR 'loss reduction') AND ('food security' OR 'food insecurity' OR 'nutrition security' OR 'food availability' OR 'food access' OR 'malnutrition') AND ('East Africa' OR 'Kenya' OR 'Uganda' OR 'Tanzania' OR 'Rwanda' OR 'Burundi' OR 'Ethiopia' OR 'Somalia' OR 'South Sudan'))

Filters: 2015–2025; English; Article, Review, Conference Paper

Agricola (via ProQuest)

text

(('sustainable diet*' OR 'indigenous crop*' OR 'underutilized crop*' OR 'dietary diversity' OR 'agroecology' OR 'traditional food*' OR 'biofortif*' OR 'neglected crop*') AND ('post-harvest' OR 'postharvest' OR 'storage' OR 'hermetic' OR 'solar dryer' OR 'cooling' OR 'cold chain' OR 'fermentation' OR 'processing' OR 'loss reduction') AND ('food security' OR 'food insecurity' OR 'nutrition security' OR

'food availability' OR 'food access' OR 'malnutrition') AND ('East Africa' OR 'Kenya' OR 'Uganda' OR 'Tanzania' OR 'Rwanda' OR 'Burundi' OR 'Ethiopia' OR 'Somalia' OR 'South Sudan'))
Filters: 2015–2025; English

Google Scholar

Search string used in advanced search:text
'sustainable diets' OR 'indigenous crops' OR 'dietary diversity' AND 'post-harvest' OR 'storage' OR 'solar drying' AND 'food security' AND 'Kenya' OR 'Tanzania' OR 'Uganda' OR 'Ethiopia' OR 'Rwanda'
Limit: First 200 results screened; 2015–2025

African journals online (AJOL)

Search string:text
('food security' OR 'nutrition security') AND ('post-harvest' OR 'storage' OR 'sustainable diets' OR 'indigenous crops') AND (Kenya OR Tanzania OR Uganda OR Rwanda OR Ethiopia)
Filters: 2015–2025; English

Institutional repositories

- ILRI Repository: Search for 'post-harvest' AND 'food security' AND ('Kenya' OR 'Tanzania' OR 'Ethiopia')
- CGIAR Repository: Search for 'sustainable diets' OR 'indigenous crops' AND 'post-harvest'
- World Agroforestry (ICRAF): Search for 'indigenous vegetables' OR 'food security' AND 'post-harvest'

Grey literature sources

Organization	Website	Search strategy
FAO	www.fao.org	'post-harvest' AND 'East Africa' AND 'food security'
World Bank	www.worldbank.org	'agriculture' AND 'post-harvest' AND 'Africa'
IFPRI	www.ifpri.org	'food security' AND 'post-harvest' AND 'East Africa'
HarvestPlus	www.harvestplus.org	'biofortification' AND 'Africa'
ACTS	www.acts-net.org	'post-harvest' AND 'Kenya'

Appendix S3: Risk of bias assessment results (complete MMAT and RoB 2.0 results for each included study)

A. MMAT results for non-RCT studies – complete Component-Level scores

Table A3. 1: MMAT Component-Level scores for all included non-RCT studies.

Study	MMAT category	Q1 (qual)	Q2 (qual)	Q3 (qual)	Q4 (qual)	Q5 (qual)	Q1 (quant)	Q2 (quant)	Q3 (quant)	Q4 (quant)	Q5 (quant)	Overall rating
Kansanga et al. (2025)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	Yes	No	Moderate
Kilelu et al. (2024)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	Yes	No	Moderate
Kirui et al. (2025)	Qualitative	Yes	Yes	Yes	Yes	No	-	-	-	-	-	Moderate
Muriuki (2015)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	Yes	No	Moderate
Mutungi et al. (2016)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	Yes	No	Moderate
Ndlovu et al. (2024)	Qualitative	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-	High
Barzigar et al. (2025)	Quantitative descriptive	-	-	-	-	-	Yes	No	Yes	Yes	No	Low
ACTS/CCN (2025)	Qualitative	Yes	Yes	Yes	Yes	No	-	-	-	-	-	Moderate
Chesterman and Neely (2015)	Qualitative	Yes	Yes	Yes	Yes	No	-	-	-	-	-	Moderate
De Jong et al. (2024)	Quantitative descriptive	-	-	-	-	-	Yes	No	Yes	No	No	Low
Poncet et al. (2024)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	Yes	No	Moderate
Wayua et al. (2024)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	Yes	No	Moderate
Kamugisha (2023)	Quantitative descriptive	-	-	-	-	-	Yes	No	Yes	No	No	Low
Clean Cooling Network (2025)	Qualitative	Yes	Yes	Yes	Yes	No	-	-	-	-	-	Moderate
ISAAA AfriCenter (2025)	Qualitative	Yes	Yes	No	Yes	No	-	-	-	-	-	Low
Kalibwani (2015)	Qualitative	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-	High
Sanni et al. (2019)	Qualitative	Yes	Yes	Yes	Yes	No	-	-	-	-	-	Moderate
Hunter et al. (2019)	Mixed methods	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Moderate
Naziri et al. (2017)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	No	No	Low
Mnukwa et al. (2025)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	Yes	No	Moderate
MIT D-Lab (2023)	Qualitative	Yes	Yes	No	No	No	-	-	-	-	-	Low
Ogwu et al. (2025)	Qualitative	Yes	Yes	Yes	Yes	No	-	-	-	-	-	Moderate
Hawaz et al. (2025)	Quantitative descriptive	-	-	-	-	-	Yes	Yes	Yes	Yes	Yes	High
Mabhaudhi et al. (2017)	Systematic review	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-	High
Tripathy et al. (2025)	Systematic review	Yes	Yes	Yes	Yes	No	-	-	-	-	-	Moderate

Note: **MMAT criteria for qualitative studies:** Q1 = Is the qualitative approach appropriate? Q2 = Are the qualitative data collection methods adequate? Q3 = Are the findings adequately derived from the data? Q4 = Is the interpretation of results sufficiently substantiated by data? Q5 = Is there coherence between qualitative data sources, collection, analysis, and interpretation? **MMAT criteria for quantitative descriptive studies:** Q1 = Is the sampling strategy relevant to address the research question? Q2 = Is the sample representative of the target population? Q3 = Are the measurements appropriate? Q4 = Is the risk of nonresponse bias low? Q5 = Is the statistical analysis appropriate to answer the research question? 'Yes' = criterion met; 'No' = criterion not met; '-' = not applicable. Qual = Qualitative; Quant = Quantitative.

B. RoB 2.0 Results for RCT

Study: Ndegwa et al. (2016)

Domain	Judgment	Support
D1: Randomization process	Low risk	Adequate randomization method described
D2: Deviations from intended interventions	Low risk	Treatment and control groups clearly separated
D3: Missing outcome data	Low risk	Low attrition (≤5%)
D4: Measurement of outcome	Low risk	Objective outcome measures
D5: Selection of reported result	Low risk	Outcomes prespecified and reported
Overall	**Low risk**	

C. Risk of bias summary

Quality category	Count	Percentage
High quality (low risk)	5	19%
Moderate quality (some concerns)	15	56%
Low quality (high risk)	7	26%
Total	**27**	**100%**

Common limitations identified

- Cross-sectional designs precluding causal inference (12 studies)
- Lack of control groups for technology evaluations (8 studies)
- Limited longitudinal follow-up (15 studies)
- Small sample sizes (6 studies)
- Self-reported outcome measures (9 studies)

Appendix S4: Certainty of evidence assessment (modified GRADE)

Overall certainty ratings

Domain	Certainty	Justification	Supporting studies (n)
Post-Harvest Technology Outcomes	Moderate	Consistent positive findings across multiple study designs; effect sizes documented; however, most studies had moderate risk of bias and lacked long-term follow-up (>2 years).	18
• Loss reduction (30–50%)	Moderate	Multiple technology types (drying, cooling, hermetic) show consistent effects; studies from multiple countries; some quasi-experimental designs.	12
• Income increases (30–50%)	Low to Moderate	Consistent findings but primarily from cross-sectional surveys and program evaluations without control groups; potential selection bias.	10
• Shelf life extension	Moderate	Documented in multiple studies with objective measurements; consistent patterns across crops and technologies.	9
Sustainable Diet Outcomes	Low	Few rigorous designs (RCTs) limited to one study; high heterogeneity in interventions and outcomes; indirectness of outcome measures (proxy indicators vs. direct nutritional status).	16
• Dietary diversity improvement	Low	Consistent patterns across studies but primarily observational; cultural and contextual factors cause heterogeneity.	11
• Nutritional status improvement	Very Low	Limited anthropometric/biochemical data; most studies use dietary diversity as proxy; no long-term follow-up.	5
• Agronomic/Climate resilience	Moderate	Strong agronomic evidence base; laboratory and field experiments; consistent crop performance data.	8
Synergistic effects	Very Low	Very few studies; no controlled designs; primarily conceptual or indirect evidence; no studies specifically designed to test synergy.	3
Facilitators & barriers	Moderate	Consistent thematic patterns across multiple qualitative and mixed-methods studies; triangulation across sources; but limited quantitative validation.	27

Detailed certainty assessment by outcome

Outcome 1: Post-harvest loss reduction

Domain	Rating	Explanation
Risk of Bias	Some concerns	Most studies moderate risk; few RCTs; selection bias in program evaluations
Inconsistency	No serious inconsistency	Loss reduction ranges (30–50%) relatively consistent across technologies
Indirectness	No serious indirectness	Direct measurement of loss reduction; relevant to review question
Imprecision	Some concerns	Wide ranges reported; not all studies report confidence intervals
Publication Bias	Undetected	Potential overrepresentation of positive findings
Certainty	**MODERATE**	

Outcome 2: Income increases from technology adoption

Domain	Rating	Explanation
Risk of Bias	Serious concerns	Most studies cross-sectional; potential selection bias; self-reported income
Inconsistency	No serious inconsistency	30–50% range consistent across studies
Indirectness	No serious indirectness	Direct income measurement
Imprecision	Serious concerns	Small sample sizes in many studies; wide ranges
Publication Bias	Undetected	Potential overrepresentation of positive findings
Certainty	**LOW TO MODERATE**	

Outcome 3: Dietary Diversity Improvement

Domain	Rating	Explanation
Risk of Bias	Serious concerns	Primarily observational; limited control groups; recall bias
Inconsistency	Some concerns	Variation by country, crop type, and intervention design
Indirectness	Some concerns	Often use dietary diversity scores rather than direct nutritional outcomes
Imprecision	Some concerns	Small sample sizes; limited geographic coverage
Publication Bias	Undetected	Potential overrepresentation
Certainty	**LOW**	

Outcome 4: Synergistic Effects (Combined Interventions)

Domain	Rating	Explanation
Risk of Bias	Very serious concerns	No studies specifically designed to test synergy; evidence from case reports
Inconsistency	Not applicable	Insufficient studies to assess
Indirectness	Serious concerns	Conceptual inference rather than direct measurement
Imprecision	Very serious concerns	Very few studies; all small-scale
Publication Bias	Undetected	Insufficient evidence to assess
Certainty	**VERY LOW**	

Certainty Levels by Evidence Category

Evidence category	High	Moderate	Low	Very low	Total
Post-harvest technology loss reduction	0	12	0	0	12
Post-harvest technology income increases	0	2	8	0	10
Sustainable diet dietary diversity	0	0	9	2	11
Sustainable diet nutritional status	0	0	0	5	5
Synergistic effects	0	0	0	3	3

Appendix S5: Full characteristics of included studies

Author & year	Country	Study design	Population (sample size)	Intervention/ technology	Outcome measured	Evidence type	Quality/risk of bias
Ndegwa et al. (2016)	Kenya	RCT	600 households (300 treatment, 300 control)	Hermetic storage bags (PICS)	Maize loss reduction; income; benefit-cost ratio	Primary	High
Mutungi et al. (2016)	Tanzania	Quasi-experimental	200 households	Metal silos for grain storage	Pesticide use reduction; storage loss reduction	Primary	Moderate
Muriuki (2015)	Kenya	Experimental (Laboratory)	5 amaranth species	Blanching + solar drying	Protein, Zn, β-carotene retention; vitamin C	Primary	Moderate
Kansanga et al. (2025)	Kenya	Cross-sectional survey	1,001 vegetable growers	Solar-powered cold storage	Willingness to adopt; drivers of adoption	Primary	Moderate
Kilelu et al. (2024)	Kenya	Cross-sectional survey	400 farmers	Cold chain technologies	Food loss; value chain dynamics	Primary	Moderate
Kirui et al. (2025)	Kenya	Case study	200 farmers (Nyakazi Organics)	Solar dryers for indigenous vegetables	Income increase; loss reduction; time savings	Grey literature (Review)	Moderate
Mabhaudhi et al. (2017)	South Africa (regional)	Systematic review	120 studies reviewed	Indigenous/ underutilized crops	Drought tolerance; nutritional value	Review	High
Ndlovu et al. (2024)	Sub-Saharan Africa	Systematic review	87 studies reviewed	Underutilized crop species	Dietary diversity; climate resilience; barriers	Review	High
Barzigar et al. (2025)	Tanzania	Program evaluation	150 fish processors	Solar-powered fish dryers	Processing time; contamination; emissions	Primary	Low
ACTS/CCN (2025)	Kenya	Pilot evaluation	200 farmers	'Try Before You Buy' cooling hub	Loss reduction; income; market access	Grey literature (Report)	Moderate
Chesterman and Neely (2015)	Kenya	Program evaluation	40+ projects	Climate-smart agriculture (incl. hermetic storage)	Adoption; policy implications	Grey literature (Report)	Moderate
De Jong et al. (2024)	Kenya	Policy brief	N/A	Biofortified crops (orange maize, sweet potato)	Nutrition; income; seed system constraints	Grey literature (Policy brief)	Low
Poncet et al. (2024)	Regional	Case study	Coffee farming systems	Diversification strategies	Sustainability; income	Primary	Moderate
Wayua et al. (2024)	Kenya	Fact sheet	N/A	Zero-energy brick coolers	Shelf-life extension; loss reduction	Grey literature (Fact sheet)	Moderate
Kamugisha (2023)	Tanzania	Case study	120 farmers	Zero-energy cooling technologies	Economic welfare; loss reduction	Primary	Low
Clean Cooling Network (2025)	Kenya	Pilot evaluation	Cooperative members	'Try Before You Buy' cooling hub	Price premiums; market access	Grey literature (Report)	Moderate
ISAAA AfriCenter (2025)	Ethiopia/Kenya/ Uganda	Program report	1,000+ farmers	Sweet sorghum biorefinery	Syrup production; bioethanol; income	Grey literature (Report)	Low
Ogwu et al. (2025)	Regional	Book chapter	N/A	Sorghum biorefinery model	Value addition; market creation	Grey literature (Book chapter)	Moderate
Kalibwani (2015)	Uganda	Case study	5 cooperatives	Farmer cooperatives	Bargaining power; income	Primary	High
Hawaz et al. (2025)	Regional	Review	N/A	Traditional fermented foods	Food safety; nutrition; technology	Review	High
Sanni et al. (2019)	Kenya	Evaluation report	Off-grid refrigeration users	Off-grid cold storage	Livelihood impacts	Grey literature (Report)	Moderate
Hunter et al. (2019)	Global/Regional	Review	N/A	Neglected/ underutilized species	Nutrition; food systems	Review	Moderate
Mnukwa et al. (2025)	Sub-Saharan Africa	Systematic review	85 studies	Climate-smart agricultural practices	Adoption; livelihoods	Review	Moderate
Tripathy et al. (2025)	Global	Review	N/A	Storage solutions for perishables	Post-harvest loss reduction	Review	Moderate
MIT D-Lab (2023)	Kenya/Tanzania	Technical report	N/A	Room-sized cooling chambers	Technology design; feasibility	Grey literature (Report)	Low
Naziri et al. (2017)	Uganda	Evaluation report	Value chain actors	Fresh value chain interventions	Post-harvest losses	Grey literature (Report)	Low
Bokelmann et al. (2022)	Kenya	Synthesis / review (value-chain framework)	Multiple African indigenous vegetables (AIVs) value-chain actors	African indigenous vegetables (AIVs) promotion, processing, and market upgrading	Diet diversity; climate resilience; income; production, post-harvest, gender, and market constraints	Review (project synthesis)	Moderate