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Beyond Technology: Gender and Indigenous Knowledge Systems as Foundations of Sustainable Food Innovation in Sub-Saharan Africa

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Abstract
Technological interventions have been the dominant framing of sustainable food innovation in Sub-Saharan Africa, often neglecting the sociocultural and knowledge systems that influence the production, processing, and consumption of food. This study re-conceptualizes food innovation through a product and process lens and emphasizes the role of gendered Indigenous knowledge systems in shaping the diversity of food products and the methods through which they are produced and processed. This study, based on a systematic literature review (2020–2025), shows that gender relations and Indigenous knowledge systems (IKS) are key drivers of product innovation (e.g., climate-resilient crops, diversified diets, and traditional food products) and process innovation (e.g., fermentation, agroecological production, preservation, and water and soil management practices). The findings show that women are at the forefront of both domains, especially in food processing and value addition, where indigenous knowledge creates adaptive and context-specific innovation. However, structural inequalities continue to hinder their ability to scale up these innovations in the sector. This study introduces a Gendered Indigenous Innovation Framework (GIIF) to conceptualize the co-evolution of product and process innovations in socio-cultural, economic, and environmental systems. Evidence shows that the integration of gender-responsive and Indigenous knowledge-based approaches enhances food quality, reduces post-harvest loss, improves climate resilience, and strengthens sustainable livelihoods. The study concludes that African food systems must shift away from technocentric models towards endogenous and inclusive innovation systems that recognize locally embedded product and process innovations.

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1. Introduction

Climate variability, rapid population growth, and enduring socioeconomic inequalities are increasing the pressure on food systems in Sub-Saharan Africa (Mabhaudhi *et al*., 2022) [27]; (FAO, 2023) [17]. Significant investments have been made in modernizing agriculture; however, food insecurity and malnutrition persist at alarming rates (World Bank, 2021) [41]. Much of the current innovation conversation revolves around technological interventions, including better seed varieties, mechanization, and digital tools (Barrett *et al*., 2020) [7]. However, these approaches tend to ignore how food systems work, particularly the food produced (product innovation) and how it is produced, processed, and preserved (process innovation) (Ericksen, 2008)

[15]. Therefore, many interventions are not consistent with the realities of smallholder systems, where food innovation is part of everyday practice and is not only driven by external technologies (HLPE, 2019) [20].

Smallholder farmers, who produce most of the food in the region, work within complex systems of gender relations and Indigenous Knowledge Systems (IKS) (Altieri and Nicholls, 2020) [5]. In these systems, women are important actors in product innovation through diversification of food products, development of traditional foods, and adaptation of diets, and in process innovation, including seed selection, fermentation, preservation, and post-harvest handling of food (Adebo, 2020) [1]; (Quisumbing *et al*., 2021) [33]. These practices are based on Indigenous knowledge and are constantly being improved to meet environmental and socio-economic challenges (Mapfumo *et al*., 2023) [28]. However, women are systemically restricted from accessing land, finance, markets, and decision-making platforms despite their critical contributions, limiting the scaling and recognition of these innovations in the agricultural sector (Meinzen-Dick *et al*., 2019) [29]. Simultaneously, IKS is underrepresented in formal innovation systems that tend to favor externally developed technologies over locally embedded knowledge systems (Chivenge *et al*., 2021) [12]

This study calls for a rethinking of sustainable food innovation in Sub-Saharan Africa from a product and process perspective. This is because gendered Indigenous knowledge systems are central to shaping food outputs and the processes that sustain them (Njuki *et al*. 2022) [30]. Drawing on a systematic review of the recent literature, this study shows that product and process innovations are socially embedded, context-specific, and co-evolving (Tendall *et al*., 2015) [38]. The study also proposes a Gendered Indigenous Innovation Framework (GIIF) to explain how these innovations emerge and contribute to resilience, sustainability, and food-system transformation. Thus, this study promotes a move away from technocentric approaches towards innovation systems that are endogenous, inclusive, and local knowledge driven.

2. Methods

2.1. Study Design

This study employed a systematic narrative review to examine the influence of gender relations and Indigenous Knowledge Systems (IKS) on product and process food innovations in smallholder farming systems in sub-Saharan Africa. This review moves beyond technocentric interpretations of innovation by focusing on food product diversification and the evolution of production, processing, and preservation practices within local food systems. A qualitative synthesis approach was adopted to capture the context-specific, socially embedded, and non-linear nature of innovation in informal and indigenous food systems, where conventional quantitative meta-analytical approaches are often inadequate.

2.2. Data Sources and Search Strategy

The review drew on peer-reviewed literature from *Scopus*, *Web of Science*, and *Google Scholar* to capture multidisciplinary research on food system innovation in smallholder farming systems in sub-Saharan Africa. Additional policy and applied research documents were sourced from the Food and Agriculture Organization and the World Bank to incorporate regional assessments and development perspectives relevant to the transformation of food systems.

The search strategy combined thematic keywords and Boolean operators to identify studies related to product and process innovation, gender, Indigenous Knowledge Systems (IKS), and sustainability. Core search terms included "product innovation AND food systems Africa," "process innovation AND agriculture Africa," "indigenous food processing AND Africa," "gender AND food systems innovation Africa," and "agroecology AND food production innovation." Additional synonymous terms and combinations were used to broaden the coverage.

The search prioritized studies examining locally adapted innovations within smallholder farming systems, including traditional food systems, climate resilience, sustainable agricultural practices, food processing, and preservation technologies. This approach enabled the identification of literature reflecting the interconnected and co-evolving nature of product and process innovations in resilient food systems.

2.3. Inclusion and Exclusion Criteria

Studies published between 2020 and 2026 were included to capture recent evidence of food system innovation, sustainability, and resilience in smallholder farming systems. The review focused primarily on sub-Saharan Africa, selectively incorporating studies from comparable smallholder systems in other developing regions where relevant contextual insights were provided.

Eligible studies addressed product innovation, process innovation, or their interactions within smallholder food systems. Product innovation studies included topics such as crop diversification, indigenous and traditional foods, nutritional enhancement and value addition. Process innovation studies have focused on food processing and preservation practices, including fermentation, drying, storage technologies, agroecological production methods, and soil and water management systems. The review also prioritized studies examining cross-cutting dimensions, particularly gender relations and Indigenous Knowledge Systems (IKS), owing to their central role in shaping food innovation and resilience.

Studies were excluded if they focused exclusively on industrialized or high-technology innovations that lacked relevance to smallholder contexts. Articles unrelated to food systems, agriculture, or rural livelihoods, as well as studies lacking empirical or conceptual relevance to the research objectives were also omitted to ensure analytical rigor and thematic consistency.

2.4. Analytical Framework and Synthesis

A thematic synthesis approach was used to analyze the reviewed literature using a product–process innovation framework to examine innovation dynamics in smallholder farming systems in sub-Saharan Africa. The framework categorizes studies into three domains: product innovation, process innovation, and cross-cutting dimensions that influence food system transformation. This structure enabled a systematic assessment of how innovations interact to strengthen resilience, sustainability, and adaptive capacity of the health system. The product innovation domain focuses on indigenous food products, crop diversification, nutritional enhancement, and value-added strategies that improve food security, dietary diversity, and livelihoods. The emphasis was on traditional foods and locally adapted products contributing

to climate-resilient systems.

The process innovation domain examines food processing and preservation practices, including fermentation, drying, storage technologies, agroecological production, soil, and water management. These studies were analyzed for their contributions to reducing post-harvest losses, improving food quality and safety, and enhancing resource efficiency and climate resilience in smallholder systems in the Philippines. The cross-cutting dimension explored gender relations, Indigenous Knowledge Systems, and environmental adaptation strategies. The emphasis was on women's roles in food production, processing, preservation, and diversification, and the contribution of indigenous knowledge to locally adapted and sustainable innovation.

The synthesis identified patterns of co-evolution between product and process innovations and assessed their implications for resilience, sustainability, and food system transformation. The analysis showed that innovations in smallholder systems are interconnected, with improvements in production and processing shaping food diversity, quality, and availability, while product innovations drive the demand for improved processes and preservation systems.

3. Results

3.1. Product Innovations in Sub-Saharan African Food Systems

The review concludes that the drivers of product innovation in Sub-Saharan Africa are the diversification and adaptation of local food products. The crops are drought-resistant varieties of sorghum and millet and traditional food products from them, such as fermented porridge, beverages, and composite flours. These innovations boost nutritional diversity, diet resilience, and food security, especially in climate-stressed environments. The study emphasizes that product innovation is not just about introducing new foods but also about reconfiguring and improving traditional existing foods. Indigenous crops are valued for their nutritional and adaptive properties and are the linchpin for transforming sustainable food systems. Women are often at the forefront of such innovations and play a crucial role in the preparation and adaptation of food and knowledge transfer.

3.2. Process Innovations in Production, Processing, and Preservation

Production, processing, and preservation process innovations are critical for improving the resilience, productivity, and sustainability of smallholder farms in sub-Saharan Africa. These farmers, who produce a large amount of the region's food, often struggle with post-harvest losses, nutrient deficiencies, limited access to technology, and climate risks (Mabhaudhi *et al*., 2022) [27]; (Thornton *et al*., 2018) [39]. Affordable and locally adaptable innovations are important for improving food availability, nutritional quality, and livelihood security.

Fermentation technologies are culturally embedded in smallholder farming systems. They extend the shelf life of perishable foods and enhance the bioavailability of nutrients, digestibility, and microbial safety (Adebo 2020) [1]; (Oguntoyinbo & Narbad 2021) [32]. Fermented products based on cereals, milk, cassava, and legumes are important in rural communities where there is no refrigeration. These technologies contribute to reducing food loss and waste, diversifying diets, and improving nutrition during shortages.

Innovation is required in drying, storage, and post-harvest handling. The preservation of grains, fruits, and vegetables is achieved by solar drying systems, hermetic storage bags, metal silos, and moisture management practices, which reduce pests and contamination (Affognon *et al*., 2015) [2]; (Stathers *et al*., 2020) [37]. These interventions reduce economic losses and improve market participation, thus stabilizing income, food security, and resilience to market shocks.

Process innovation can improve the situation of smallholders in Sub-Saharan Africa. These innovations improve household resilience and the sustainability of food systems through reduced losses, improved food quality, and increased resource efficiency (Tendall *et al*., 2015) [38]. They are valuable for inclusive climate-resilient agricultural development because they are available and affordable.

3.3. Gendered Dynamics of Product and Process Innovation in Smallholder Farming Systems

Across the studies reviewed on smallholder farming systems in sub-Saharan Africa, gender was a major factor that influenced the development, adoption, and diffusion of product and process innovations. Women play an important role in the production, processing, preservation, and local marketing of food at the household level and are thus important actors in the innovation and resilience of the food system (Doss, 2018) [13]; (Quisumbing *et al*., 2021) [33]. Their contributions are found in informal and community-based food systems, where localized knowledge, labour, and resource management help household nutrition and livelihoods.

Women contribute to the development and diversification of food products through value-added practices that improve dietary diversity, marketability, and income generation. In many rural communities, women transform raw agricultural products into processed foods, such as fermented cereals, dried vegetables, dairy products, and legume-based foods, which have extended shelf lives and enhanced nutritional qualities (Adebo, 2020) [1]; (Njuki *et al*., 2022) [30]. Such innovations are important for household food security and provide avenues for small-scale entrepreneurship and access to local markets.

Likewise, women dominate post-harvest processing and preservation activities in smallholder farms. Their participation in drying, storage, fermentation, packaging, and food preparation reduces food loss and ensures availability during periods of scarcity (FAO, 2023) [17]. Women sustain local food systems by using indigenous preservation techniques and adaptive processing in a climate-and economically uncertain world. Furthermore, women play an important role in maintaining traditional seed systems, conserving agrobiodiversity, and protecting indigenous crop varieties that are more resilient to drought, pests, and changing conditions (Carr and Thompson, 2014) [9]. Women contribute, but their ability to scale and commercialize innovations is limited by structural inequalities. Women's potential to innovate and make decisions is limited by their access to resources such as land, credit, agricultural inputs, training, digital technologies, and extension services (Meinzen-Dick *et al*., 2019) [29]; (Quisumbing *et al*., 2021) [33]. Gendered social norms limit women's participation in formal markets and networks, and thus their ability to fully benefit from innovation systems and commercialization processes. These inequalities constrain the potential for growth and effectiveness of promising

innovations in smallholder farming systems. However, women remain key actors in innovation, adaptation, and resilience in informal food systems in sub-Saharan Africa. Their indigenous knowledge, processing expertise, and community networks make significant contributions to sustainable food production and household food security. Gender-responsive innovation policies and interventions that address structural barriers to increasing women's access to resources, technologies, capacity building, and decision-making are essential to strengthen food system resilience. Thus, it is imperative to mainstream gender into innovation systems to promote the inclusive, equitable, and sustainable development of smallholders.

3.4. Co-Evolution of Product and Process Innovations in Smallholder Farming Systems

One of the major findings of the reviewed literature is that innovations in products and processes in smallholder farming systems are interdependent and co-evolved. Innovations in production, processing, preservation, and resource management influence the quality, diversity, accessibility, and stability of food products in local food systems (Tendall *et al*., 2015) [38]; (Ericksen, 2008) [15]. Such interconnection is a sign of the systemic nature of food innovation, with changes in one part of the food value chain affecting other parts. In smallholder systems, the production processes determine the variety and quality of products for consumption and commercialisation.

Generally, the increase in diversification of farming practices and sustainable approaches results in an increased number of nutrient-rich crops, legumes, and indigenous food species being processed into value-added products (Mabhaudhi *et al*., 2022) [27]. For example, diversified cropping systems add to the diversity of diets and offer opportunities for the development of processed foods based on cereals, legumes, roots, and traditional crops adapted to local conditions. Therefore, process innovations at the farm level encourage product innovation and diversification of rural food systems. Processing and preservation technologies also influence the usability, marketability, and nutritional quality of food products. Improved techniques of fermentation, drying, packing, and storage result in increased food safety, extended shelf life, and reduction in post-harvest losses, thus increasing the availability of food products for household consumption and market participation (Adebo, 2020) [1]; (Stathers *et al*., 2020) [37]. These innovations in preservation processes are found in many smallholder contexts and allow for the availability of seasonal produce throughout scarcity, contributing to more stable and resilient food systems. These process improvements allow the commercialization of locally processed products, thus providing additional income to rural households.

In addition, innovations in soil, water, and resource management systems have a positive impact on food product outcomes by stabilizing agricultural productivity under changing climate conditions. Better water management, moisture conservation, and sustainable land-use practices (Rockström *et al*. 2017) [36] have resulted in steady crop production to provide a steady supply of raw materials for food processing and value-added activities. This relationship demonstrates how process innovations aimed at the efficiency of resource use may enhance the availability of food and the resilience of the system.

In smallholder farming systems, food innovation is not linear or technologically isolated, as shown by the co-evolution of product and process innovations. Rather, it is the outcome of the dynamic interaction of production practices, processing systems, environmental management, and socio-economic conditions within broader socio-ecological systems (HLPE, 2019) [20]. Product innovations are often the result of process improvements; however, new products may require more efficient processes and preservation techniques. This relationship is reciprocal and contributes to the adaptive capacity of smallholder food systems, demonstrating the importance of integrated, systems-based approaches to agricultural innovation and food security in sub-Saharan Africa.

3.5. Implications for Resilience and Sustainability in Smallholder Farming Systems

The integration of product and process innovations in smallholder farming in sub-Saharan Africa influences resilience, food security, and sustainability. These innovations help households cope with climatic, economic, and social shocks by improving food production, processing, and distribution (Tendall *et al*., 2015) [38]; (Mabhaudhi *et al*., 2022) [27]. Locally adapted products and improved processes enhance food system stability and adaptability under uncertain conditions. Integrated innovation for improving the climate resilience of smallholder farms. Adaptive strategies, such as product diversification and resource-efficient practices, help buffer climate variability and food shortages (Thornton *et al*., 2018) [39]. Better storage reduces post-harvest losses, and diverse products provide nutritional and income alternatives when crops fail, increasing the adaptive capacity of rural communities.

Product and process innovations contribute directly to food security by creating diverse, accessible, and stable food supplies. Technological advances have improved the availability of nutritious food throughout the year, reducing fluctuations in seasonal access and promoting dietary diversity (FAO, 2023) [17]. Farmers can better store excess produce, increase market engagement, and reduce waste, thereby improving food access and economic resilience. Product diversification promotes nutritional resilience and livelihood diversification in smallholder farming systems. Innovations support sustainability through low-input, resource-efficient practices. Many depend on local materials and indigenous methods, thereby reducing reliance on costly inputs (HLPE 2019) [20]. These approaches reduce environmental degradation and increase resource efficiency, thereby supporting sustainable food systems. Localized innovation pathways enhance socioeconomic sustainability by providing better accessibility to resource-constrained communities.

Indigenous knowledge and gender-responsive approaches are integral to effective innovation systems. Indigenous knowledge provides context-specific strategies for production and environmental management (Altieri & Nicholls, 2020) [5]. Gender-responsive approaches guarantee women equitable access to resources and decision-making (Quisumbing *et al*., 2021) [33]. Including these dimensions increases social inclusion, innovation uptake, and the resilience of smallholder food systems. These findings underscore the need for integrated food system approaches that recognize product innovation, process innovation,

Indigenous knowledge, and gender equity to advance resilient and sustainable smallholder agriculture in Sub-Saharan Africa.

4. Discussion

4.1. Rethinking Innovation Through Product and Process Lenses

In Sub-Saharan African food systems, innovation is often narrowly defined as external technologies, such as improved seeds or mechanization. However, the evidence points to the fact that the major changes are best understood in terms of product and process transformations embedded in local systems. Product innovation encompasses the diversification and upgrading of food products, such as nutrient-dense native grains, fermented foods, and composite flours. Innovation of processes refers to the ways of production, processing, preservation, and distribution (Akinola *et al*., 2020) [4]; (Amissah *et al*., 2025) [6]. These innovations are predominantly adoptive and incremental and are based on indigenous knowledge systems rather than imposed technologies from outside (Mabhaudhi *et al*., 2020) [27]; (Chivenge *et al*., 2021) [12].

Improvements in fermentation, drying, storage, and agroecological production are highlighted as ways to improve food quality, shelf life, and resilience without the use of high-cost inputs (Adebo *et al*., 2021) [1]; (Agyei *et al*., 2020). This is in line with broader thinking on innovation systems, where outcomes are generated through continuous adaptation and learning within socio-ecological contexts (Barrett *et al*., 2022) [7]; (Klerkx *et al*., 2021) [25]. Therefore, sustainable food innovation can be better understood as the co-evolution of better food products and the processes that sustain them, rather than merely a question of technology adoption (van Wijk *et al*., 2020) [40].

4.2. Gendered Dimensions of Product and Process Innovations

Product and process food innovations are deeply gendered. Women are central to product innovation, especially in the development of various food products based on native crops and in adapting recipes and nutritional practices. They are also central to process innovation, especially in fermentation, drying, preservation, and small-scale processing systems (Doss *et al*., 2021) [14]; (Zannou *et al*., 2022) [43]. These practices are rooted in Indigenous knowledge systems and have been passed down from generation to generation for continuity and adaptation.

The role of women greatly increases innovation. Gender-responsive interventions improve product and process efficiency and raise adoption rates and resilience (Lecoutere *et al*., 2023) [26]; (Quisumbing *et al*., 2022) [34]. However, the exclusion of women from decision-making hampers the effectiveness of the innovation system. Thus, product and process innovations are not only technical improvements but are also socially embedded and gendered (Huyer *et al*., 2021) [22].

4.3. Interactions Between Production, Processing, and Environmental Conditions

Environmental conditions, production systems, and new product and process innovations are strongly correlated. Climate variability influences the development of resilient food products, including drought-resistant crops and adaptive production and processing techniques (Nyong *et al*., 2021) [31]; (IPCC, 2022) [23]. Agroecological practices, including intercropping, soil conservation, and organic nutrient management, directly impact the quality and availability of food products (Bezner Kerr *et al*., 2022) [8]; (Altieri & Nicholls, 2020) [5].

Enhanced post-harvest drying, storage, and preservation technologies minimize losses and stabilize food supply across seasons (Affognon *et al*., 2015) [2]; (Kitinoja, 2021). These interactions produce feedback loops in which production processes influence food products, and innovations in processing develop resilience. This underscores the importance of product and process innovations as elements of food system transformation rather than standalone interventions.

4.4. Policy Implications for Product and Process Innovation Systems

Product and process innovation are emphasized, requiring changes in the policy framework. Current policies are input- and technology-driven and do not cater to local innovations. Policies for sustainable food systems should promote the development of indigenous products and local processing systems, including traditional foods, value addition, and small-scale enterprises (FAO 2023) [17]; (HLPE 2021) [21]. It is also important to have gender-responsive policies to enable women to lead innovation in products and processes. This includes better access to land, finance, markets, and extension services (World Bank, 2022) [42]. There is much that can be done to improve food security and economic resilience in the region by developing local processing facilities and marketing channels for local products, for example. Ultimately, good policy should support innovation systems that are context-specific and inclusive and build on existing knowledge and practice rather than replacing them.

4.5. Case Study Insights

In operationalizing the “beyond technology” paradigm, Table 1 synthesizes the ways in which gendered indigenous knowledge systems (IKS) drive product and process food innovations in selected sub-Saharan African contexts. The table shows how the nature of food products and the processes through which they are produced, processed, and preserved are influenced by locally embedded practices.

Table 1: Product and process food innovations driven by gender and indigenous knowledge systems in selected Sub-Saharan African countries

Country	Food System Context	Product Innovation (What Food is Produced/Improved)	Process Innovation (How Food is Produced/Processed)	Role of Gender & IKS	Food System Outcomes	Key Supporting References
Zimbabwe	Semi-arid smallholder systems facing drought and maize instability	Indigenous grains (sorghum, millet); diversified products such as porridge, fermented beverages, composite flours	Indigenous fermentation, sun-drying, improved storage systems, small-scale milling	Women manage seed selection, preservation, and processing; intergenerational knowledge transfer	Improved dietary diversity, reduced post-harvest losses, enhanced climate resilience	Mabhaudhi *et al.* (2020); Adebo *et al.* (2021); Doss *et al.* (2021)
Kenya	Agroecological smallholder systems with increasing climate variability	Diverse food products including indigenous vegetables, legumes, cereals; nutrient-rich diets	Agroecological practices (intercropping, composting, natural pest control); community seed systems	Women-led cooperatives manage seed banks and knowledge exchange; IKS guides crop diversity	Increased food diversity, improved soil fertility, enhanced sustainability and adoption rates	Bezner Kerr *et al.* (2022); Chivenge *et al.* (2021); Lecoutere *et al.* (2023)
Ethiopia	Highland farming systems with soil degradation risks	Traditional foods (e.g., injera from teff and mixed grains); improved nutritional composition	Fermentation processes, traditional grain processing, terracing, water conservation practices	Women dominate food processing and household nutrition decisions; IKS informs land and food systems	Sustained productivity, improved nutrition, enhanced resource conservation	Nyong *et al.* (2021); Akinola *et al.* (2020); Zannou *et al.* (2022)
Burkina Faso	Arid and semi-arid systems with water scarcity and land degradation	Climate-resilient foods based on millet and sorghum; diversified traditional diets	Zaï pits, stone bunds, soil fertility restoration, localized water harvesting systems	Women adapt and apply water and soil management practices; community-based knowledge sharing	Increased crop yields, improved food availability, strengthened climate adaptation	Huyer *et al.* (2021); Nyong *et al.* (2021); Barrett *et al.* (2022)

Table 1 offers empirical evidence of the co-evolution of product and process innovations within gendered indigenous knowledge systems as the locus of food innovation in Sub-Saharan Africa. In all cases, product innovation, as manifested in diverse, nutritious, and climate-resilient foods, cannot be separated from process innovation, including locally adapted production, processing, and resource management practices. The influx of high-impact evidence also shows that these innovations are not marginal or informal but are increasingly seen in global food system research as crucial routes for improving resilience, sustainability, and food security. Importantly, women were discovered to be key players in both fields, supporting the claim that gender is a structural determinant of innovation, rather than an ancillary issue.

4.6. The Gendered Indigenous Innovation Framework (GIIF)

Figure 1 presents the Gendered Indigenous Innovation Framework (GIIF) as an integrated model, showing how sustainable food innovation in Sub-Saharan Africa arises from social, ecological, and institutional dynamics. Contextual drivers, such as climate change, demographic pressure, market dynamics, and policy environments, create conditions for food systems. These drivers shape the urgency, direction, and nature of innovation (Food and Agriculture Organization, 2023) [17]; (Intergovernmental Panel on Climate Change, 2022) [23]; (Thornton *et al*., 2021). Climate variability and socioeconomic pressures have increased the need for adaptive innovation in African food systems (Barrett *et al*., 2022) [7]; (van Wijk *et al*., 2020) [40].

Gender relations and indigenous knowledge systems (IKS) are core elements of the framework. Gender relations affect resource access, decision-making, labor, and benefits, while IKS offers knowledge of seed systems, soil fertility, biodiversity, and food processing (Doss *et al*., 2021) [14]; (Mapfumo *et al*., 2022) [28]. These elements interact bidirectionally, as knowledge systems are gendered and gender roles evolve through the application of knowledge (Lecoutere *et al*., 2023) [26]; (Huyer *et al*., 2021) [22]. The framework identifies three mediating systems that translate core interactions into practice. The sociocultural system governs norms and knowledge transmission, affecting innovation diffusion (Agarwal, 2021) [3]; (Carr & Onzere, 2020) [10]. The economic system reflects livelihood strategies and value chain participation, with women often being undervalued (Quisumbing *et al*., 2022) [34]; (Ragasa *et al*., 2020) [35]. The environmental system represents agroecological conditions managed through indigenous practices that enhance climate resilience (Nyong *et al*., 2021) [31]; (Bezner Kerr *et al*., 2022) [8]. These systems interact to shape innovation, such as indigenous seed systems, agroecological farming, gendered food processing, and informal market innovations. Innovation is nonlinear and co-evolutionary, with feedback loops enabling learning, adaptation, and system transformation (Klerkx *et al*., 2021) [25]; (Hall *et al*., 2021).

The framework highlights multidimensional outcomes, including improved food and nutrition security, climate resilience, sustainable livelihoods, biodiversity conservation, and gender equity. These outcomes are interconnected and contribute to resilient food systems (HLPE 2021) [21]; (Food and Agriculture Organization & International Fund for Agricultural Development, 2024) [18].

The framework includes enabling conditions such as gender-responsive policies, secure land rights, inclusive extension systems, participatory research, and investments in women and youth. These are vital for scaling innovation and

addressing inequalities in food system transformation (World Bank, 2022) [42]; (CGIAR, 2023); (Njuki *et al*., 2022) [30]. Overall, Figure 1 emphasizes that sustainable food innovation in Sub-Saharan Africa is a context-dependent, socially embedded system driven by gender dynamics and indigenous knowledge systems.

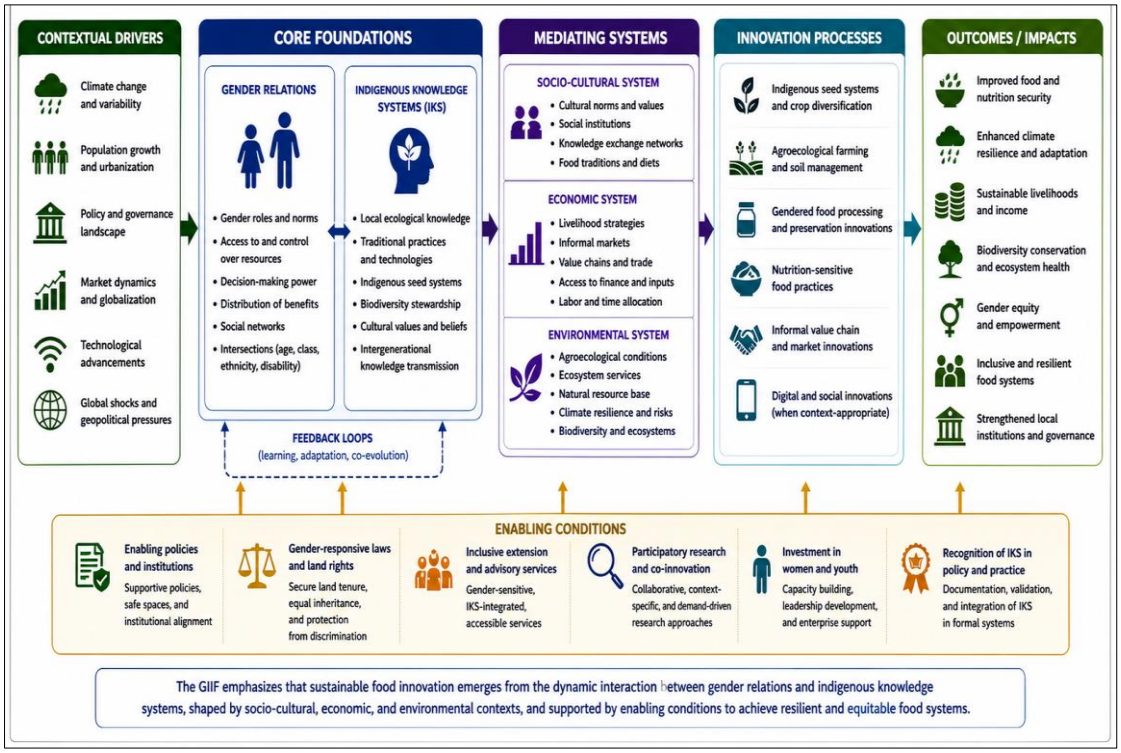

Fig 1:

5. Conclusion

This study shows that sustainable food innovation in Sub-Saharan Africa cannot be fully understood through technocentric paradigms alone. Instead, innovation arises from the interaction between gender relations and indigenous knowledge systems (IKS), shaping food production, processing, and distribution in smallholder settings. Evidence from Zimbabwe, Kenya, Ethiopia, and Burkina Faso reveals that product and process innovations, including indigenous crops, traditional food processing, agroecological practices, and water management, are deeply rooted in local knowledge systems and are often led by women, the key custodians of food systems. These innovations boost climate resilience, dietary diversity, and livelihood sustainability in the face of environmental and economic uncertainty. The Gendered Indigenous Innovation Framework (GIIF) advances scholarship by viewing food innovation as a socially embedded, non-linear, context-specific process that emphasizes gender as a structural determinant of innovation pathways. Indigenous knowledge systems are dynamic sources of innovation.

Policy implications stress moving beyond one-size-fits-all technological solutions to endogenous and inclusive innovation systems. This involves integrating Indigenous knowledge into formal frameworks, enhancing women's access to land, finance, and services, and supporting community-based knowledge co-creation. Future research should explore scaling gendered Indigenous innovations, especially in digital agriculture, climate-smart interventions and market systems. More gender-disaggregated data and interdisciplinary research are needed to capture the complexity of food-system innovation in diverse African contexts. In conclusion, achieving sustainable food systems in Sub-Saharan Africa depends on embedding innovation within the daily lives, cultural knowledge, and empowerment of local communities, with a strong focus on the crucial role that women play in driving these transformations.

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