Sustainable Farming Practices and Household Food Security in Rural Burundi

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Abstract

Sustainable agriculture is broadly acknowledged as essential for tackling food insecurity, climate change, and rural poverty in developing nations. Nevertheless, in Burundi, smallholder farming continues to be heavily reliant on rainfall, which makes households susceptible to climate variabilities and ongoing vulnerability, thus hindering the efficacy of current agricultural methods in providing resilient, stable food systems. This systematic review synthesizes empirical evidence on the effects of sustainable farming practices on household food security outcomes in rural Burundi. Specifically, it assesses practices like integrated soil fertility management (ISFM), agroforestry, conservation agriculture, climate-smart agriculture, irrigation, and rainwater harvesting, among others, against key food security dimensions such as availability, access, utilisation, and stability. Following PRISMA guidelines for literature identification, screening, inclusion, and quality appraisal, 16 peer-reviewed empirical studies published between 2015 and 2025, comprising six nationwide studies and ten sub-national studies covering six provinces, were included. The findings reveal that ISFM, including fertiliser use, improved seeds, composting, crop diversification, and soil conservation, is the most widely adopted approach and demonstrates consistent short-term positive effects on food security, mainly by boosting crop yields and farm income, often supplemented by pesticide use. However, other practices with recognised potential for enhancing long-term resilience, like agroforestry, conservation agriculture, and water management techniques, remain limited in adoption and scale. Additionally, persistent structural constraints like land scarcity, weak intensification, limited diversification, and poor market integration undermine sustainability, leaving food security gains vulnerable to climatic and economic shocks. ISFM by itself is insufficient to ensure food security in Burundi because of environmental risks. Consequently, it is essential for policies to transition towards integrated, climate-resilient strategies that address structural limitations as well as constraints related to land and credit; enhance local institutions; promote gender equality; and finance agricultural innovations tailored to specific contexts. Practice requires combining these actions to build lasting resilience.

Keywords: Sustainable Farming, Productivity, Adoption, Food Security, Resilience

1.0. Introduction

Globally, agriculture faces mounting pressure to ensure food security for a projected 9.7 billion people by 2050, all while confronting climate change, land degradation, and population growth (FAO et al., 2025). Despite global efforts, approximately 700-735 million people remain undernourished, revealing deep structural weaknesses within food systems (FAO et al., 2025). Climate change intensifies these challenges by disrupting rainfall, increasing temperatures, and

heightening extreme weather events, which directly threaten productivity and disproportionately impact smallholder farmers in developing countries (Rahman et al., 2025). In response, sustainable land management and climate-resilient practices are increasingly seen as essential for balancing food production with ecosystem conservation (Robinson, 2024). This global crisis is most acute in Sub-Saharan Africa, where nearly 30% of the population is undernourished due to poverty, reliance on rain-fed agriculture, and low adaptive capacity (FAO et al., 2025; World Bank, 2025). Within this fragile context, Burundi epitomises the challenge of achieving food security. As one of Africa's most densely populated countries, over 90% of its population depends on subsistence agriculture, yet chronic malnutrition is widespread, with many rural households unable to meet minimum dietary requirements (Niragira et al., 2015; IFAD, 2022; Slosse et al., 2024). The sector's productivity is severely undermined by climate change, which manifests as erratic rainfall, soil degradation, and the constraints of small, fragmented farms (Verschelde et al., 2012; Pacifique Batungwanayo et al., 2023; Aboyitungiye & Suryanto, 2025). Consequently, Burundi's agricultural systems struggle to provide stable food supplies, perpetuating a cycle of poverty and hunger that underscores the urgent need for sustainable farming practices to enhance household food security.

In Sub-Saharan Africa, a critical problem impeding the link between sustainable farming and food security is the paradoxical risk associated with the partial adoption of sustainable agricultural practices (SAPs). While the region faces severe climate pressures with climate variability reducing yields by up to 30% in arid zones and postharvest losses reaching 30–40% annually (Olarewaju et al., 2025), farmers often adopt practices incrementally due to financial and knowledge constraints. However, evidence from northern Ghana reveals that adopting only a single practice, such as fertilizer use, can unexpectedly decrease farm income, undermining household welfare. In contrast, adopting a comprehensive package of improved seeds, fertilizer, and soil and water conservation yields substantial benefits, increasing farm income by 23% and improving household dietary diversity by 14% (Setsoafia et al., 2022). This disparity underscores that fragmented adoption, driven by structural barriers, not only fails to deliver the promised food security gains but can actively worsen household economies, perpetuating a cycle of vulnerability and low investment in sustainable agriculture.

Within Sub-Saharan Africa, Burundi's agricultural system is exceptionally vulnerable, confronting intersecting crises of food insecurity, profound land scarcity, and poverty. The sector employs over 80% of the population, yet productivity is severely constrained by average farm sizes below 0.5 hectares, a situation exacerbated by one of the continent's highest population densities, leading to intense land fragmentation and soil degradation (Kessler et al., 2015; IFAD, 2025). Consequently, widespread food insecurity persists, with numerous rural households facing crisis-level food shortages (WFP, 2024). In this context, the adoption of Sustainable Farming Practices (SFPs) is not merely an environmental consideration but a fundamental prerequisite for transformation. SFPs including agroecological principles, Integrated Soil Fertility Management (ISFM), and climate-smart agriculture, offer a crucial pathway to enhance resilience, productivity, and resource optimization (Mperejekumana et al., 2023; Manirakiza et al., 2024). Evidence from Burundi confirms that approaches like integrated farm planning and farmer field schools can significantly boost crop yields and farm incomes while improving soil health and nutrient management (Kessler et al., 2015; Manirakiza et al., 2025). Furthermore, advancing agricultural sustainability through these practices is intrinsically linked to better household dietary diversity and nutrition security (Emera et al., 2025). Despite the demonstrated potential of these innovations, their sustainable adoption remains limited, underscoring persistent structural and institutional barriers. Overcoming these hurdles to transition towards SFPs is therefore critical for reversing soil nutrient mining, buffering against climatic variability, and ultimately securing food production and rural livelihoods (Nyairo et al., 2020).

Although sustainable farming practices are widely recognised as beneficial, their adoption among smallholder farmers in Burundi remains low and uneven. This is largely due to a combination of socio-economic challenges, weak institutional support, and gender-related barriers (Nyairo et al., 2020; Nchanji et al., 2023). Moreover, existing studies tend to focus on specific practices, regions, or disciplines, resulting in fragmented evidence and a lack of a clear understanding of what works, for whom, and under what conditions. This systematic review addresses this gap by bringing together empirical evidence on the impacts, determinants, and effectiveness of sustainable farming practices within Burundi’s smallholder context. It critically examines interventions such as ISFM, agroecology, and climate-smart technologies to identify both successful strategies and ongoing challenges, including issues related to food agency and gender inequalities in access to resources

(Nchanji et al., 2023; Slosse et al., 2024). The study also contributes to global development priorities. It supports SDG 2 (Zero Hunger) and SDG 13 (Climate Action) by exploring ways to strengthen food security through climate-resilient agriculture. In addition, it aligns with SDG 5 (Gender Equality) by promoting inclusive adoption and with SDG 12 (Responsible Consumption and Production) by promoting sustainable production systems. Finally, the findings are intended to inform policymakers, practitioners, and development partners, including those implementing national initiatives such as the National Agriculture Strategy (2018–2027), to design more effective, evidence-based interventions that promote a food-secure and sustainable future in Burundi. Largely, the review is expected to generate robust insights to guide policy formulation, strengthen development programming, and shape future research on sustainable farming and food security in rural Burundi.

To address the persistent food security challenges facing rural Burundi, alongside the fragmented nature of existing empirical evidence, this systematic review is guided by a clear and focused set of objectives. The overarching purpose of the study is to conduct a systematic review and synthesis of empirical evidence regarding the impact of sustainable farming practices on household food security outcomes in rural Burundi. More specifically, it aims to explore the documented impacts of practices such as soil and water conservation, agroforestry, crop diversification, and the application of improved seeds, among others, on essential food security indicators, including food availability, access, utilisation, and stability at the household level. By consolidating findings from existing empirical studies, this review clarifies the extent to which these practices improve agricultural productivity, generate income, enhance dietary diversity, and strengthen resilience against climatic and economic shocks. Additionally, the study identifies and synthesizes the mechanisms through which sustainable farming practices influence food availability, access, utilization, and stability among rural households. This results in a comprehensive evidence base that addresses existing knowledge gaps and facilitates more targeted, context-specific interventions aimed at enhancing food and nutrition security.

1.2 Statement of the Problem

Burundi's population is predominantly rural, with more than 80% relying on rain-fed agriculture for their livelihoods (Batungwanayo et al., 2023). The sector contributes about 39.6% to the country's GDP and provides approximately 95% of the national food supply (INADES-Formation,

2025). However, this heavy reliance on subsistence farming occurs against a backdrop of extreme population pressure, with average farm sizes shrinking to less than 0.50 hectares per family, and severe soil degradation (Kessler et al., 2015; Batungwanayo et al., 2023). The situation is critically exacerbated by climate change; farmers in regions like the northeast perceive significant increases in temperature and rainfall unpredictability, leading to crop failures and food shortages (Batungwanayo et al., 2023). While sustainable farming practices such as integrated soil fertility management (ISFM), agroforestry, and climate-smart agriculture are promoted as solutions, a critical problem persists: household food security remains elusive for many, with a large portion of the population living below the poverty line and facing chronic malnutrition (IFAD, 2019; World Bank, 2025).

The magnitude of this problem is stark. Burundi is frequently identified as a country with high levels of food insecurity, and climatic shocks have direct, devastating consequences, including famine and displacement (Batungwanayo et al., 2023; WFP, 2024). For instance, a study in the northeastern provinces found that climatic threats cause farming losses of between 30% and 80% for affected households, directly undermining food availability and stability (Batungwanayo et al., 2023). Although farmers are adopting various strategies with over 80% implementing at least one adaptation method like changing crop varieties or planting shade trees, these efforts are often fragmented and constrained by a lack of capital, information, and access to credit (Batungwanayo et al., 2023; Manirakiza et al., 2025). This indicates that while the problem of food insecurity is severe and widely recognised, the solutions being implemented on the ground are not yet sufficient to achieve widespread and stable food security.

Previous research in Burundi has largely focused on either the technical aspects of specific sustainable practices, such as ISFM (Kessler et al., 2015), or on farmers' perceptions of and barriers to climate change adaptation (Batungwanayo et al., 2023). However, a critical gap remains in the systematic synthesis of evidence linking the full range of these practices directly to the four dimensions of household food security, including availability, access, utilisation, and stability. It is poorly understood how interventions like agroforestry, conservation agriculture, or rainwater harvesting holistically impact not just yields (availability) but also income (access), dietary diversity (utilisation), and resilience to shocks (stability) within the specific socio-economic and environmental context of rural Burundi (Manirakiza et al., 2024; Adaptation Fund, 2025). This

study is therefore significant as it will provide policymakers, organisations, and development practitioners with a consolidated evidence base to design more effective, integrated interventions that genuinely enhance the food security of vulnerable smallholder farmers. The purpose of this systematic review is to synthesise and critically appraise the empirical evidence on how sustainable farming practices affect household food security outcomes in rural Burundi, thereby identifying effective strategies and knowledge gaps to inform future research and development policy.

Empirical Literature Review

2.1 Sustainable Farming Practices and Food Security

Generally, sustainable farming practices are known as integrated approaches that enhance agricultural productivity and resilience while preserving environmental resources. The IPCC (2019) classifies these into supply-side and demand-side options. Key practices include improving soil organic matter, erosion control, diversified crop-livestock systems, and ISFM, which combines fertilizer, organic inputs, and improved germplasm. In Burundi, the Plan Intégré du Paysan (PIP) approach, which serves as a bottom-up, multi-scale framework closely aligns with sustainable agriculture principles. Rather than focusing solely on isolated, plot-level interventions, the PIP approach prioritises the comprehensive integration of environmental stewardship, economic viability, and social well-being at the household level. It focuses on creating an integrated family farm plan that embodies the household's long-term vision while encouraging diversified production, efficient resource utilisation, and the health of soil and ecosystems. By enhancing resilience to climatic and economic shocks and improving the sustainability of livelihoods, this approach redefines farming as a purposeful, knowledge-driven enterprise rather than a mere subsistence activity (Kessler et al., 2015).

Sustainable farming practices are intrinsically linked to strengthening all four pillars of food security, ensuring long-term resilience in the face of climate and economic shocks. As noted, "The food security conceptual model is universally anchored on four interdependent pillars: availability, access, utilisation, and stability" (IPCC, 2019), and practices such as conservation agriculture, agroforestry, and climate-smart technologies directly enhance availability by improving soil health and sustaining crop yields under changing climatic conditions. These practices can also improve access by increasing farm productivity and incomes, thereby enabling households to afford food

more easily, even amid market fluctuations. Furthermore, diversified farming systems improve utilization by promoting dietary diversity and enhancing nutritional outcomes, while environmentally sustainable approaches reduce reliance on harmful inputs, thereby improving food safety. Importantly, sustainable farming builds resilience against climate extremes and economic disruptions, thereby reinforcing stability across food systems; this is particularly critical given that, as highlighted in the World Bank (2025) update, food price inflation continues to erode access for vulnerable populations, especially in regions like Africa, where food insecurity persists despite broader global progress.

2.2 Theoretical Framework

2.2.1 The Theory of Change for Sustainable Agriculture

The Theory of Change (ToC) for sustainable agriculture posits that achieving long-term food security requires a fundamental shift from top-down technology transfer approaches toward models that prioritize farmer agency, participatory innovation, and the development of integrated, resilient agricultural systems. It further provides a structured framework for tracing the causal pathway from interventions such as farmer training, access to inputs, and institutional support, through intermediate outcomes such as improved knowledge, adoption of sustainable practices, and enhanced adaptive capacity, to long-term impacts, including environmental resilience, food security, and improved livelihoods. Rather than being attributed to a single founder, this ToC represents a synthesis of conceptual frameworks advanced by multiple international organizations, including the Food and Agriculture Organization, the Consultative Group on International Agricultural Research, and the Climate Change, Agriculture and Food Security, alongside contributions from a wide range of scholars and development practitioners. As illustrated by the PIP approach in Burundi, this change is not sparked by the introduction of a single practice but by triggering a farmer's intrinsic motivation to invest in their future (Kessler et al., 2015). The process begins with conscientisation, in which farmers, through dialogue, become aware that they can collectively improve their reality. This awareness fosters intrinsic motivation, leading to the co-creation of a holistic farm plan, “PIP”, that integrates crop production, soil management, and non-farm activities. This plan becomes a dynamic tool for learning and adaptation. While such

household-level transformation is critical, its sustainability and scalability depend on supportive structures beyond the farm.

This fundamental transformation at the household level needs to be reinforced by a supportive, enabling environment to achieve broad-scale and sustained impact. The theory highlights that resilience at the farm level alone is inadequate without complementary institutional and market innovations at both community and national levels. This includes access to credit, insurance, fair markets, and supportive policies. When household plans are embedded in coherent village or district development plans, agriculture becomes a viable livelihood. Consequently, the sustained adoption of sustainable practices such as ISFM becomes a means of achieving the farmer's own vision of prosperity and resilience, leading to systemic improvements across the four pillars of food security. Enabling environments align household actions with systemic support, driving sustainable adoption, resilience, and comprehensive improvements in food security.

2.2.2 Food Security Impact Pathways

SFPs influence food security through four interconnected impact pathways:

Agronomic Pathway: Sustainable practices directly enhance the availability pillar. ISFM and soil conservation improve soil health, close nutrient cycles, and boost crop productivity and yield stability. The IPCC (2019) notes that diversification reduces production risks from pests and climate variability. In Burundi's PIP approach, this is operationalized through targeted investments in soil fertility and erosion control within the integrated farm plan, securing the household's food production base (Kessler et al., 2015).

Economic Pathway: These practices improve household access to food by increasing and diversifying income. Enhanced yields generate surplus for sale, while integrated farm planning often incorporates high-value crops or non-farm enterprises. This increases purchasing power, which is critical as the World Bank (2025) reports that food price inflation severely erodes food access. Strengthened links to markets and value chains, a goal of the PIP approach, further bolster economic resilience.

Nutritional Pathway: This pathway enhances the utilisation pillar. Diversified farming systems, integrating legumes, vegetables, fruits, and livestock, directly increase the variety of foods available for household consumption, improving dietary diversity and micronutrient intake. The IPCC states that diversified production is a key strategy for improving nutrition, especially in vulnerable smallholder contexts where market access is limited (IPCC, 2019).

Resilience Pathway: This pathway underpins the stability of all other food security pillars by strengthening the capacity to withstand shocks. Climate-smart practices such as water harvesting and agroforestry enhance adaptive capacity to climate variability, while the integrated, multi-scale planning of the PIP approach reinforces social and institutional resilience through community cooperation and stronger linkages to support systems. Consequently, vulnerability to climate extremes and economic disruptions, identified by the IPCC and World Bank as key threats to food security, is reduced. In this context, food security directly influences human health, economic stability, and social cohesion by determining access to safe, nutritious food. Adequate access improves dietary diversity and health outcomes (Emera et al., 2025), supports productivity and income stability (Nzabakenga et al., 2013; Niragira et al., 2018), and fosters inclusion and community resilience, contrary to deepening poverty and limitation of choices imposed by food insecurity (Nyairo et al., 2020; Slosse et al., 2024; Aboyitungiye & Suryanto, 2025).

2.2.3 Theoretical Foundation of the Study

The SLF provides a foundation for understanding how subsistence farming communities in rural Burundi navigate vulnerability and build resilience through sustainable agriculture. It posits that households mobilize five forms of capital, notably, natural, human, financial, physical, and social, to pursue livelihood strategies that shape food security outcomes. In Burundi's agrarian context, sustainable farming practices are the primary means of strengthening this capital base. Natural capital, the foundational resource of soil and water, is directly enhanced through practices such as Integrated Soil Fertility Management (ISFM), which combats severe soil degradation endemic to the region (Kessler et al., 2015). Human capital, encompassing the knowledge needed to implement these practices, is built through extension services and participatory approaches such as Farmer Field Schools (Manirakiza et al., 2025). These strategies aim to increase yields and generate financial capital from crop sales, enabling reinvestment in physical capital, such as

improved storage facilities to reduce post-harvest losses. Critically, social capital, fostered through cooperatives and farmer groups, underpins this entire system by facilitating knowledge sharing and improving market access (Birachi et al., 2011). Thus, sustainable farming acts as the engine driving the synergistic accumulation of all five capitals, moving households from mere survival toward more secure livelihoods.

In Burundi, where climate shocks and land pressure threaten food systems, the Sustainable Livelihoods Framework (SLF) underscores how sustainable agriculture strengthens food security. Climate change intensifies soil erosion and rainfall variability, degrading natural capital critical to rural livelihoods (Aboyitungiye & Suryanto, 2025). Sustainable farming practices, such as agroecological soil conservation and water management, enhance human capital and protect this resource base (Nyamweru et al., 2023). Improved productivity builds financial capital, enabling households to access food and invest in resilience-enhancing assets like irrigation. These gains enhance food availability, access, and utilisation through stable yields and diversified diets (Mperejekumana et al., 2023). Strengthening inclusive social capital addresses gender inequalities and improves adaptive capacity and stability (Nchanji et al., 2023; Slosse et al., 2024). Sustainable agriculture strengthens livelihoods, enhances resilience, and secures all four pillars of food security.

2.2.4 Agroecological Theory

The Agroecology theory, largely advanced by Miguel Altieri, conceptualizes agriculture as an ecological system where biological interactions, biodiversity, and natural processes drive productivity and sustainability. It emphasizes principles such as nutrient recycling, diversification, and synergy between crops, livestock, and the environment. Agroecology promotes reduced dependence on external inputs while enhancing soil fertility, ecosystem services, and resilience to climate change. This perspective aligns with evidence from Burundi, where agroecological innovations improve both agricultural productivity and environmental outcomes (Manirakiza et al., 2024). Moreover, by integrating local knowledge with scientific practices, agroecology strengthens farmers' adaptive capacity to climate variability and shocks, which are major threats to food systems (Nyairo et al., 2020; Aboyitungiye & Suryanto, 2025). Thus, the theory provides a holistic framework for sustainable farming rooted in ecological balance.

Agroecological theory directly informs sustainable farming practices by encouraging integrated approaches such as intercropping, agroforestry, organic soil management, and water conservation. These practices enhance productivity while maintaining environmental integrity and supporting long-term resilience. For instance, integrated soil fertility management and farm planning approaches reflect agroecological principles by combining organic and inorganic inputs to optimise soil health and yields (Kessler et al., 2015). Similarly, farmer-field-school models promote experiential learning and collective action, thereby reinforcing knowledge sharing and the adoption of sustainable practices (Manirakiza et al., 2025). Agroecology also recognises the socio-economic dimensions of farming, including gender roles, market access, and income diversification, which influence technology uptake and livelihood outcomes (Nzabakenga et al., 2013; Nchanji et al., 2023). Consequently, it links ecological sustainability with improved livelihoods, food security, and resilient agricultural systems.

3.0 Methodology

3.1 Search Strategy

Comprehensive electronic searches were conducted across multidisciplinary databases, including AGRIS, Web of Science, Scopus, Google Scholar, and the Directory of Open Access Journals (DOAJ). The search strategy employed key terms such as “climate-smart agriculture (CSA),” “sustainable farming practices,” “smallholder food security,” “subsistence farming,” “productivity,” “adoption,” and “resilience,” combined with Boolean operators to optimise sensitivity and specificity. The review focused on studies published between 2015 and 2025 to capture recent evidence and innovations. Only peer-reviewed articles (qualitative, quantitative, and mixed methods) and systematic reviews with quantitative components were included. Duplicate records were removed, and studies published outside the timeframe or from non-scholarly sources were excluded, ensuring a rigorous evidence base for synthesis.

3.2 Document Selection and Eligibility Criteria

The systematic review adhered to established eligibility criteria to facilitate the identification and selection of pertinent studies. Table 1 provides a summary of the inclusion and exclusion criteria utilised during the screening of titles, abstracts, and full texts.

Table 1

Inclusion and Exclusion Criteria

Studies features	Inclusion criteria	Exclusion criteria
Type of study	Peer-reviewed empirical quantitative, qualitative, mixed methods review, complemented with a quantitative approach.	Review articles, meta-analyses, editorials, commentaries, theoretical papers without empirical analysis, conference abstracts without full papers, reports, working papers, and policy papers
Publication status	Published articles	Unpublished articles
Date of publication	Articles published between 2015 and 2025	Articles published outside the 2015-2025 timeframe are excluded
Study language	Articles published in the English language	Articles not published in the English language
Study population	Smallholder farmers, subsistent farming communities and households	Large-scale commercial farming and non-agricultural sectors
Geographical coverage	Studies conducted in Burundi	Studies conducted outside Burundi
Agroecological thoughts	Studies examining crop systems and mixed crop–livestock systems	Studies not examining crop systems and mixed crop–livestock systems
Interventions of interest	Studies examining conservation agriculture, agroforestry, improved seed varieties, soil and water conservation, climate-smart agriculture/livestock	Studies not examining conservation agriculture, agroforestry, improved seed varieties, soil and water conservation, climate-smart agriculture/livestock
Study outcomes	Studies that report the following outcomes: agricultural yield or production; income or welfare;	Studies that do not report any of the following outcomes: agricultural yield or production; income or welfare;

	adaptive capacity or resilience; or adoption determinants.	adaptive capacity or resilience; or adoption determinants.
Methodology utilised	Studies that utilised of appropriate analytical technique	Studies that do not utilise appropriate analytical technique

3.3 Screening Procedure

The screening procedure for this systematic review adhered to a structured, transparent methodology consistent with established protocols. It utilized a multi-stage, iterative method to pinpoint pertinent literature regarding sustainable farming in Burundi. Initially, 30 journal articles were identified through specialized academic databases such as AGRIS, Web of Science, Scopus, Google Scholar, and the Directory of Open Access Journals (DOAJ). An additional search conducted via Google Scholar yielded 10 more articles, bringing the total to 40 records for preliminary assessment. The first phase of screening involved reviewing titles, abstracts and keywords, which resulted in the exclusion of six articles: four studies were deemed irrelevant, and two were identified as duplicates, leaving 34 articles for full-text evaluation. A thorough examination of these full texts led to the exclusion of an additional 18 studies that failed to meet the inclusion criteria. As a result, 16 journal articles were ultimately incorporated into the final review. This final collection consisted of 11 quantitative studies, 4 mixed-methods studies, and 1 review article that was supplemented with an econometric model. The inclusion of the latter, despite not being fully empirical, is justified by the limited number of available studies on sustainable farming in Burundi.

3.4 Quality Assessment

A rigorous and comprehensive quality assessment framework was applied to ensure the methodological rigour, analytical relevance, and credibility of the studies included in this systematic review on the adoption of sustainable farming or climate-smart agriculture and its effects on household food security in rural Burundi. Guided by established systematic review principles articulated by Popay et al. (2006) and Gough et al. (2012), the review prioritised empirical robustness, transparency of research design, and the reliability of reported findings. Only

studies providing valid, reproducible, and policy-relevant evidence on the link between sustainable farming or CSA practices and household food security outcomes were retained. Particular emphasis was placed on methodological clarity, including clearly articulated research objectives or questions, well-defined interventions, and the use of appropriate analytical frameworks to capture food security dynamics within households in smallholder farming systems.

The inclusion criteria were limited to peer-reviewed empirical studies employing primary, secondary, or mixed data sources, published between 2015 and 2025, that reflect developments in sustainable farming/agriculture or CSA discourse following the Paris Agreement and the Sustainable Development Goals. Conceptual, opinion-based, and non-peer-reviewed publications were excluded. Only articles published in reputable, indexed academic databases such as AGRIS, Web of Science, Scopus, Google Scholar, and the Directory of Open Access Journals (DOAJ) were considered, while predatory or non-scholarly sources were excluded to preserve academic integrity. Methodological transparency was mandatory, including clearly defined food security indicators, measurable outcomes, and empirical generalisability. Qualitative, quantitative, and mixed-methods studies, including qualitatively oriented studies supplemented by quantitative evidence, were included to address Burundi's limited empirical base. Studies with unclear methodologies were excluded, resulting in a final selection of 16 high-quality studies from a pool of 40 full-text articles. The process of data identification, inclusion and exclusion is presented in Figure 1 below.

Figure 1

Quality Appraisal Framework

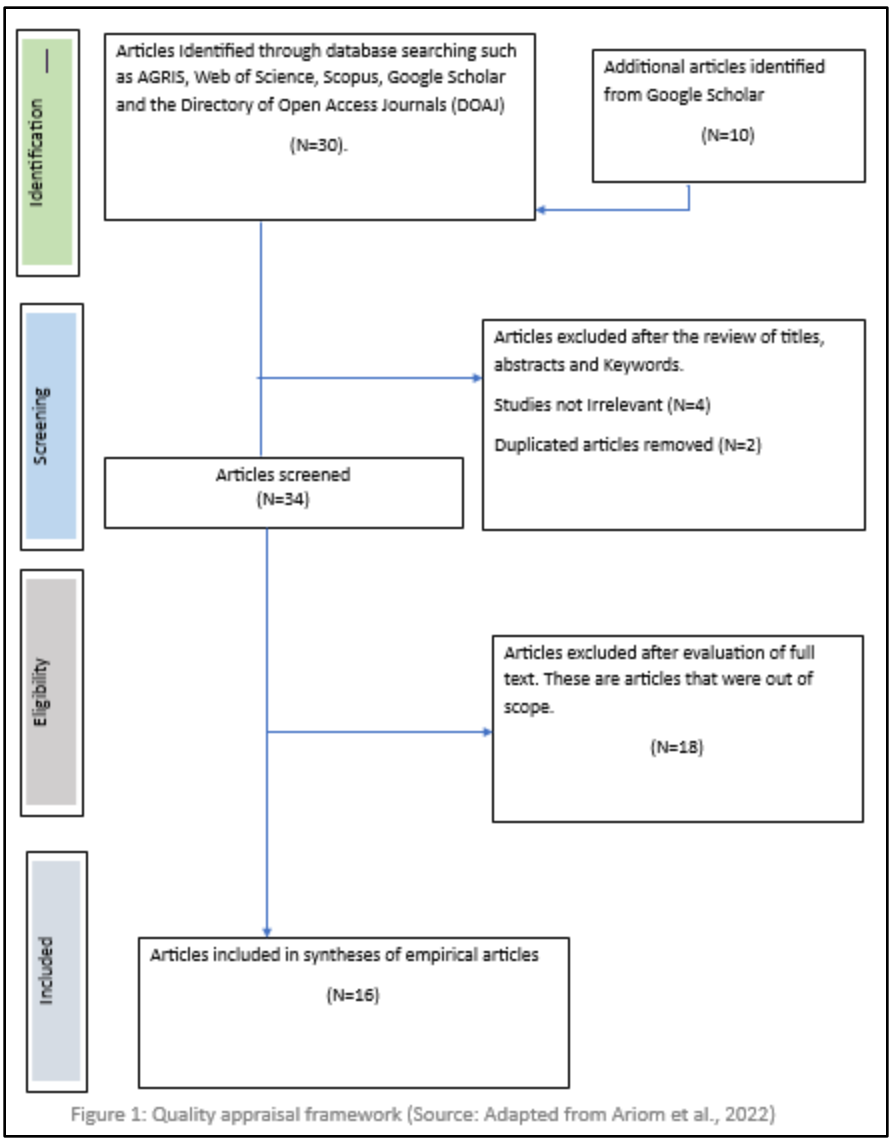


Figure 1: Quality appraisal framework (Source: Adapted from Ariom et al., 2022)

3.5 Data Extraction Procedures

The systematic review employed a structured and transparent methodology for data extraction and analysis, synthesising evidence from 16 empirical studies published between 2015 and 2025. Guided by established systematic review procedures outlined by Popay et al. (2006) and Gough et al. (2012), and adhering to the PRISMA framework, the review followed a sequential process encompassing data extraction, content analysis, and quality assurance. This approach ensured methodological rigour, consistency, and replicability in synthesising findings across the selected studies.

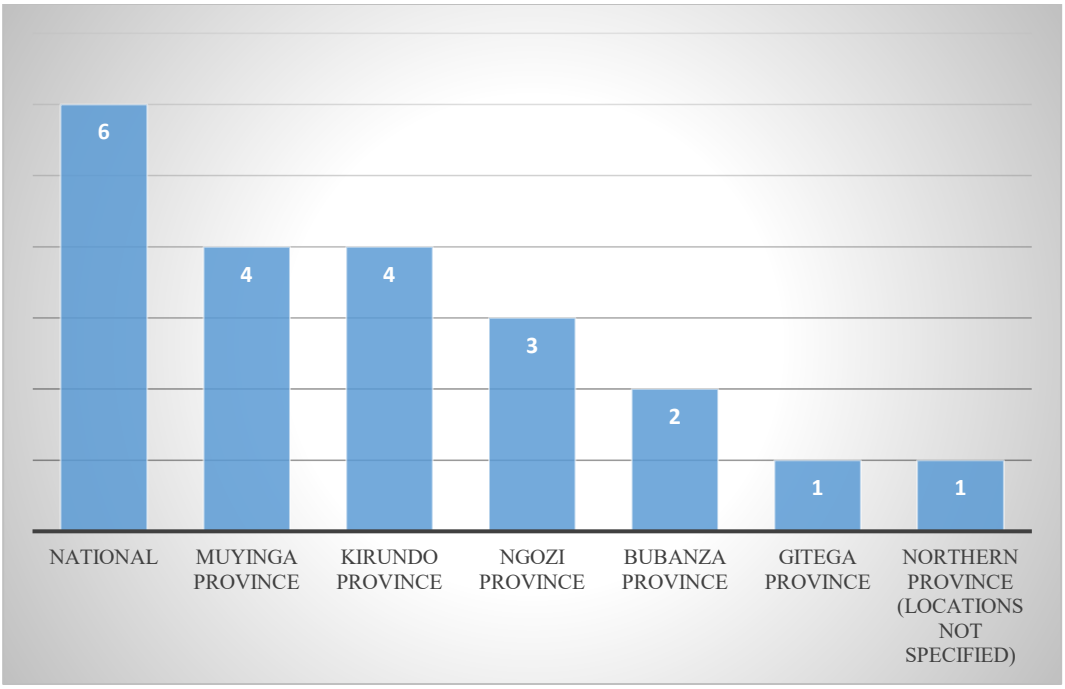
Data extraction was conducted using a predefined codebook aligned with the objectives of the review. Key data captured included author(s) and publication year, study title, geographic location, research methodology, sustainable farming practices examined, food security indicators and measures, impact outcomes, and contextual or moderating factors. Additional information on journal type and the clarity of analytical approaches was also documented. The analysis focused on regions of study, types of sustainable farming practices, food security indicators, methodological approaches, and impact measures, with findings systematically organized to enable comparative assessment of sustainable farming impacts across diverse agro-ecological contexts in Burundi. A quality appraisal framework was applied to ensure the inclusion of robust, peer-reviewed empirical studies focusing on smallholder farming households in rural Burundi. Methodological rigour was assessed based on sample adequacy, analytical appropriateness, treatment of endogeneity, and reliability of results, while studies lacking empirical validation were excluded to ensure that conclusions were grounded in credible evidence.

4.0 Findings

4.1 Distribution of Investigated Studies per Province

Figure 2

Frequency of Provinces Studied



The distribution of studies across regions or provinces of Burundi shows a strong emphasis on nationally aggregated studies and selected northern provinces, with notable spatial imbalances. National-level analyses dominate the literature (n=6), suggesting a preference for broad, policy-oriented perspectives that often mask important subnational heterogeneity in socio-economic, agroecological, and institutional conditions. At the subnational level (regions or provinces), Muyinga and Kirundo provinces are the most frequently studied (n=4, each), followed by Ngozi (n=3) and Bubanza (n=2), reflecting a research focus on northern and north-eastern Burundi where population density, land pressure, and food insecurity challenges are pronounced. In contrast, Gitega Province, despite being the political capital and a strategic administrative centre, is represented in only one study, while one additional study vaguely refers to the "Northern Province" without specifying locations, limiting analytical clarity. This uneven geographical coverage reveals a methodological bias toward more accessible or historically prioritized provinces, potentially neglecting southern and western provinces with distinct livelihood systems and vulnerability profiles. As an implication, the evidence used to inform national policy and development programming may not be fully representative, risking the design of interventions that are poorly adapted to under-researched regions. Hence, subsequent studies should adopt more balanced, spatially explicit designs to enhance contextual relevance, equity, and the robustness of policy recommendations in Burundi.

4.2 Sustainable Farming Practices (SFP) Investigated

Figure 3

Frequency of Sustainable Farming Practices Adopted

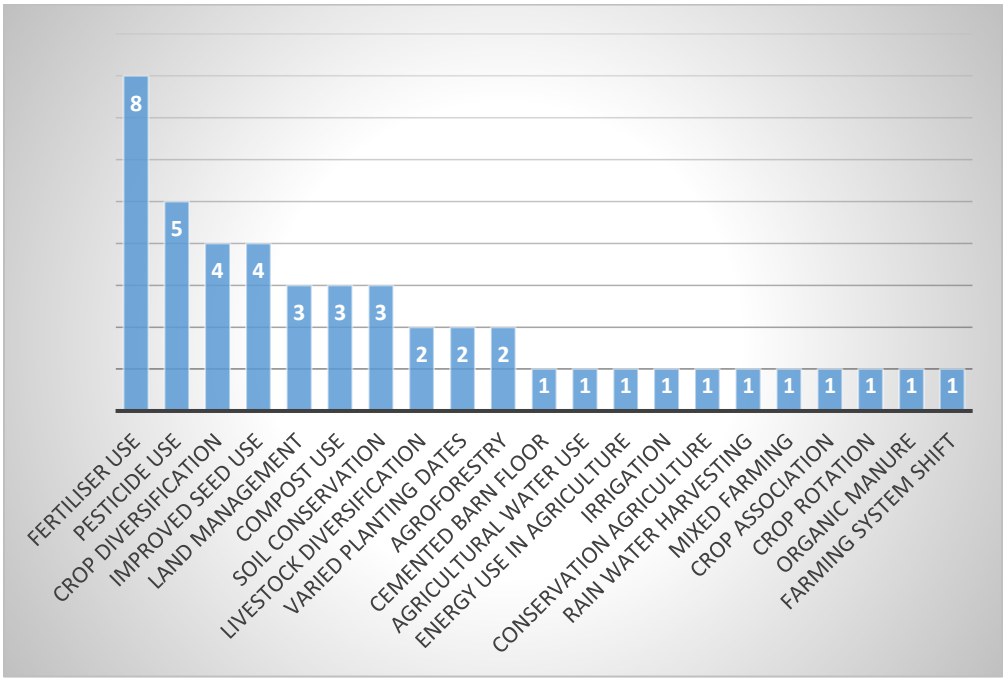


Figure 3 shows that sustainable farming practices investigated in the literature are heavily concentrated around ISFM, with fertiliser use (n=8) dominating. This reflects a pragmatic focus on input-based strategies that can deliver short-term productivity gains and are relatively easy to measure empirically. Other ISFM practices, such as crop diversification, improved seed use, land management, compost use, and soil conservation, appear moderately, suggesting recognition of complementary agronomic approaches that enhance soil health and resilience.

The use of pesticides (n=5) is the second dominant Sustainable Farming Practice (SFP). However, the distribution SFP reveals important gaps. Transformative and system-level practices, including agroforestry, conservation agriculture, mixed farming, water harvesting, irrigation, energy use, and farming system shifts, are rarely investigated (frequency of 1–2). This bias suggests that much of the evidence base prioritizes incremental adjustments over structural changes that are critical for long-term sustainability and climate resilience (Colloff et al., 2021). In addition, livestock

integration and resource-efficiency practices receive limited attention, despite their relevance for circular nutrient flows and diversified livelihoods.

The implications are twofold. For research, there is a need to broaden analytical focus beyond ISFM inputs to integrated, landscape- and system-oriented practices, using longer time horizons to capture cumulative benefits. For policy and development programming, over-reliance on fertilisers and pesticides risks environmental trade-offs; therefore, incentives should promote balanced adoption portfolios that combine soil health, biodiversity, water management, and energy efficiency to support resilient and truly sustainable farming systems.

4.3 Food Security Indicators Reported

Table 1

Food Security Indicators and Measures Reported

Food Security Indicator	Measurement	Frequency
Food production index	Agricultural output	1
Food consumption	Output quantity	1
Dietary diversity score	Standardized lists (10 food groups for women; 7 for children)	1
Adoption rates of technologies (Farmer Field School (FFS) vs Non-Farmer Field School)	Annual gross margin per cow (US$)	1
Agricultural yield	Yield in Kg/ha	2
Gender access and adopt of CSA technologies (improved seeds, pesticides, irrigation, and conservation agriculture)	Adoption rate	1
Food accessibility	Calories/adult equivalent/day	1
Income based food security	Income/adult equivalent	1
Minimum food security threshold (sufficient energy, protein, and fat supply for household consumptions)	Model outcomes compared to actual farm choices	1
Household livelihood vulnerability (proxy to climate-linked food insecurity)	Clustering of household based on FAMD score	1
Agriculture income per household (proxy for prevailing power and ability to secure food and livelihood)	Field survey data on agricultural income (crops and livestock)	1
Self-reported impact on climate change on crop production and food availability (perceived for short risk)	Rate of adoption	1
Productivity per unit of land	Yield in Kg/ha, size of farm	1
Household Food Insecurity Access Scale	Consumption of non-preferred food	1
Quantity of beans scored for food	Yield (kg/ha)	1
Yield (beans) changes	Production after 1 year of adoption	1

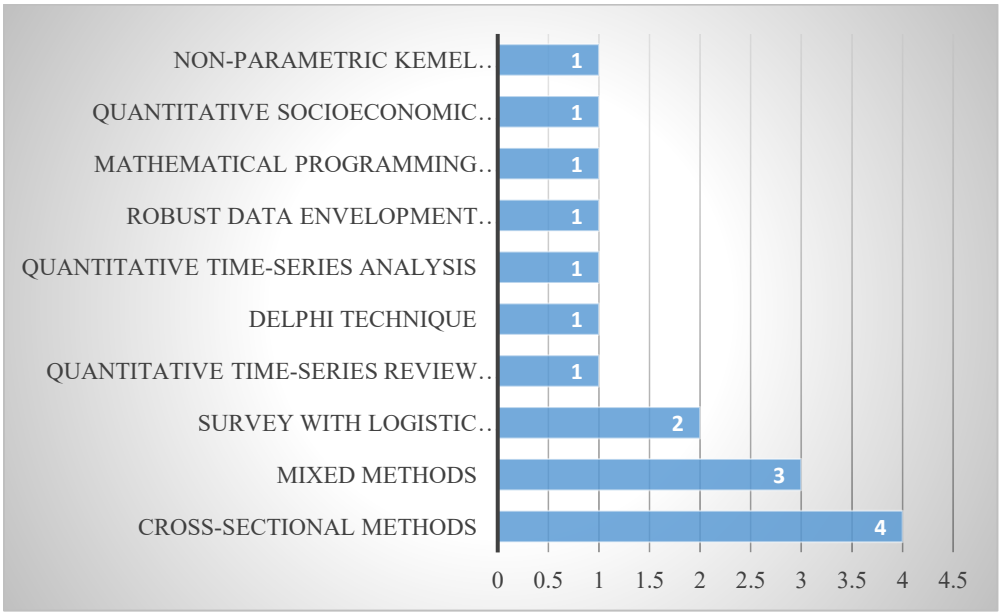
Across the reviewed studies, food security was operationalised using a diverse but fragmented set of indicators that span availability, access, utilization, and stability dimensions, though with uneven emphasis. Availability-oriented measures dominated, notably agricultural yield (kg/ha), productivity per unit of land, crop-specific outputs (beans), and food production indices, reflecting a strong production-centric framing of food security. Access and economic capacity were captured through income-based indicators (income per adult equivalent, agricultural income per household), caloric intake per adult equivalent, and adoption-linked proxies such as gross margins and CSA technology uptake, implicitly assuming income and adoption translate into food access. Utilization and diet quality were less frequently assessed, with only one study employing dietary diversity scores and another using the Household Food Insecurity Access Scale, suggesting limited attention to nutritional adequacy and experiential dimensions of food insecurity. Stability and vulnerability were addressed indirectly through livelihood vulnerability clustering and self-reported climate

impacts, which, while contextually relevant, rely on perception-based or model-dependent measures that may reduce comparability. The heterogeneity of indicators constrains cross-study synthesis and obscures multidimensional trade-offs of CSA adoption. The heavy reliance on yield and income proxies risks overstating food security gains without accounting for intra-household distribution, gendered access, and diet quality. Consequent studies should adopt standardized, multidimensional food security metrics alongside production indicators to generate more policy-relevant and comparable evidence.

4.4 Methodological Approaches of the Investigated Studies

Figure 4

Frequency of Methods Utilised



Across the 16 reviewed articles, a strong reliance on quantitative and cross-sectional methodologies is evident, with cross-sectional designs (n=4) and survey-based analyses dominating the evidence base. These approaches are valuable for identifying associations and adoption patterns at a point in time, especially when combined with econometric tools such as logistic regression. However, their inability to capture temporal dynamics limits causal inference. The inclusion of mixed methods (n=3) strengthens analytical depth by integrating quantitative results with contextual insights, although such studies often lack systematic integration between

components. A smaller subset employed advanced analytical techniques, including time-series econometric models (n=1), data envelopment analysis (n=1), kernel regression (n=1), and mathematical programming (n=1), which enhance rigour and efficiency analysis but are data-intensive and less generalizable. The use of the Delphi technique (n=1) adds expert-driven foresight but may be prone to subjective bias. In general, the current studies demonstrate methodological robustness in their statistical analyses, yet they are constrained by the absence of longitudinal, experimental, and participatory designs. Filling these gaps is crucial to advancing causal understanding and ensuring policy relevance.

4.5 Contextual and Moderating Factors

In Burundi, entrenched contextual factors, including rain-fed agricultural dependence within a climate crisis of droughts and floods (Aboyitungiye & Suryanto, 2025), severe land scarcity, and degradation (Niragira et al., 2015; Mperejekumana et al., 2023), create systemic vulnerability to food insecurity. However, household outcomes are critically moderated by socio-economic variables. Access to off-farm income improves dietary diversity (Emera et al., 2025), and education reduces vulnerability (Nyairo et al., 2020). Conversely, poverty constrains food agency (Slosse et al., 2024), while gender norms and limited access to credit or extension service restrict adaptive capacity (Nchanji et al., 2023; Manirakiza et al., 2025). Farm size, soil quality, and labour also moderate productivity (Verschelde et al., 2012; Niragira et al., 2018). A key critique is that many studies and interventions focus on farm-level moderators while underemphasizing deeper structural market issues, inequitable gender norms, and consistent policy support necessary for sustained change (Manirakiza et al., 2025; Nchanji et al., 2023). Furthermore, data limitations often restrict granular analysis of these interactions (Mperejekumana et al., 2023). The primary implication is that effective adaptation requires integrated policies that move beyond singular technical fixes. These must simultaneously address contextual barriers like land degradation and climate risks while actively strengthening key moderators: enhancing off-farm livelihood opportunities, ensuring equitable access to resources and education, and embedding farmer-centric extension within supportive institutions and markets (Kessler et al., 2015; Jean Claude Nyamweru et al., 2023).

4.6 Impact Outcomes

Climate variability is a central driver of food production and food security outcomes. While precipitation benefits food production in the short term, it becomes detrimental in the long run under shifting climatic regimes, whereas temperature consistently has adverse long-term effects (Aboyitungiye & Suryanto, 2025). These macro-level findings, however, may obscure sub-national heterogeneity and household-level coping dynamics, and the assumption of stable long-run relationships risks underestimating non-linear thresholds and adaptive responses.

The impacts of climate stressors are further mediated by socio-economic conditions. Off-farm income improves dietary diversity for women and children, while agricultural production diversity alone does not (Emera et al., 2025), challenging policy narratives that equate on-farm diversification with nutritional gains. Persistent gender inequalities in access to CSA technologies are evident, although women sometimes use certified seeds more than men (Nchanji et al., 2023), a paradox that highlights how adoption metrics may mask deeper constraints. Similarly, while smallholder farmers may be technically efficient, they often remain food insecure because their production does not meet household caloric requirements (Niragira et al., 2018). Ultimately, climate-linked food insecurity emerges from biophysical stress interacting with unequal access to technology, limited income diversification, and entrenched land inequalities.

Technological, agroecological, and institutional interventions can partially mitigate these vulnerabilities, though their effectiveness remains uneven. ISFM, combined with improved bean varieties, increased yields by up to 74% (Kessler et al., 2015), and agroecological innovations similarly increased production (Birachi et al., 2011; Manirakiza et al., 2024). However, many studies emphasize short-term productivity without adequately assessing long-term resilience or labour burdens. Adaptation strategies are widely adopted (around 92%) and shaped by education, farm size, and credit access (Pacifique Batungwanayo et al., 2023), yet high adoption rates may overstate adaptive capacity if strategies are incremental. Moreover, persistent low food agency remains evident, with most households consuming non-preferred foods; only off-farm income significantly improves autonomy (Slosse et al., 2024). Capacity gaps among extension agents further constrain outcomes (Nyamweru et al., 2023), pointing to institutional weaknesses that undermine sustained change.

5.0 Discussion

The evidence synthesized indicates that food security outcomes in Burundi are shaped by the interplay of climate stressors, structural farm constraints, and households' capacity to adopt productivity and resilience-enhancing strategies. Time-series and econometric studies show precipitation variability and rising temperatures significantly affect food production, reflecting dependence on rain-fed smallholder agriculture (Aboyitungiye & Suryanto, 2025). Chronic land scarcity and fragmentation, with farm sizes below one hectare, limit output expansion, yielding only modest welfare gains despite higher land productivity on smaller plots (Verschelde et al., 2012; Niragira et al., 2018). Sustainable practices such as ISFM and agroecology improve yields and income, but the benefits depend on access to inputs, knowledge, and institutional support (Kessler et al., 2015; Manirakiza et al., 2024; Manirakiza et al., 2025). Complementary off-farm income enhances dietary diversity and buffers shocks, showing food security is influenced by broader livelihood portfolios (Nzabakenga et al., 2013; Emera et al., 2025). However, access is uneven, as gender norms and land tenure inequalities restrict women's adoption of beneficial technologies (Nchanji et al., 2023). Water–energy–food nexus analyses indicate durable gains require alleviating systemic constraints through resource coordination and infrastructure (Mperejekumana et al., 2023). Generally, technical interventions boost productivity, but their effects are mediated by socioeconomic status, education, gender relations, and institutional capacity. Thus, policies must integrate climate adaptation, livelihood diversification, and inclusive capacity building to achieve sustained food security beyond subsistence (Birachi et al., 2011; Nyairo et al., 2020; Slosse et al., 2024).

Comparative evidence from Burundi demonstrates that climate vulnerability, productivity, and food security outcomes vary systematically by region due to differing biophysical and socio-economic conditions. In the foothills of Mumirwa, favourable rainfall and erosion-sensitive landscapes create an environment where sustainable land management practices like soil conservation, crop diversification, and organic nutrient management yield significant gains in both agricultural yields and environmental quality (Manirakiza et al., 2024). Conversely, in the northeastern part of the country, higher exposure to rainfall variability and climate shocks leads farmers to prioritize short-term coping strategies, including crop switching and adjusting planting calendars, rather than long-term investments, highlighting greater livelihood vulnerability and

weaker institutional support in these areas (Pacifique Batungwanayo et al., 2023; Aboyitungiye & Suryanto, 2025). Similarly, studies in northern Burundi show that food security and agricultural income are closely tied to land size, market access, and diversification, with income gains relying more on off-farm employment and commercialization than on yield increases alone, a reflection of land scarcity and denser populations (Nzabakenga et al., 2013; Niragira et al., 2015).

Nationally, analyses indicate that while smaller farms often achieve higher land productivity, welfare and food security outcomes remain uneven, particularly where market access and extension services are limited (Niragira et al., 2018; Verschelde et al., 2012). These disparities are further compounded by gender, as women in more remote provinces face significant barriers to accessing climate-smart technologies, information, and decision-making power, which diminishes the potential food security benefits of effective agricultural practices (Nchanji et al., 2023). Overall, the provincial comparison underscores that regions with stronger institutional presence and agroecological suitability, such as Mumirwa, are more effective at translating sustainable practices into food security gains. In contrast, climatically stressed and infrastructure-poor regions fall behind, reinforcing the necessity for territorially differentiated policies for food security and climate adaptation (Mperejekumana et al., 2023; Nyairo et al., 2020).

Research indicates that climate-smart and sustainable agricultural practices enhance food security in Burundi through interconnected biophysical, socioeconomic, and institutional mechanisms. Initially, practices like ISFM and agroecology counter the negative biophysical impacts of climate variability like erratic rainfall and rising temperatures by improving soil health, water retention, and ultimately stabilizing crop yields (Kessler et al., 2015; Aboyitungiye & Suryanto, 2025). However, the translation of these productivity gains into household food security is constrained by structural factors, primarily small and fragmented landholdings, which limit surplus production (Verschelde et al., 2012). Socioeconomic factors then mediate impact: access to extension services and vocational training ensures effective implementation of innovations (Manirakiza et al., 2025), while off-farm income diversifies livelihoods and bolsters dietary diversity (Emera et al., 2025). Critically, institutional and social dimensions, especially gender norms affecting resource access, determine the distribution of these benefits, leading to varied food security outcomes across different households and regions (Nchanji et al., 2023).

The synthesized studies demonstrate methodological strengths that bolster the credibility of evidence on climate, agriculture, and food security in Burundi. Macro-level analyses employ long-term time-series data and econometric techniques such as cointegration and vector error correction models to robustly identify long-run relationships and dynamic adjustments (Aboyitungiye & Suryanto, 2025). Micro-level research utilizes farm-household surveys, non-parametric efficiency analysis, and quasi-experimental approaches to derive context-specific insights into causal pathways and behaviours (Verschelde et al., 2012; Kessler et al., 2015; Manirakiza et al., 2025), while mixed-method designs integrate quantitative results with qualitative perceptions (Nyairo et al., 2020; Pacifique Batungwanayo et al., 2023). However, significant weaknesses persist, including reliance on cross-sectional data limiting causal inference and capturing adaptation over time (Nzabakenga et al., 2013; Niragira et al., 2015), geographically constrained samples reducing external validity, and widely varying food security indicators hindering comparability (Slosse et al., 2024; Emera et al., 2025). Furthermore, gender and institutional factors are often treated as control variables rather than explicitly modelled mechanisms, potentially leading to an underestimation of their mediating role (Nchanji et al., 2023). This limits a comprehensive understanding of how these factors shape CSA adoption outcomes.

6.0 Conclusion

The synthesis of the reviewed studies demonstrates that food security outcomes in Burundi arise from the complex interplay among climate variability, structural agricultural constraints, and socio-economic capacities that shape farmers' ability to adopt sustainable practices. The evidence consistently shows that climate stressors, particularly rainfall variability and rising temperatures, undermine agricultural productivity in predominantly rain-fed farming systems, thereby exacerbating vulnerability among smallholder households. At the same time, structural limitations such as land scarcity, fragmentation, and soil degradation constrain the extent to which productivity improvements can transform into meaningful welfare gains. Although sustainable farming practices, particularly integrated soil fertility management and agroecological approaches, have demonstrated the capacity to increase yields and stabilize production, the literature reveals a strong bias toward short-term, input-based interventions rather than more transformative system-level practices that could enhance long-term resilience. Food security measurement across studies is also uneven, with most analyses emphasizing production and income indicators while largely

neglecting dietary quality, food utilization, and stability dimensions, thereby limiting a comprehensive understanding of household well-being. Socio-economic moderators further shape outcomes, as education, off-farm income opportunities, access to extension services, and gender relations strongly influence both technology adoption and the distribution of benefits. Importantly, regional disparities highlight that provinces with stronger institutional presence and more favourable agroecological conditions tend to convert sustainable practices into improved food security more effectively than areas characterised by climate stress, weak infrastructure, and limited market access. Methodologically, the dominance of cross-sectional and survey-based studies provides valuable insights into adoption patterns but restricts causal inference and long-term assessment of adaptation processes. Finally, the evidence suggests that while technical agricultural innovations contribute to productivity improvements, sustainable food security in Burundi requires integrated strategies that simultaneously address climatic risks, land constraints, livelihood diversification, institutional capacity, and gender equity to ensure that productivity gains metamorphose into durable and inclusive food system resilience.

7.0 Recommendations

The findings suggest that future research and policy interventions in Burundi should prioritize more spatially balanced and context-specific approaches to agricultural development and food security. Greater attention is needed for underrepresented provinces, particularly in southern and western regions, to ensure that national strategies reflect the diversity of agroecological conditions and livelihood systems. Research agendas should expand beyond input-based practices such as fertiliser and pesticide use to encompass more transformative, system-oriented approaches, such as agroforestry, conservation agriculture, water management, and integrated crop–livestock systems. Strengthening the measurement of food security is equally important; studies and programmes should adopt standardised, multidimensional indicators that capture not only production and income but also dietary quality, food utilisation, and household stability. In addition, future investigations should incorporate longitudinal, participatory, and experimental designs to better understand long-term adaptation processes and the causal impacts of sustainable farming practices.

From a policy perspective, improving food security requires integrated strategies that address both agricultural productivity and broader socio-economic constraints. Investments should focus on strengthening extension services, improving farmer training, and expanding access to credit and agricultural inputs while promoting knowledge-intensive and environmentally sustainable practices. Policies should also support livelihood diversification through off-farm employment opportunities, which have been shown to improve dietary diversity and household resilience. Addressing gender inequalities in access to land, technologies, and information is essential to ensure equitable benefits from agricultural innovation. Furthermore, coordinated investments in rural infrastructure, markets, and climate-resilient resource management are needed to reduce structural barriers faced by smallholder farmers. By combining technological innovation with institutional strengthening and inclusive development policies, Burundi can enhance the resilience of its agricultural systems and achieve more sustainable and equitable food security outcomes.

Data availability statement

All original contributions supporting this study are contained within the article and supplementary files. Further information can be obtained by contacting the corresponding author.

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Conflict of interest

The author certifies that this research was conducted without any commercial or financial relationships that might be interpreted as a potential conflict of interest.

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