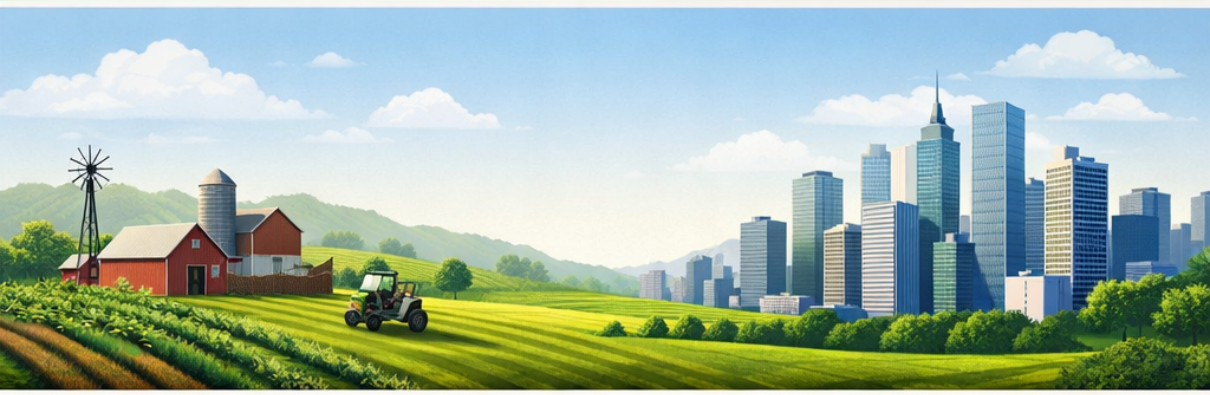

RURAL–URBAN DYNAMICS AND AGRICULTURAL TRANSFORMATION

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RURAL–URBAN DYNAMICS AND AGRICULTURAL TRANSFORMATION- 2026

ISBN: 978-625-93129-9-6

DOI: 10.5281/zenodo.18380642

Edited By

Olugbenga David OLORUNTOVA

January / 2026

İstanbul, Türkiye

Date: 26.01.2026

Halic Publishing House
İstanbul, Türkiye
www.halicyayinevi.com

adopted by Esma AKSAKAL
ISBN: 978-625-93129-9-6

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PREFACE

This book brings together interdisciplinary studies that address critical challenges and opportunities within agricultural development, food systems, and rural livelihoods, particularly in developing economies. The chapters collectively emphasize the role of policy, finance, innovation, and technology in enhancing food security, reducing losses, and promoting sustainable economic growth.

The chapter Rural–Urban Migration and Its Implications for Agricultural Development: Evidence, Policy Responses, and Innovation Pathways in Nigeria examines demographic shifts and their effects on agricultural productivity and rural economies. By analyzing policy options and innovation-driven responses, it provides valuable insights into managing migration dynamics while sustaining agricultural development.

Financial and market-oriented perspectives are explored in Strengthening Feed Security in West Africa: Unleashing the Strategic Potential of Financial Institutions for Sustainable Livestock Systems and The Economics of Eco-Innovation: Consumer Acceptance of Betel Leaf (Piper betle) Bath Bombs. Together, these chapters highlight how access to finance, investment strategies, and consumer behavior can drive sustainable production systems and support the adoption of environmentally friendly innovations.

The final chapter, Food Irradiation for Mitigating Post-Harvest Losses in Nigeria, focuses on a technological solution to one of the most persistent challenges in food systems. By addressing post-harvest losses, it underscores the importance of integrating science, policy, and innovation to improve food availability and resilience. Collectively, the chapters offer a comprehensive perspective on pathways toward sustainable and inclusive agri-food systems.

Editorial Team
January 26, 2026
Türkiye

CHAPTER 1
RURAL–URBAN MIGRATION AND ITS IMPLICATIONS FOR AGRICULTURAL DEVELOPMENT: EVIDENCE, POLICY RESPONSES, AND INNOVATION PATHWAYS IN NIGERIA

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INTRODUCTION

Rural–urban migration has become one of the most influential forces shaping demographic change, economic transformation, and agricultural development in Nigeria. Over the past several decades, Nigeria has experienced rapid population growth alongside accelerated urbanization, largely driven by the continuous movement of people from rural areas to urban centers. This migration trend reflects persistent disparities in economic opportunities, infrastructure development, and access to social services between rural and urban regions. For a country in which agriculture remains a major source of employment, income, and food supply, the implications of large-scale rural–urban migration for agricultural development are profound and far-reaching. Nigeria's agricultural sector employs a substantial proportion of the rural population and plays a critical role in national food security, poverty reduction, and economic diversification. Despite its importance, the sector continues to face structural challenges, including low productivity, limited mechanization, land fragmentation, inadequate access to finance, weak extension systems, poor rural infrastructure, and increasing exposure to climate-related risks. These challenges have contributed to declining farm profitability and reduced the attractiveness of agriculture, particularly among younger generations. As a result, rural youths increasingly perceive migration to urban areas as a pathway to improved livelihoods, education, and social mobility, thereby accelerating the pace of rural–urban migration.

The expansion of Nigeria's major cities such as Lagos, Abuja, Ibadan, Kano, Onitsha, and Port Harcourt has occurred at a scale that often outpaces the capacity of urban economies to generate sufficient formal employment opportunities. While urban centers attract migrants with the promise of jobs, higher wages, and better access to services, many migrants ultimately find themselves engaged in informal and precarious forms of employment. Nonetheless, the continuous flow of migrants from rural areas has significant implications for agricultural systems, particularly in terms of labor availability, farm management practices, land use, and productivity outcomes. From an agricultural development perspective, rural–urban migration presents a complex paradox.

On one hand, the out-migration of able-bodied individuals reduces the availability of agricultural labor, contributes to the aging of the farming population, and undermines the capacity of rural households to sustain labor-intensive farming systems. In some regions, migration has led to farmland abandonment, declining crop yields, and increased reliance on food imports, thereby heightening food security concerns. On the other hand, migration can generate positive spillover effects through remittance flows, knowledge transfer, and investment in agricultural technologies and non-farm rural enterprises. Migrant remittances often provide critical financial resources that enable rural households to invest in farm inputs, hire labor, adopt improved technologies, or diversify into higher-value agricultural and agribusiness activities.

Understanding the dual nature of rural–urban migration is essential for designing effective agricultural and rural development policies in Nigeria. Rather than viewing migration solely as a threat to agricultural sustainability, it is increasingly recognized as an integral component of livelihood strategies in a changing socio-economic environment. Migration decisions are influenced not only by economic factors but also by social aspirations, environmental pressures, institutional arrangements, and policy contexts. Consequently, the impacts of migration on agriculture vary across regions, farming systems, and household types. This chapter critically examines rural–urban migration and its implications for agricultural development in Nigeria. Specifically, it seeks to address three interrelated questions. First, what are the key drivers of rural–urban migration in Nigeria, and how do economic, social, and environmental factors interact to shape migration decisions? Second, how does rural–urban migration affect agricultural labor supply, farming systems, productivity, and food security outcomes? Third, what policy responses and innovation pathways can help transform migration pressures into opportunities for inclusive and resilient agricultural development? To address these questions, the chapter draws on the Push–Pull Theory of Migration and the Sustainable Livelihoods Framework to provide a robust analytical foundation. These frameworks facilitate a nuanced understanding of migration as both a response to structural constraints and a livelihood diversification strategy.

By integrating theoretical insights with empirical evidence and policy analysis, the chapter contributes to ongoing debates on the role of migration in agricultural transformation and rural development in Nigeria.

The chapter is structured as follows. Following this introduction, the next section conceptualizes rural–urban migration and urbanization within the Nigerian context. Subsequent sections present the theoretical framework, examine the drivers of rural–urban migration, analyze its implications for agricultural development, and review policy responses and strategic interventions. The chapter then explores agricultural innovation opportunities and farmer-level challenges before concluding with policy implications and recommendations for fostering sustainable agricultural development amid ongoing rural–urban migration.

1. CONCEPTUALIZING RURAL–URBAN MIGRATION AND URBANIZATION

Rural–urban migration refers to the movement of individuals or households from rural areas where agriculture is typically the dominant economic activity to urban centers characterized by higher population density, greater economic diversification, and increased access to social and physical infrastructure. In the context of developing countries such as Nigeria, rural–urban migration is not merely a demographic phenomenon but a complex socio-economic process that reflects underlying structural inequalities in development, resource allocation, and livelihood opportunities. Understanding this process is essential for analyzing its implications for agricultural development and rural transformation. Urbanization, closely linked to rural–urban migration, is defined as the increasing proportion of a country's population residing in urban areas. While natural population growth contributes to urban expansion, rural–urban migration remains the principal driver of urbanization in Nigeria. Since the 1980s, Nigeria has experienced one of the fastest urbanization rates in Sub-Saharan Africa, driven largely by sustained rural–urban migration. This trend has resulted in the rapid growth of major cities such as Lagos, Abuja, Ibadan, Kano, Benin City, Onitsha, and Port Harcourt, often without corresponding expansion in infrastructure, housing, and formal employment opportunities.

Although rural–urban migration and urbanization are often used interchangeably, they represent distinct but interrelated processes. Migration refers to the act of movement by individuals or households, while urbanization describes the aggregate demographic outcome of these movements over time. From an agricultural development perspective, this distinction is important because the impacts of migration on agriculture are mediated through changes in labor allocation, household composition, land use, and investment patterns rather than urban growth per se.

In Nigeria, rural areas are predominantly agrarian, with livelihoods centered on smallholder farming, livestock rearing, fishing, and related activities. These rural economies are often characterized by limited economic diversification, low levels of industrialization, and inadequate access to social services such as education, healthcare, electricity, and potable water. In contrast, urban areas offer a broader range of employment opportunities in manufacturing, construction, trade, transportation, and services, as well as better access to education, healthcare, and social networks. These disparities create strong incentives for rural residents particularly youths and working-age adults to migrate to urban centers. Rural–urban migration in Nigeria is also shaped by historical and institutional factors. Colonial and post-colonial development policies tended to concentrate investments in urban centers, reinforcing rural–urban inequalities in infrastructure, education, and economic opportunities. This pattern of uneven development has persisted over time, contributing to the marginalization of rural areas and the erosion of the economic viability of smallholder agriculture. As a result, migration has become an integral component of household livelihood strategies, particularly among rural households seeking to cope with poverty, risk, and uncertainty.

The nature of rural–urban migration in Nigeria has evolved over time. Earlier migration flows were often seasonal or circular, with migrants maintaining strong ties to their rural communities and returning during peak agricultural seasons. However, contemporary migration patterns increasingly involve long-term or permanent relocation, particularly among younger migrants pursuing education or non-farm employment opportunities.

This shift has significant implications for agricultural labor supply, as it reduces the availability of able-bodied workers during critical farming periods and weakens intergenerational knowledge transfer within farming households. Gender dimensions are also central to understanding rural–urban migration in Nigeria. While male migration has traditionally dominated migration flows, female migration has increased in recent decades, driven by educational aspirations, employment opportunities in the informal and service sectors, and changing social norms. Female out-migration can have mixed effects on agricultural systems, potentially increasing women's workloads in rural areas while also enhancing household income through remittances and urban employment. These gendered migration patterns influence decision-making processes, labor allocation, and resource management within agricultural households. Another important dimension of rural–urban migration is its interaction with land use and spatial transformation. As rural populations decline or age, some agricultural land may be abandoned or underutilized, particularly in areas where labor-intensive farming systems predominate. Conversely, in peri-urban areas, agricultural land is increasingly converted to residential, commercial, and industrial uses in response to urban expansion. This dynamic reshapes agricultural production systems, often favoring intensive, market-oriented farming practices such as vegetable production, poultry, and aquaculture near urban centers.

From a broader development perspective, rural–urban migration reflects the structural transformation of the economy, characterized by shifts in labor from agriculture to non-agricultural sectors. In theory, such transformation can enhance productivity and economic growth if supported by adequate employment creation and institutional capacity. In practice, however, Nigeria's urban labor markets have struggled to absorb the growing influx of migrants productively, resulting in widespread informal employment and underemployment. This outcome underscores the importance of examining rural–urban migration not only as a demographic trend but also as a development challenge with significant implications for agricultural sustainability and food security.

2. THEORETICAL FRAMEWORK

This chapter is anchored in two complementary theoretical perspectives: the Push–Pull Theory of Migration and the Sustainable Livelihoods Framework (SLF). Together, these frameworks provide a robust analytical lens for understanding rural–urban migration in Nigeria and its implications for agricultural development. While the Push–Pull Theory explains the motivations and direction of migration flows, the Sustainable Livelihoods Framework situates migration within broader household livelihood strategies, emphasizing its dynamic interaction with agricultural systems, institutional contexts, and vulnerability factors.

Push–Pull Theory of Migration

The Push–Pull Theory conceptualizes migration as a response to differential conditions between areas of origin and destination. According to this theory, individuals or households are "pushed" out of their places of origin by adverse economic, social, or environmental conditions, while they are simultaneously "pulled" toward destinations offering perceived opportunities and improved living standards. Migration decisions, therefore, reflect a rational assessment of relative costs and benefits, shaped by both objective conditions and subjective perceptions. In rural Nigeria, push factors are closely linked to structural constraints within the agricultural sector. These include low and unstable farm incomes, limited access to productive land, inadequate agricultural inputs, weak extension services, and poor rural infrastructure. Smallholder farming, which dominates Nigeria's agricultural landscape, is largely rain-fed and highly vulnerable to climate variability. Recurrent droughts in the northern regions and flooding in the Middle Belt and southern areas have disrupted agricultural production, increased production risks, and undermined livelihood security. These challenges reduce the attractiveness of agriculture, particularly for younger generations seeking stable and remunerative livelihoods.

Institutional weaknesses further intensify push factors. Limited access to agricultural finance, insecure land tenure arrangements, and fragmented input and output markets constrain farmers' capacity to invest in productivity-enhancing technologies.

Social services in rural areas, including education and healthcare, are often inadequate, reinforcing perceptions of rural disadvantage. Together, these conditions create strong incentives for rural residents to seek alternative livelihood opportunities outside agriculture. Urban centers, in contrast, exert powerful pull factors. Cities are perceived as spaces of economic opportunity, offering higher wages, diversified employment options, better access to education and healthcare, and improved living conditions. The concentration of industries, service-sector activities, and government institutions in urban areas reinforces these perceptions. Even when urban employment is informal or precarious, the prospect of cash income and social mobility continues to attract rural migrants. Social networks, including family members and friends already residing in urban areas, further reduce migration risks and facilitate movement through information sharing and initial support.

Applied to agricultural development, the Push–Pull Theory helps explain the sustained outflow of labor from rural farming communities and the resulting demographic changes within the agricultural workforce. Youth out-migration, in particular, reflects the combined effect of strong rural push factors and persistent urban pull factors. This dynamic has direct implications for agricultural productivity, labor availability, and the long-term sustainability of farming systems in Nigeria. However, while the Push–Pull Theory is useful for identifying the drivers of migration, it has limitations. It tends to treat migration as an individual decision, often overlooking household-level strategies, social relations, and institutional contexts. To address these limitations, this chapter complements the Push–Pull Theory with the Sustainable Livelihoods Framework.

3. SUSTAINABLE LIVELIHOODS FRAMEWORK

The Sustainable Livelihoods Framework provides a holistic approach to understanding how households construct and sustain their livelihoods under conditions of risk and uncertainty. Developed within the context of rural development research, the framework emphasizes the interaction between livelihood assets, institutional processes, vulnerability contexts, and livelihood outcomes. Migration is viewed not merely as a response to distress but as a strategic choice within a broader portfolio of livelihood activities.

According to the SLF, rural households draw on five types of capital assets: human, natural, financial, physical, and social capital. Human capital includes labor, education, skills, and health; natural capital encompasses land, water, and other natural resources; financial capital refers to savings, credit, and remittances; physical capital includes infrastructure, tools, and equipment; and social capital comprises networks, norms, and social relations. The availability and quality of these assets shape households' capacity to pursue different livelihood strategies, including agriculture, non-farm activities, and migration. In the Nigerian context, many rural households face constraints across multiple forms of capital. Limited access to education and extension services constrains human capital development, while land fragmentation and environmental degradation undermine natural capital. Financial capital is often scarce due to limited access to formal credit and insurance, and physical infrastructure such as roads, storage facilities, and irrigation systems is inadequate in many rural areas. These constraints increase livelihood vulnerability and encourage households to diversify their income sources through migration.

Within the SLF, migration is conceptualized as a form of livelihood diversification that can reduce risk and enhance household resilience. By sending one or more members to urban areas, households can access alternative income streams through remittances, which may be used to support consumption, invest in agricultural inputs, or finance education and healthcare. Migration can also facilitate knowledge transfer, as migrants acquire new skills, ideas, and social networks that may benefit rural livelihoods upon return. At the same time, the SLF draws attention to the potential trade-offs associated with migration. The reallocation of labor away from agriculture can reduce on-farm labor availability, particularly during peak farming seasons. This may increase labor burdens for remaining household members, often women and elderly farmers, and constrain agricultural productivity. The net impact of migration on agricultural development therefore depends on the balance between labor losses and the potential benefits of remittances, investment, and innovation. Institutional and policy contexts play a critical role in shaping these outcomes. Government policies, market structures, and social norms influence access to assets, the costs and benefits of migration, and the ability of households to convert livelihood strategies into positive outcomes.

In Nigeria, weak rural institutions and limited support for smallholder agriculture often limit the capacity of households to leverage migration for agricultural transformation. Conversely, supportive policies such as improved access to credit, extension services, and markets—can enhance the positive linkages between migration and agricultural development.

4. INTEGRATING THE FRAMEWORKS

By integrating the Push–Pull Theory and the Sustainable Livelihoods Framework, this chapter offers a comprehensive analytical approach to rural–urban migration and agricultural development in Nigeria. The Push–Pull Theory highlights the structural drivers and spatial dimensions of migration, while the SLF situates migration within household livelihood strategies and emphasizes its dynamic interactions with agriculture, institutions, and vulnerability contexts. Together, these frameworks underscore that rural–urban migration in Nigeria is neither inherently detrimental nor uniformly beneficial to agricultural development. Rather, its outcomes are contingent on the broader socio-economic and policy environment. Understanding these theoretical perspectives provides a foundation for analyzing the drivers, challenges, and opportunities associated with rural–urban migration, as well as for designing policies that harness migration as a catalyst for inclusive and sustainable agricultural transformation.

5. DRIVERS OF RURAL–URBAN MIGRATION IN NIGERIA

Rural–urban migration in Nigeria is a complex and multidimensional phenomenon shaped by interrelated economic, social, environmental, and institutional factors. While migration patterns vary across regions and socio-economic groups, the underlying drivers consistently reflect structural imbalances between rural and urban areas. Understanding these drivers is essential for assessing the implications of migration for agricultural development and for designing effective policy interventions.

5.1 Economic Drivers

Economic factors constitute the most prominent drivers of rural–urban migration in Nigeria. Rural livelihoods are predominantly anchored in smallholder agriculture, which is characterized by low productivity, limited mechanization, and high vulnerability to external shocks. Farm incomes are often insufficient to meet household needs, particularly in the context of rising costs of living, input prices, and population pressure on land. These conditions generate strong incentives for rural residents, especially youth, to seek alternative income opportunities in urban centers.

Unemployment and underemployment in rural areas further intensify economic push factors. Agricultural activities are often seasonal, resulting in periods of idle labor and income instability. The limited presence of agro-processing industries and rural non-farm enterprises restricts opportunities for income diversification within rural communities. In contrast, urban areas are perceived as offering more diversified employment opportunities in manufacturing, construction, trade, transportation, and the service sector. Even when such jobs are informal or low-paying, the availability of regular cash income remains a powerful attraction. Income inequality between rural and urban areas reinforces migration flows. Urban wages are generally higher than rural farm earnings, creating a persistent rural–urban income gap. This disparity is amplified by differences in access to financial services, markets, and economic infrastructure. For many rural households, migration represents a rational economic strategy to improve household welfare through remittances and income diversification.

5.2 Demographic and Social Drivers

Demographic pressures play a significant role in shaping migration dynamics. Nigeria's rapidly growing population, combined with high fertility rates in rural areas, has increased pressure on land and natural resources. Land fragmentation resulting from inheritance practices reduces farm sizes, limiting the viability of agriculture as a primary livelihood, particularly for younger household members. As access to land becomes increasingly constrained, rural youth are more likely to migrate in search of alternative livelihoods.

Education is another important social driver of migration. Rural areas often suffer from inadequate educational facilities, limited access to quality schooling, and shortages of trained teachers. As education levels rise, particularly among youth, aspirations for non-agricultural employment increase. Educated rural youth may perceive agriculture as unattractive or incompatible with their skills and expectations, prompting migration to urban areas where educational and professional opportunities are perceived to be greater.

Social networks and family ties also influence migration decisions. Established migrant networks in urban areas reduce the costs and risks associated with migration by providing information, accommodation, and job referrals. These networks facilitate chain migration, whereby the presence of earlier migrants encourages subsequent migration from the same rural communities. Over time, migration becomes institutionalized as a socially accepted and expected livelihood pathway.

5.3 Environmental and Climate-Related Drivers

Environmental degradation and climate variability have emerged as critical drivers of rural–urban migration in Nigeria. Agriculture in Nigeria is largely dependent on natural rainfall, making it highly sensitive to changes in climatic conditions. Increasing incidence of droughts, floods, and erratic rainfall patterns has disrupted agricultural production, reduced crop yields, and heightened livelihood insecurity among rural households.

In northern Nigeria, desertification and declining soil fertility have reduced the availability of arable land and pasture, undermining both crop farming and livestock production. In the Middle Belt and southern regions, flooding has damaged farmlands, destroyed infrastructure, and displaced farming communities. These environmental stressors exacerbate existing economic vulnerabilities and compel affected households to adopt migration as an adaptation strategy. Climate-induced migration is often temporary or seasonal, but repeated environmental shocks can transform short-term mobility into permanent relocation. In such contexts, migration functions as a coping mechanism that enables households to diversify income sources and reduce exposure to agricultural risks.

However, the cumulative effect of environmentally driven migration can weaken rural agricultural systems by accelerating labor loss and undermining local food production.

5.4 Institutional and Policy Drivers

Institutional weaknesses and policy failures significantly contribute to rural–urban migration in Nigeria. Limited public investment in rural development has resulted in persistent disparities in infrastructure, social services, and economic opportunities between rural and urban areas. Poor road networks, inadequate electricity supply, limited access to clean water, and weak healthcare systems reduce the quality of life in rural communities and reinforce perceptions of rural neglect.

Agricultural policies have often failed to provide adequate support to smallholder farmers. Inconsistent input subsidy programs, weak extension services, and limited access to affordable credit constrain farmers' ability to improve productivity and profitability. Land tenure insecurity further discourages long-term investment in agriculture, particularly among youth and women. These institutional constraints reduce the attractiveness of farming as a livelihood and contribute to migration pressures. Urban-biased development policies also play a role in shaping migration patterns. The concentration of public institutions, industries, and infrastructure in urban areas creates spatial inequalities that favor cities as centers of economic and social opportunity. This imbalance reinforces rural–urban migration by systematically privileging urban development at the expense of rural transformation.

5.5 Security and Conflict-Related Drivers

In recent years, insecurity and conflict have emerged as important drivers of rural–urban migration in Nigeria. Insurgent activities, banditry, farmer–herder conflicts, and communal violence have disrupted rural livelihoods and displaced farming populations, particularly in the northern regions. Insecurity restricts access to farmlands, discourages investment, and increases the risks associated with agricultural production. Forced migration resulting from conflict often leads to the abandonment of agricultural activities and the loss of productive assets.

Displaced rural populations frequently seek refuge in urban areas, where humanitarian assistance, security, and economic opportunities are perceived to be more accessible. The long-term consequences of conflict-induced migration include reduced agricultural output, increased urban poverty, and heightened pressure on urban infrastructure and services.

5.6 Synthesis of Migration Drivers

The drivers of rural–urban migration in Nigeria are deeply interconnected, with economic, social, environmental, institutional, and security factors reinforcing one another. Migration decisions are rarely driven by a single factor; rather, they reflect the cumulative impact of multiple constraints and opportunities operating at household, community, and national levels. From an agricultural development perspective, these drivers highlight the structural challenges facing rural economies and underscore the need for integrated policy responses that address both migration pressures and the underlying weaknesses of the agricultural sector.

6. IMPLICATIONS OF RURAL–URBAN MIGRATION FOR AGRICULTURAL DEVELOPMENT IN NIGERIA

Rural–urban migration has far-reaching implications for agricultural development in Nigeria, influencing labor availability, productivity, household livelihoods, land use patterns, food security, and the overall sustainability of rural economies. While migration can generate benefits through income diversification and remittance flows, its cumulative effects have increasingly posed challenges to the agricultural sector, particularly in a context where smallholder farming remains the backbone of national food production.

6.1 Agricultural Labor Dynamics and Workforce Shortages

One of the most immediate and visible impacts of rural–urban migration is the reduction in the availability of agricultural labor. Migration in Nigeria is highly selective, with a disproportionate outflow of young, able-bodied, and economically active individuals from rural areas.

This demographic group constitutes the most productive segment of the agricultural workforce, and its departure creates labor gaps, especially during peak farming periods such as land preparation, planting, weeding, and harvesting. Labor shortages increase the cost of farm operations as remaining farmers rely on hired labor, which may be scarce or expensive. Smallholder farmers who cannot afford hired labor often respond by reducing the scale of cultivation, abandoning labor-intensive crops, or delaying farm operations, leading to lower yields. In extreme cases, farmlands may be left uncultivated, particularly in communities experiencing sustained out-migration. These dynamics contribute to declining agricultural productivity and weaken the resilience of rural food systems.

6.2 Aging Farming Population and Intergenerational Implications

Rural–urban migration accelerates the aging of the agricultural workforce in Nigeria. As younger household members migrate to urban areas, farming activities increasingly fall to older adults who may lack the physical strength, resources, or willingness to adopt improved technologies. The aging farming population poses serious challenges for the future of agriculture, including reduced innovation, slower technology adoption, and declining competitiveness. Intergenerational knowledge transfer is also disrupted by migration. Traditional farming knowledge, which is often transmitted informally from parents to children, becomes weakened as youth disengage from agriculture. This loss of experiential knowledge undermines the continuity of local farming systems and erodes community-based agricultural practices that are adapted to local ecological conditions.

6.3 Household Livelihoods and Income Diversification

At the household level, rural–urban migration can contribute to livelihood diversification and income stability. Remittances sent by migrants constitute an important source of income for many rural households, enabling them to meet basic needs, invest in education and healthcare, and cope with economic shocks.

In some cases, remittance income is used to purchase farm inputs, hire labor, or invest in livestock production, thereby supporting agricultural activities indirectly. However, the positive effects of remittances on agriculture are not uniform. Where migration becomes permanent and ties to agriculture weaken, remittances may be directed primarily toward consumption rather than productive investment. Furthermore, households that depend heavily on remittances may reduce their engagement in farming, leading to declining agricultural output over time. Thus, while migration can enhance household welfare, it may simultaneously undermine agricultural participation and long-term food production.

6.4 Gender Roles and Agricultural Workload

Rural–urban migration has significant gendered implications for agricultural development. Male-dominated migration patterns, particularly in northern Nigeria, often leave women with increased responsibility for farm management and household food production. While this shift can enhance women's roles in decision-making, it frequently results in increased workloads without corresponding access to resources such as land, credit, extension services, and labor-saving technologies. Women farmers often face structural constraints that limit their productivity, including insecure land tenure, limited access to improved inputs, and exclusion from formal agricultural support programs. As a result, feminization of agriculture driven by male out-migration may not translate into productivity gains unless accompanied by targeted gender-responsive interventions. Without such support, increased female participation may exacerbate labor burdens and perpetuate low productivity.

6.5 Land Use Changes and Agricultural Systems Transformation

Rural–urban migration influences land use patterns and agricultural systems in multiple ways. In areas experiencing high levels of out-migration, agricultural land may be abandoned, underutilized, or converted to non-agricultural uses. Labor-intensive cropping systems, such as root crops and traditional mixed farming, may decline as farmers shift toward less labor-demanding activities or exit agriculture altogether.

Conversely, in peri-urban areas, proximity to urban markets can stimulate agricultural intensification and commercialization. Farmers near cities may adopt market-oriented production systems focused on vegetables, poultry, dairy, and aquaculture to meet urban food demand. While these transformations can enhance income opportunities, they often benefit better-resourced farmers and may marginalize smallholders lacking access to capital, land, and market information.

6.6 Food Security and National Agricultural Output

The cumulative effects of rural–urban migration have important implications for food security in Nigeria. Declining agricultural labor, reduced farm sizes, and land abandonment can constrain domestic food production, increasing reliance on food imports. This dependency exposes the country to external price shocks and undermines food sovereignty, particularly during periods of global supply disruptions. At the same time, rapid urban population growth driven by migration increases food demand, placing additional pressure on domestic food systems. The mismatch between rising demand and constrained supply contributes to food price volatility, which disproportionately affects low-income urban and rural households. These dynamics highlight the interconnectedness of migration, agriculture, and food security at both local and national levels.

6.7 Agricultural Investment and Innovation

Migration also affects investment patterns and innovation in agriculture. The perception of agriculture as an unattractive livelihood, reinforced by youth out-migration, reduces incentives for both public and private investment in the sector. Financial institutions may view agriculture as high-risk, particularly in areas experiencing labor shortages and declining productivity.

Nevertheless, migration can also create opportunities for innovation. Exposure to urban environments may enable migrants to acquire new skills, knowledge, and capital that can be reinvested in agriculture upon return. Return migrants may introduce improved farming practices, mechanization, or agribusiness models, contributing to agricultural modernization.

However, the extent to which such positive spillovers occur depends on supportive policies, access to resources, and institutional capacity.

7. POLICY RESPONSES AND INSTITUTIONAL INTERVENTIONS ADDRESSING RURAL–URBAN MIGRATION IN NIGERIA

Successive Nigerian governments have recognized rural–urban migration as both a development challenge and a reflection of structural weaknesses in the rural economy. Policy responses have therefore focused largely on revitalizing agriculture, improving rural livelihoods, and creating employment opportunities capable of retaining population in rural areas, particularly youth. While these interventions have recorded mixed outcomes, they provide important insights into how migration pressures can be addressed through agricultural and rural development strategies.

Agricultural Policy Frameworks and Migration Dynamics

Nigeria's agricultural policy landscape has evolved significantly over the past two decades, shifting from subsistence-oriented production toward market-led, value-chain-based development. Major national frameworks, including the Agricultural Transformation Agenda (ATA), the Agricultural Promotion Policy (APP), and the National Agricultural Technology and Innovation Policy (NATIP 2022–2027), emphasize productivity enhancement, agribusiness development, and private-sector participation. These policies implicitly address rural–urban migration by seeking to make agriculture more profitable and attractive, especially for young people. By promoting mechanization, improved inputs, and value addition, the policies aim to reduce the drudgery associated with farming and enhance income prospects. However, implementation gaps, limited funding, and uneven regional coverage have constrained their effectiveness in reducing migration pressures at scale.

Youth-Focused Agricultural Initiatives

Youth unemployment has been identified as a major driver of rural–urban migration in Nigeria.

In response, several youth-focused agricultural initiatives have been introduced to encourage young people to view agriculture as a viable career rather than a last-resort livelihood. Programs such as the Youth Farm Lab, N-Power Agro, and various state-level agripreneurship schemes seek to equip young people with technical skills, start-up capital, and access to markets. While these initiatives have generated success stories, their overall impact on migration remains limited due to issues of sustainability, scale, and post-program support. Many beneficiaries face challenges related to land access, finance, and market linkages after program completion, leading some to abandon agriculture in favor of urban employment. Strengthening follow-up support, mentorship, and institutional coordination is therefore critical for enhancing the migration-reducing potential of youth agricultural programs.

Rural Infrastructure Development

Inadequate rural infrastructure remains one of the most persistent push factors driving migration in Nigeria. Poor road networks, unreliable electricity, limited irrigation facilities, and weak storage and processing infrastructure increase transaction costs and reduce the competitiveness of rural agriculture. Recognizing this, public investment programs have increasingly prioritized rural infrastructure as a foundation for agricultural development. Road rehabilitation projects, rural electrification initiatives, and irrigation development schemes have improved access to markets and enhanced production potential in some regions. However, infrastructure development has been uneven, with many remote farming communities remaining underserved. Without sustained and inclusive infrastructure investment, rural areas will continue to lag behind urban centers, reinforcing migration flows.

Agricultural Finance and Credit Interventions

Access to finance is a critical determinant of agricultural viability and migration decisions. Limited access to affordable credit constrains farmers' ability to invest in improved technologies, expand production, and withstand economic shocks.

In response, Nigeria has implemented several agricultural finance initiatives, including the Anchor Borrowers' Programme, the Nigeria Incentive-Based Risk Sharing System for Agricultural Lending (NIRSAL), and various microcredit schemes. These interventions aim to reduce financial barriers to agricultural investment and enhance farmers' income prospects. While they have increased credit availability for some categories of farmers, challenges related to loan recovery, elite capture, and exclusion of small-scale and women farmers persist. Strengthening transparency, financial literacy, and inclusive targeting mechanisms is essential for ensuring that finance interventions contribute meaningfully to reducing migration pressures.

Land Tenure Reforms and Institutional Constraints

Secure land tenure is fundamental to agricultural investment and long-term livelihood sustainability. In Nigeria, customary land tenure systems coexist with statutory frameworks, often resulting in ambiguity and insecurity. Youth, women, and migrants frequently face barriers to land access, limiting their ability to engage productively in agriculture. Efforts to reform land administration and improve tenure security have been slow, constrained by legal, political, and cultural factors. Nevertheless, improving land governance remains a critical institutional intervention for addressing rural–urban migration. Secure land rights can encourage investment in agriculture, enhance productivity, and increase the attractiveness of rural livelihoods, particularly for young farmers.

Extension Services and Capacity Building

Effective agricultural extension services play a central role in supporting productivity growth, technology adoption, and resilience to climate change. Extension systems in Nigeria, however, remain under-resourced and characterized by high extension agent–farmer ratios, limited mobility, and inadequate training.

Strengthening extension services can help farmers adopt labor-saving technologies, climate-smart practices, and market-oriented production systems, thereby mitigating some of the agricultural challenges associated with migration. Integrating digital extension platforms and private-sector participation offers promising avenues for expanding outreach and improving service delivery.

Coordination and Integrated Territorial Development

One of the major limitations of Nigeria's policy response to rural–urban migration is weak coordination across sectors and levels of government. Migration, agriculture, infrastructure, education, and employment policies are often implemented in isolation, reducing their collective impact. International experience suggests that integrated territorial development approaches linking rural production with urban markets are more effective in managing migration pressures. Such approaches emphasize functional linkages between rural and urban areas, including value-chain integration, agro-processing clusters, and market connectivity. By recognizing the interdependence of rural and urban systems, integrated strategies can transform migration from a disruptive force into a driver of balanced development.

Policy Effectiveness and Remaining Gaps

Despite numerous interventions, rural–urban migration in Nigeria remains high, indicating persistent structural challenges. Policy effectiveness has been constrained by limited funding, weak institutional capacity, governance challenges, and insufficient monitoring and evaluation. Addressing these gaps requires stronger political commitment, stakeholder engagement, and evidence-based policy design.

Agricultural Innovation Opportunities and Strategic Pathways Forward

Agricultural innovation offers critical pathways for addressing the challenges posed by rural–urban migration in Nigeria while harnessing its potential benefits for agricultural transformation.

As labor availability in rural areas declines and urban food demand rises, innovation becomes essential for improving productivity, enhancing resilience, and creating attractive livelihood opportunities within agricultural value chains. Strategic investments in technology, institutional reform, and market integration can reposition agriculture as a dynamic sector capable of retaining and attracting human capital.

Mechanization and Labor-Saving Technologies

Mechanization represents one of the most direct responses to labor shortages caused by rural–urban migration. The adoption of labor-saving technologies such as tractors, planters, harvesters, and small-scale processing equipment can reduce reliance on manual labor and increase operational efficiency. In Nigeria, mechanization has historically been limited by high costs, fragmented landholdings, and inadequate access to finance. Innovative service delivery models, including tractor-hiring centers and equipment-sharing platforms, have emerged as viable solutions for smallholder farmers. These models lower entry barriers and allow farmers to benefit from mechanization without owning equipment. Expanding such initiatives through public–private partnerships can significantly enhance productivity and mitigate labor constraints in migrant-sending communities.

Climate-Smart Agriculture and Resilience Building

Climate variability is both a driver and a consequence of rural–urban migration, making climate-smart agriculture (CSA) a strategic priority. CSA practices, including improved seed varieties, water-efficient irrigation, soil conservation techniques, and agroforestry, enhance resilience to climate shocks while improving yields and incomes.

Promoting CSA can reduce livelihood vulnerability in rural areas, thereby lowering distress-driven migration. Extension services, research institutions, and development partners play a crucial role in disseminating climate-smart technologies and supporting farmer adaptation. Integrating CSA into national agricultural strategies strengthens the sector’s capacity to absorb demographic and environmental pressures.

Value Chain Development and Agro-Processing

Rural–urban migration underscores the need to move beyond primary production toward integrated agricultural value chains. Value addition through agro-processing creates employment opportunities in rural and peri-urban areas, particularly for youth and women. Processing activities such as rice milling, cassava processing, poultry feed production, and horticultural packaging increase farm-gate prices and reduce post-harvest losses.

Strengthening value chains also enhances linkages between rural producers and urban consumers, transforming migration from a unidirectional labor drain into a circular flow of goods, capital, and knowledge. Investments in storage, transportation, quality standards, and market information systems are essential for realizing these benefits.

Urban and Peri-Urban Agriculture

Urban and peri-urban agriculture has gained prominence as a response to rapid urbanization and growing food demand. In Nigeria, vegetable production, poultry farming, aquaculture, and small-scale livestock enterprises have expanded around major cities. These activities shorten supply chains, reduce transport costs, and improve access to fresh food for urban populations. Urban agriculture also provides livelihood opportunities for migrants who retain agricultural skills but lack access to rural land. Supporting urban agriculture through appropriate land-use planning, extension services, and regulatory frameworks can contribute to sustainable city food systems while easing pressure on rural areas.

Digital Agriculture and Knowledge Transfer

Digital technologies offer transformative potential for addressing migration-related challenges in agriculture. Mobile-based advisory services, digital marketplaces, and financial technologies improve access to information, markets, and credit, particularly for young farmers. Digital platforms can also facilitate knowledge transfer between migrants and rural communities, enabling the diffusion of innovations and best practices. Encouraging digital inclusion in rural areas requires investment in connectivity, digital literacy, and institutional support.

When effectively deployed, digital agriculture can enhance productivity, transparency, and inclusiveness across agricultural value chains.

Return Migration and Skills Reinvestment

Return migration presents an underutilized opportunity for agricultural development. Migrants who return to rural areas often bring new skills, perspectives, and capital acquired in urban settings. Creating enabling conditions for returnees, including access to land, finance, and business support, can stimulate agricultural entrepreneurship and innovation.

Policies that recognize migration as a circular process rather than a permanent exit from agriculture are more likely to capture these positive spillovers. Integrating return migration into rural development planning can help transform migration into a catalyst for rural revitalization.

Strategic Pathways Forward

Harnessing agricultural innovation in the context of rural–urban migration requires coordinated and inclusive strategies. Key priorities include scaling mechanization services, mainstreaming climate-smart agriculture, strengthening value chains, supporting urban agriculture, and leveraging digital technologies. Equally important is fostering institutional environments that encourage youth participation, gender equity, and private-sector investment.

By aligning innovation strategies with migration dynamics, Nigeria can address labor constraints while unlocking new opportunities for agricultural growth and rural transformation.

CONCLUSION

Rural–urban migration remains one of the most significant demographic and socio-economic processes shaping agricultural development in Nigeria. This chapter has examined the multifaceted drivers, dynamics, and implications of migration from rural agrarian communities to urban centers, highlighting its complex relationship with agricultural productivity, rural livelihoods, and food security.

Anchored in the Push–Pull Theory of Migration and the Sustainable Livelihoods Framework, the analysis demonstrates that migration is not merely a symptom of agricultural decline but also an adaptive response to structural constraints and livelihood vulnerability.

The evidence reviewed in this chapter indicates that sustained rural–urban migration has contributed to labor shortages, aging farming populations, and shifts in land-use patterns, with important consequences for agricultural output and sustainability. These challenges are particularly pronounced in labor-intensive crop systems and climate-sensitive regions, where out-migration exacerbates production risks and undermines food security. At the same time, migration has generated new opportunities through remittance inflows, labor reallocation, knowledge transfer, and the expansion of urban and peri-urban agriculture. These dynamics underscore the dual nature of migration as both a development challenge and a potential driver of agricultural transformation.

Nigeria's policy responses have increasingly recognized the need to make agriculture more productive, profitable, and attractive, particularly for young people. Initiatives such as the Agricultural Transformation Agenda, the Anchor Borrowers' Programme, and the National Agricultural Technology and Innovation Policy reflect efforts to modernize agriculture, promote value-chain development, and integrate technology into farming systems. However, the persistence of rural–urban migration suggests that policy impacts have been uneven and constrained by structural bottlenecks, including weak rural infrastructure, limited access to finance, insecure land tenure, and inadequate extension services.

From a policy perspective, addressing the agricultural implications of rural–urban migration requires a shift from reactive interventions to integrated and forward-looking strategies. First, sustained investment in rural infrastructure roads, electricity, irrigation, and storage facilities is essential for improving agricultural productivity and reducing the rural–urban development gap. Improved infrastructure enhances market access, lowers transaction costs, and increases the profitability of farming, thereby reducing distress-driven migration.

Second, strengthening agricultural innovation systems is critical. Mechanization and labor-saving technologies must be scaled through inclusive service models that are accessible to smallholder farmers. Climate-smart agricultural practices should be mainstreamed to enhance resilience to environmental shocks, particularly in migration-prone regions. Research–extension–farmer linkages need to be revitalized to ensure that innovations reach end users effectively.

Third, land tenure reforms and improved access to agricultural finance are fundamental to revitalizing rural livelihoods. Secure land rights encourage long-term investment, while affordable credit enables farmers to adopt improved technologies and expand production. Special attention should be given to youth and women, whose participation in agriculture is often constrained by institutional and socio-cultural barriers.

Fourth, integrated rural–urban development approaches should be promoted to harness the complementarities between rural production and urban consumption. Strengthening agricultural value chains, supporting agro-processing, and expanding urban and peri-urban agriculture can create employment opportunities across the rural–urban continuum. Such approaches help transform migration into a circular and mutually beneficial process rather than a unidirectional drain on rural labor.

Finally, migration itself should be explicitly incorporated into agricultural and rural development planning. Recognizing migration as a livelihood strategy allows policymakers to design interventions that leverage remittances, facilitate return migration, and promote skills reinvestment in agriculture. Programs that support migrant entrepreneurs, encourage returnees, and foster knowledge exchange can convert migration pressures into engines of rural innovation.

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CHAPTER 2
STRENGTHENING FEED SECURITY IN WEST AFRICA: UNLEASHING THE STRATEGIC POTENTIAL OF FINANCIAL INSTITUTIONS FOR SUSTAINABLE LIVESTOCK SYSTEMS

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INTRODUCTION

In West Africa, the livestock sector remains a cornerstone of rural economies, food and nutrition security, and sustainable development (Anaso et al., 2024b; FAO, 2020). Beyond providing direct employment and augmenting household income, the industry supplies high-quality animal protein, which is critical for human growth, productivity, and overall health (Anaso et al., 2021a,b; Smith et al., 2013). Livestock also play multifaceted roles in mixed crop–livestock systems, which dominate West African agriculture: they supply draft power, contribute to soil fertility management through manure production, and offer households a traditional mechanism for capital accumulation and financial resilience (Anaso & Anaso, 2025; McDermott et al., 2010). Given these diverse contributions, the livestock sector is directly linked to achieving several Sustainable Development Goals (SDGs), including SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 8 (Decent Work and Economic Growth), while also indirectly supporting SDG 13 (Climate Action) through integrated agroecological practices.

Despite its socioeconomic and developmental significance, the sector faces persistent structural challenges, chief among them being chronic feed scarcity and escalating feed costs (Olafadehan et al., 2023; Akinmoladun et al., 2019). Feed represents the largest component of production costs—typically 60–70% in both smallholder and commercial operations—making it the principal bottleneck to productivity, profitability, and resilience (FAO, 2018; Anaso et al., 2025a–f). Therefore, ensuring feed security—defined as consistent, affordable, and sustained access to high-quality feed—emerges as a foundational requirement for strengthening West African livestock systems (Anaso, 2025a–c; ILRI, 2020).

The drivers of feed insecurity in the region are complex and interrelated. Climatic stressors, including frequent droughts, high interannual variability, and erratic rainfall patterns, reduce the availability and quality of both cultivated and natural forage resources (Ayantunde et al., 2018; Njie et al., 2021). Simultaneously, rising global feed commodity prices and supply-chain disruptions inflate costs for imported feedstuffs such as maize and soybean meal (World Bank, 2022).

Indigenous feed resources are further constrained by overgrazing, soil degradation, and unsustainable management of communal rangelands (Tarawali et al., 2011; UNCCD, 2020). Compounding these challenges are inefficient feed distribution systems, low processing and storage capacities, and inadequate market infrastructure, which are particularly problematic during the long dry season when feed scarcity peaks.

Traditional interventions have predominantly emphasized agronomic and technological solutions, including the improvement of forage cultivars, enhanced utilization of crop residues and agro-industrial by-products, and the adoption of feed conservation practices such as haymaking, silage production, and improved fodder storage (Anaso, 2025d; Ayantunde et al., 2018; Tarawali et al., 2011). While these advances have contributed to localized improvements, their broader impact remains constrained without complementary financial mechanisms that enable adoption, scalability, and commercial viability.

Financial intermediation is therefore central to transforming West African feed systems. Sustainable feed solutions require access to affordable credit lines, livestock insurance, warehouse-receipt and inventory financing systems, and capital investment in feed processing, storage, and transport infrastructure (FAO & AfDB, 2020; Alliance for Financial Inclusion, 2021). In this context, a diverse spectrum of financial actors—including microfinance institutions, agricultural development banks, cooperative societies, and private investors holds strategic importance. By reducing liquidity constraints, mitigating production and market risks, and providing structured financing, these institutions can facilitate the wider uptake of innovative feed technologies, promote climate-smart feeding strategies, and enhance the resilience of livestock-based livelihoods in West Africa. Ultimately, integrating robust financial mechanisms with technological and agronomic interventions is essential for creating feed systems that are not only productive but also sustainable, equitable, and resilient to climate and market shocks.

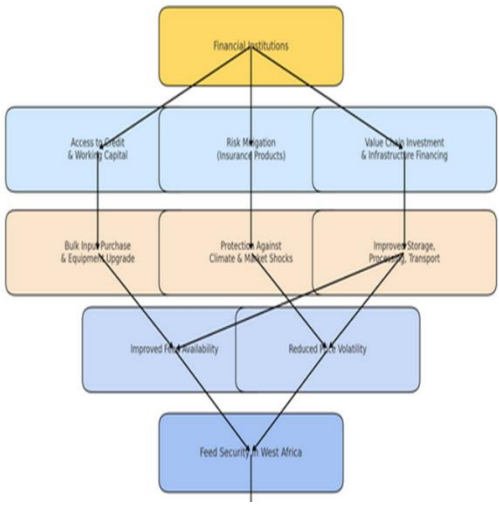

Figure 1. Financial Intermediation Pathways for Sustainable and Resilient Feed Systems in West Africa

1. THE ROLE OF FINANCIAL INSTITUTIONS IN FEED SECURITY

In order to improve feed security in West Africa, financial institutions (FIs) such as commercial banks, microfinance institutions, agricultural development banks, and regional development finance agencies are essential. The resilience and sustainability of livestock production systems are greatly improved by each of the three interrelated channels via which their effect operates: value chain development, risk reduction, and loan access (FAO & AfDB, 2020; AFI, 2021).

Access to Credit and Working Capital

Affordable and well-structured credit facilities form the backbone of a functional feed value chain. Access to financing enables feed producers, processors, aggregators, and livestock farmers to:

- Procure bulk raw materials during peak harvest periods when prices are lowest.
- Upgrade processing and mixing equipment to improve efficiency and quality.

- Maintain smooth production cycles throughout the dry season, when feed shortages are most severe.
- Scale innovations such as silage production, hay baling, and utilization of agro-industrial by-products.

Nigerian empirical data shows that these treatments are effective. By establishing organized input-credit agreements and lowering financial obstacles for smallholder farmers, the Central Bank of Nigeria's Anchor Borrowers' Programme (ABP) has increased the availability of grain (CBN, 2023). In a similar vein, Ghana's Agricultural Development Bank (ADB) has created specialized lending programs for the aquaculture and poultry industries, enabling cost reductions through bulk feed procurement and boosting competitiveness (ADB, 2022). Accessible finance directly increases feed affordability and stabilizes supply chains, as demonstrated by similar programs in Senegal, Mali, and Côte d'Ivoire (IFAD, 2020).

Risk Mitigation and Insurance Mechanisms

West African livestock and feed systems are inherently vulnerable to climate-related shocks, including recurrent droughts, prolonged heat stress, erratic rainfall patterns, and increasing climate variability, all of which directly affect feed availability, forage quality, animal health, and overall productivity. These biophysical risks are further compounded by economic vulnerabilities arising from feed price volatility linked to international grain markets, exchange rate fluctuations, and supply chain disruptions (World Bank, 2022). For livestock producers particularly smallholder and pastoral households that dominate animal agriculture in Nigeria and across West Africa such uncertainties translate into unstable incomes, heightened production risk, and reduced willingness to invest in improved feeding strategies and productivity-enhancing technologies.

In this context, financial institutions and risk-transfer mechanisms play a critical role in strengthening the resilience of livestock production systems. By deploying risk-reduction instruments, credit guarantees, and agricultural insurance products, financial actors help buffer producers against climate and market shocks, thereby safeguarding farm assets and stabilizing livelihoods.

Access to insurance and tailored financial services reduces the exposure of farmers to catastrophic losses, enhances their creditworthiness, and supports informed decision-making regarding long-term investments in improved feed resources, climate-smart feeding practices, and animal health interventions.

One increasingly important innovation is index-based weather insurance, which triggers payouts when objectively measured indicators—such as rainfall deficits, temperature thresholds, or vegetation indices—fall below predefined levels that are strongly correlated with production losses. Unlike traditional indemnity-based insurance, index-based products reduce transaction costs, minimize moral hazard, and enable faster payouts, making them particularly suitable for dispersed smallholder and pastoral systems (Greatrex et al., 2015). Such schemes have demonstrated potential to protect livestock keepers from feed shortages and pasture failure during drought periods, thereby reducing forced sales of animals at depressed prices.

In Nigeria, the Nigerian Agricultural Insurance Corporation (NAIC) plays a central role in promoting agricultural risk management by offering subsidized insurance schemes tailored to crop and livestock producers. NAIC coverage includes protection against drought, flooding, disease outbreaks, fire, and other climate- and production-related risks, and has been instrumental in supporting pastoralists and mixed-farming households in stabilizing production during adverse events (NAIC, 2022). By mitigating downside risk, these insurance mechanisms reduce the likelihood of distress livestock sales, preserve breeding stock, and enhance household resilience.

Collectively, the integration of climate risk insurance, financial services, and supportive policy frameworks fosters greater farmer confidence and encourages sustained investment in improved feed technologies, alternative feed resources, and climate-smart livestock management practices. When combined with innovations such as agro-industrial by-products, crop residues, and phytogenic feed additives, these financial instruments can accelerate the transition toward more resilient, productive, and sustainable livestock systems in Nigeria and the wider West African region.

Value Chain Development and Infrastructure Financing

Functional infrastructure for processing, transportation, and storage is also critical to feed security. Inadequate silos, warehouses, mills, and transportation networks exacerbate post-harvest feed losses, which frequently surpass 25% in some regions of West Africa (ILRI, 2020). In order to close these gaps, financial institutions offer medium- and long-term funding for:

- Feed mills and pelleting plants
- Storage and warehouse facilities
- Cold-chain and transport logistics
- Market aggregation centers
- Rangeland rehabilitation and fodder banks

Particularly important are regional development banks. For example, the ECOWAS Bank for Investment and Development (EBID) has funded several agricultural initiatives to improve feed distribution efficiency and rural infrastructure (EBID, 2021). Feed processing, automated forage production, and digital livestock platforms that enhance supply coordination are examples of integrated value-chain enhancements that are supported by other organizations including the African Development Bank (AfDB) (AfDB, 2022).

When taken as a whole, these financial interventions make it possible to create a feed system that is more equitable, resilient, and commercially viable one that can sustain cattle production throughout West Africa.

2. CASE STUDIES

2.1 Nigeria: Grain Financing, Ranching Reforms, and Livestock Feed Systems

Financial sector initiatives in Nigeria have increasingly focused on the structural causes of feed scarcity. By encouraging smallholder production of important feed grains including maize, sorghum, and soybeans, the Central Bank of Nigeria's Anchor Borrowers' Programme (ABP) has indirectly improved feed security (CBN, 2023). The ABP has guaranteed a more consistent flow of raw materials to feed mills by lowering reliance on imports and stabilizing the grain supply, especially during the dry season when feed shortages are most severe.

A National Ranching and Livestock Transformation Initiative (2024–2025) was recently proposed by Nigeria's federal government as a long-term solution to farmer-herder disputes and dwindling pasture resources. The program that is scheduled consists of:

- Dedicated ranch development financing windows through commercial banks and development partners.
- Establishment of fodder banks, pasture cultivation schemes, and feedlots, which directly strengthen feed availability.
- A proposed $500 million Livestock Productivity Fund, expected to leverage public–private partnerships for pasture development, fodder processing equipment, and feed storage infrastructure.
- Collaboration with the Bank of Agriculture (BOA) and Nigeria Incentive-Based Risk Sharing System for Agricultural Lending (NIRSAL) to de-risk credit for ranch operators and fodder enterprises (NIRSAL, 2024).

By lowering dependency on transhumant grazing and enhancing feed security nationally, these actions show a substantial move toward integrating financial tools with livestock system change.

2.2 Ghana: Input Credit Schemes and Feed Value Chain Stabilization

Specialized input-financing programs aimed at poultry, aquaculture, and new ruminant businesses have been developed by Ghana's Agricultural Development Bank (ADB) (ADB, 2022). Farmers can lower unit production costs by 15–30% by purchasing balanced feed, premixes, and raw materials in bulk through structured finance.

In addition:

- Under the “Planting for Food and Jobs II” (PFJ 2.0) strategy (2023–2027), the government working with commercial banks has expanded digitalized input-credit platforms to grain farmers.
- These improvements have boosted national maize and soy production, stabilizing prices for the poultry and livestock feed industries.

- Private-sector investments, supported by development finance institutions, have led to new feed mills (e.g., in Tamale and Kumasi), further improving regional feed distribution.

2.3 Senegal: Warehouse Receipt Systems and Grain Market Stabilization

When it comes to employing financial tools to stabilize the feed supply, Senegal has led the region. Farmers may now safely store grain and use the receipts as collateral to get short-term loans thanks to the implementation of warehouse receipt systems (WRS) for groundnuts, millet, and maize (World Bank, 2022; CNCWRS, 2023). This strategy has yielded several advantages:

- Stabilization of seasonal price fluctuations that affect feed affordability for poultry and ruminant producers.
- Reduction in post-harvest losses previously as high as 20% for maize thereby increasing the volume of feed grains available for livestock industries.
- Improved bargaining power for farmers, enabling them to sell grains during high-demand periods for feed manufacturers.

Senegal's National Livestock Investment Plan (2024–2028) also provides funding for community fodder stores, rangeland monitoring systems, and pasture rehabilitation—all of which greatly enhance feed security.

More Regional Examples Incudes;

Mali

Through concessional loans for equipment used in feed processing, animal fattening, and fodder production, the Agricultural Development Bank of Mali (BNDA) promotes integrated crop-livestock businesses (BNDA, 2023). The availability of dry-season fodder has increased as a result of recent investments in extensive restoration of bourgou pastures along the Niger River.

Côte d'Ivoire

The government's collaboration with the West African Development Bank (BOAD) involves funding for feed companies based on palm kernels and cassava, enhancing livestock farmers' access to inexpensive energy sources (BOAD, 2023).

Burkina Faso

Microfinance organizations such as RCPB have deployed livestock production loans linked to fodder cropping and small feed mills, increasing local feed autonomy in peri-urban areas.

3. CHALLENGES LIMITING THE IMPACT OF FINANCIAL INSTITUTIONS ON FEED SECURITY

Despite multiple initiatives by financial institutions across West Africa, several systemic constraints limit their ability to drive transformative improvements in feed security:

High and Volatile Interest Rates

Long-term investment in feed production, commercial fodder systems, and feed-milling technology is still hampered by high and volatile interest rates, which are reported to be between 22 and 35 percent for agricultural borrowers in Ghana and Nigeria (World Bank, 2023; IMF, 2024). The adoption of capital-intensive innovations like precision feed mixers, climate-smart silage units, and grain storage technologies, all crucial for balancing the feed supply chain hampered by these high financing costs.

Stringent Collateral and Creditworthiness Requirements

The majority of smallholder livestock producers do not have the official land titles or asset records needed to get commercial bank loans (FAO, 2022; GIZ, 2023). Due to poor knowledge and regulatory delays, adoption is still restricted even in countries with movable collateral registries, such as those recently expanded in Ghana and Nigeria (IFC, 2021). Pastoralists, women-owned businesses, and new ranchers taking part in government-led ranching reforms are disproportionately impacted by this.

Limited Rural Banking Penetration and Digital Finance Gaps

Financial exclusion in rural areas is still a significant obstacle. Compared to metropolitan norms, banking density is still much lower in livestock-producing regions, especially northern Nigeria, northern Ghana, Niger, and Mali (ECOWAS, 2022; AfDB, 2023). The implementation of mobile-based agricultural credit solutions is slowed by poor network infrastructure, agent liquidity limits, and limited interoperability, but digital financial services could bridge this gap (GSMA, 2023).

Low Financial Literacy and Weak Agribusiness Management Skills

Credit availability is nevertheless hampered by low financial knowledge. Producers frequently experience difficulties with cash-flow planning, loan structuring, and financial record-keeping, which lowers creditworthiness and raises default risks (Aidoo & Fromm, 2015; IFAD, 2024). Under national livestock transformation programs, pastoralists and just converted ranch proprietors have even greater training deficits.

Policy Inconsistencies and Weak Enforcement of Agricultural Credit Schemes

FI confidence in agricultural lending is undermined by policy uncertainty, which takes the form of uneven credit criteria, delayed loan disbursements, and lax repayment monitoring (Anigbogu et al., 2023; CBN, 2023). Financial institutions are less inclined to support feed production and animal value chains when non-performing loan loads are made worse by political influence and loan diversion.

Inadequate Agricultural Insurance and Risk-Sharing Mechanisms

Although livestock and crop insurance products exist, penetration is low, payout delays are common, and coverage gaps remain substantial (NAIC, 2022; World Bank, 2024).

Limited access to index-based drought and livestock insurance discourages FIs from lending to high-risk sectors such as commercial feedlots and new ranching clusters established under Nigeria's National Livestock Transformation Programme (NLTP).

4. RECOMMENDATIONS FOR STRENGTHENING THE CONTRIBUTIONS OF FINANCIAL INSTITUTIONS TO FEED SECURITY

To unlock the full potential of financial institutions in transforming West Africa's livestock and feed systems, a coordinated set of policy, financial, and technological interventions is required. The following recommendations provide a strategic roadmap:

Develop Inclusive and Tiered Financial Models

Financial institutions should create distinct financing options that take into account the various realities of livestock producers, ranging from smallholders and pastoralists to medium-sized ranchers and commercial feed processors.

Key elements include:

- Group-based lending and cooperative financing, allowing producers to pool risk and collateral (IFAD, 2024).
- Contract farming and value-chain finance, enabling feed manufacturers and processors to guarantee purchase arrangements and reduce credit risk (FAO, 2022).
- Sharia-compliant agricultural financing for producers in northern West Africa, improving cultural acceptability and uptake (AfDB, 2023).

These inclusive models help bridge the financing gap for producers traditionally excluded from formal credit systems.

Expand Digital Financial Tools and Mobile-Based Agricultural Services

Digital finance presents one of the most transformative opportunities for improving feed security.

Leveraging mobile platforms can enhance access to:

- Microloans and input credit delivered directly via mobile wallets.
- Digital savings groups, allowing producers to accumulate capital for feed purchase during lean seasons.
- Micro-insurance products such as drought index or livestock mortality insurance embedded into mobile services (GSMA, 2023).
- Real-time market and price information, improving decision-making around feed procurement and storage.

Successful models such as Kenya's M-Pawa, Ghana's Qwikloan, and Nigeria's FarmKart demonstrate the scalability of mobile agricultural finance across West Africa.

Strengthen Policy and Regulatory Reforms to Catalyze Agricultural Lending

Governments and regional bodies must implement reforms that encourage sustained financial sector participation in feed and livestock value-chain financing:

- Lowering agricultural lending rates through interest rate caps, targeted refinancing windows, and subsidized credit guarantees (World Bank, 2023; CBN, 2023).
- Expanding movable collateral systems, enabling borrowers to use livestock, feed inventory, equipment, or warehouse receipts as acceptable collateral (IFC, 2021; GIZ, 2023).
- Stabilizing fiscal and trade policies to reduce price volatility of imported feed inputs such as maize, soybean meal, and premixes (ECOWAS, 2022).

Clear, predictable policies improve lender confidence and attract private capital into feed-related investments.

Promote Public–Private Partnerships (PPPs) for Feed Infrastructure and Value-Chain Development

Public–private partnerships offer a robust mechanism for scaling feed production and minimizing regional shortages. Recommended PPP initiatives include:

- Co-investment in commercial fodder farms, silage parks, and improved pasture development critical for the new ranching initiatives in Nigeria, Ghana, and Côte d'Ivoire.
- Establishing modern feed mills and grain storage facilities, reducing seasonal fluctuations and post-harvest losses (EBID, 2021).
- Supporting logistics infrastructure, including rural roads, aggregation centers, and cold-chain systems to enhance feed distribution efficiency.

Strategic PPPs can also support the implementation of Nigeria's National Livestock Transformation Programme (NLTP), ensuring feed availability for ranching clusters and conflict-prone regions transitioning away from open grazing.

CONCLUSION

Achieving feed security in West Africa requires a comprehensive, systems-oriented strategy that simultaneously addresses the institutional, structural, financial, and technical constraints shaping livestock production. Feed insecurity in the region is not solely a problem of insufficient biomass or raw materials; rather, it reflects weaknesses across the entire feed value chain, including limited access to quality inputs, inadequate processing and storage infrastructure, poor market integration, and restricted access to finance and risk-management instruments. Consequently, the successful adoption of innovations in feed formulation, forage improvement, agro-industrial by-product utilization, and alternative feed resources is highly dependent on the availability of affordable financing, effective risk-mitigation mechanisms, and targeted investments that strengthen each node of the feed system from production and processing to distribution and end use. Within this transition, financial institutions occupy a pivotal and catalytic role.

By providing tailored credit products that align with the biological production cycles of livestock enterprises, financial institutions can reduce liquidity constraints that limit farmers' ability to invest in improved feeds, feed additives, and processing technologies. The deployment of digital financial tools—such as mobile banking platforms, digital credit scoring, and remote payment systems—further enhances financial inclusion, particularly for smallholder farmers, pastoralists, and women-led enterprises who are traditionally underserved by formal financial systems. In parallel, the expansion of livestock-specific insurance products, including index-based and bundled insurance schemes, protects producers against climate-induced feed shortages, disease outbreaks, and market shocks, thereby stabilizing incomes and reducing production risk.

However, financial innovation alone is insufficient without coordinated and enabling policy frameworks. Long-term feed system resilience requires policy reforms that reduce lending risks for financial institutions, incentivize private-sector investment in feed and agribusiness enterprises, and strengthen regulatory oversight of feed production, quality control, and distribution. Clear and enforceable standards for feed safety, feed additives, and processing practices are essential to build trust across the value chain and encourage private investment. In addition, fiscal incentives such as tax reliefs, credit guarantees, and targeted subsidies can accelerate the adoption of climate-smart feed technologies and alternative feed resources.

Equally critical is sustained investment in human and institutional capacity. Strengthening the technical and managerial capacity of smallholder farmers, producer cooperatives, feed millers, and extension agents enhances the effective uptake of improved feeding practices and financial products. Public–private partnerships can play a transformative role by facilitating investments in feed processing facilities, storage infrastructure, transportation networks, and market linkages, thereby reducing post-harvest losses and improving feed availability throughout the year. Such partnerships also provide platforms for knowledge exchange, technology transfer, and scaling of proven innovations.

By strategically integrating financial innovation with evidence-based livestock nutrition and management practices, West African countries can build resilient and sustainable feed systems that support higher productivity, improved livelihoods, and enhanced food and nutrition security. Strengthening the role of financial institutions is therefore not merely a complementary intervention but a foundational pillar for the long-term competitiveness, adaptability, and resilience of the livestock sector in the face of climate change and evolving market pressures.

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CHAPTER 3
THE ECONOMICS OF ECO-INNOVATION: CONSUMER ACCEPTANCE OF BETEL LEAF (PIPER BETLE) BATH BOMBS

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INTRODUCTION

The global beauty and wellness industry is currently experiencing a profound transformation driven by evolving consumer preferences, regulatory pressures, and heightened environmental awareness. Consumers are increasingly prioritizing products that are eco-friendly, ethically sourced, and sustainable, signalling a shift away from conventional cosmetic products that rely heavily on synthetic chemicals and non-renewable resources. In response, eco-innovation, defined as the development of products and processes that minimize environmental impact while generating economic and social value, has become a strategic imperative for firms seeking to remain competitive in this dynamic market (Horbach, 2016; Chen et al., 2020). Eco-innovative practices not only contribute to environmental sustainability but also enhance brand differentiation, build consumer trust, and create opportunities for premium pricing and market expansion.

Among the diverse segments of the wellness industry, bath and body care products have emerged as a particularly promising arena for sustainability integration. Bath bombs, which combine aesthetic appeal, aromatherapy benefits, and user experience, are widely used in self-care rituals and personal wellness routines. Traditionally composed of synthetic ingredients such as artificial fragrances, colorants, and surfactants, bath bombs present an opportunity for eco-conscious reformulation. By incorporating natural, locally sourced, or traditionally recognized ingredients, bath bombs can meet both consumers demands for sustainable products and regulatory standards promoting environmental responsibility.

One promising ingredient for sustainable innovation is the betel leaf (Piper betle), an herb native to Southeast Asia with a long-standing history of medicinal and culinary use. Betel leaves are recognized for their antimicrobial, antioxidant, and anti-inflammatory properties, making them suitable for incorporation into personal care products. Importantly, large quantities of betel leaves are discarded as agricultural or processing waste, resulting in underutilized biomass that can be redirected for value-added applications. Utilizing discarded betel leaves in bath bomb formulations exemplifies circular economy principles, wherein waste is minimized, resources are reused, and economic value is created from otherwise low-value materials.

This approach not only addresses environmental sustainability but also aligns with green consumer trends, offering products that are both functional and environmentally responsible.

Despite the growing interest in eco-innovations and herbal-based personal care products, there remains limited research on the market potential, consumer acceptance, and economic viability of such innovations, particularly in the Southeast Asian context. Understanding consumer perception and behaviour is critical, as eco-innovations may face barriers such as limited awareness, scepticism regarding efficacy, or price sensitivity. Moreover, the integration of traditional herbal knowledge with modern product innovation raises questions about how cultural heritage, perceived health benefits, and environmental values influence consumer purchase intentions and willingness to pay for sustainable products.

This study introduces Betel Leaf Bath Bombs (BE-BOMB) as a novel eco-innovative product that combines traditional herbal benefits with sustainable, zero-waste principles. Specifically, BE-BOMB leverages discarded betel leaves to create bath bombs that are environmentally friendly, therapeutically beneficial, and culturally resonant. The research aims to assess several key dimensions: consumer perception, including beliefs about product efficacy, environmental impact, and cultural relevance; acceptance and purchase intention, reflecting the likelihood of trial and adoption; and price sensitivity, which provides insight into economic viability and market positioning.

By investigating these dimensions, the study contributes to the intersection of traditional knowledge, sustainability, and consumer behaviour. It provides empirical evidence on how herbal-based eco-innovations can be positioned to appeal to environmentally conscious consumers while creating economic opportunities for small-scale producers and local communities. Furthermore, the research highlights the potential of circular economy practices in personal care product development, demonstrating how discarded agricultural resources can be valorised into marketable, high-value consumer goods.

In sum, this study addresses both theoretical and practical gaps in the fields of eco-innovation, sustainable product development, and consumer behaviour. The research findings are expected to inform entrepreneurs, product developers, and policymakers seeking to integrate traditional herbal knowledge into modern eco-friendly products, enhance market competitiveness, and promote sustainable consumption. By combining environmental sustainability, cultural heritage, and economic potential, BE-BOMB represents a model for future innovations in the wellness industry, aligning health, aesthetics, and environmental responsibility in a single product offering.

1. LITERATURE REVIEW

The increasing global focus on sustainability has reshaped innovation across multiple industries, with the beauty and wellness sector emerging as a key area of transformation. Modern consumers are becoming increasingly conscious of the environmental and social impacts of their consumption choices, prompting brands to adopt sustainable and eco-innovative practices. Eco-innovation in this sector typically encompasses the use of natural and plant-based ingredients, chemical-free formulations, recyclable or biodegradable packaging, and cruelty-free testing procedures. Such initiatives not only address environmental and ethical concerns but also enhance consumer trust, product safety, and brand reputation, making sustainability a strategic priority for competitive advantage (Gambardella et al., 2025).

Recent market analyses underscore the robust growth potential of herbal and green cosmetics. According to a report by Future Market Insights (2024), the herbal beauty products industry is projected to grow at an annual rate of approximately 6%, fuelled by rising demand for natural and plant-based alternatives. This trend is further supported by regional studies in Malaysia, which indicate that attitudes, perceived behavioural control, and environmental concern significantly influence the purchase intentions of millennials for organic and herbal cosmetics (Ooi & Wong, 2024). These findings reflect a growing consumer preference for products that align not only with personal wellness goals but also with broader environmental and ethical values.

An increasingly important framework for sustainability in the cosmetics sector is the circular economy, which prioritizes resource efficiency and waste reduction by converting by-products and discarded materials into value-added resources. Companies are increasingly leveraging agricultural residues such as fruit peels, plant leaves, and herbal extracts to create innovative, eco-friendly product ingredients. This approach supports green entrepreneurship, promotes sustainable business models, and reduces environmental burdens associated with conventional cosmetic production (García-González et al., 2025; Mancini et al., 2024). Within this context, the utilization of discarded betel leaves (Piper betle) in bath bomb production represents a promising eco-innovative opportunity. By transforming waste into functional, value-added products, businesses can integrate sustainability, innovation, and traditional herbal knowledge into commercially viable offerings.

Despite the growing awareness and preference for sustainable products, price sensitivity remains a critical barrier to adoption. In Malaysia, surveys reveal that while a majority of consumers (91%) express support for eco-friendly products, most are willing to pay only a modest premium for them (Business Today, 2025). Similarly, studies on consumer behaviour in green cosmetics show that interest does not always translate into purchase, as high prices and scepticism regarding product claims often inhibit adoption (Yusoff et al., 2023). This underscores the importance of assessing not only consumer attitudes but also economic viability and market potential when developing herbal-based and eco-friendly products.

A synthesis of the current literature reveals four key insights:

- The demand for eco-friendly and herbal cosmetics is increasing at both global and local levels, reflecting broader consumer trends towards sustainability and natural products.
- Circular economy principles, such as upcycling agricultural waste, are being increasingly integrated into beauty product innovation, offering both environmental and commercial benefits.
- Price sensitivity remains a significant barrier to adoption, even among environmentally conscious consumers, highlighting the need for careful pricing strategies in sustainable product development.

- There is limited research specifically investigating the economic viability of herbal-based bath bombs, particularly in emerging markets such as Malaysia, creating a gap in understanding consumer acceptance, willingness to pay, and market potential for such innovations.

While there is growing scholarly and commercial interest in sustainability and green entrepreneurship, empirical research addressing the intersection of traditional herbal knowledge and modern cosmetic innovations remains limited. Most studies to date focus broadly on consumer behaviour toward eco-friendly cosmetics, with few examining niche products such as herbal bath bombs that combine wellness, traditional remedies, and circular economy practices. This gap highlights the need for comprehensive studies that evaluate both consumer acceptance and market feasibility, offering actionable insights for product developers, entrepreneurs, and policymakers.

In response to this gap, the present study investigates the economic potential of Betel Leaf Bath Bombs (BE-BOMB), a novel eco-innovative product that utilizes discarded betel leaves to create sustainable, herbal-infused bath products. The research focuses on three interrelated dimensions: consumer awareness, acceptance, and willingness to pay. By examining these factors, the study aims to provide a nuanced understanding of the economic implications of eco-innovation in the wellness sector, particularly in the context of emerging markets.

Furthermore, this research situates the BE-BOMB within a broader conceptual framework that combines sustainability, consumer behaviour, and cultural knowledge. Betel leaves, widely recognized in Southeast Asia for their antimicrobial, antioxidant, and anti-inflammatory properties, are culturally significant and traditionally used for medicinal purposes. Integrating these leaves into modern wellness products exemplifies a convergence of traditional knowledge with contemporary eco-innovative practices, creating products that are environmentally responsible, culturally resonant, and commercially viable.

In conclusion, this study contributes to the literature on eco-innovation, sustainable product development, and consumer behaviour by examining a novel application of circular economy principles in herbal-based bath bombs.

By assessing both consumer perception and economic potential, the research provides insights into how sustainability, traditional knowledge, and market considerations can be effectively integrated into product innovation in the beauty and wellness industry. The findings are expected to inform entrepreneurs, product developers, and policymakers, offering practical guidance for creating sustainable, culturally meaningful, and economically viable wellness products in emerging markets such as Malaysia.

2. RESEARCH METHODOLOGY

This study employed a quantitative survey design supplemented by a small set of qualitative questions to investigate consumer awareness, acceptance, and purchase intention regarding the Betel Leaf Bath Bomb (BE-BOMB). The combination of quantitative and qualitative approaches allowed the researchers to capture both general trends in consumer behaviour and more nuanced personal opinions about product attributes such as fragrance, packaging, and formulation. By integrating these methods, the study aimed to provide a comprehensive understanding of both the economic and perceptual dimensions of eco-innovative herbal bath products.

Research Design

The primary research design was descriptive quantitative survey, chosen to systematically collect data on consumer attitudes, preferences, and willingness to pay for a novel herbal-based bath product. The inclusion of qualitative questions provided additional depth, allowing respondents to express opinions that could not be fully captured through fixed-response items. This mixed-method approach enabled the research to identify not only statistical patterns but also consumer expectations and suggestions for product improvement.

Target Population and Sampling

The target population for this study consisted of young Malaysian consumers aged 18 - 24 years, particularly those familiar with bath bombs and natural skincare products.

This demographic was selected due to their higher engagement with wellness products, awareness of sustainability issues, and willingness to adopt novel eco-friendly items.

A total of 111 respondents participated in the study. Convenience sampling was employed, which allowed for efficient recruitment of participants through universities, public spaces, and online platforms. While convenience sampling limits the generalizability of findings to the broader population, it was deemed appropriate for this exploratory study focused on identifying preliminary trends in consumer acceptance and economic potential of BE-BOMB.

Data Collection

Data for this study were collected using a structured questionnaire distributed both online and in person, allowing the researchers to reach a broad range of respondents while ensuring flexibility in participation. The questionnaire was carefully designed to include five major sections, each aimed at addressing specific research objectives and capturing both quantitative and qualitative information. The first section, Demographics, gathered essential information about respondents, including age, gender, education level, and monthly income. This data enabled the researchers to examine trends and variations in consumer behaviour across different demographic segments, providing context for understanding patterns in awareness, acceptance, and purchase intention.

The second section, Awareness and Knowledge, focused on evaluating respondents' familiarity with bath bombs, herbal skincare products, and specifically the use of betel leaves (Piper betle) in personal care. Participants were asked to rate their prior knowledge and exposure, which helped contextualize their perceptions of the product and assess how prior familiarity with herbal ingredients might influence acceptance and willingness to purchase. This section was crucial in identifying knowledge gaps and the potential impact of educational interventions or marketing communications on consumer behaviour.

The third section, Perception and Acceptance, measured attitudes toward BE-BOMB, including perceived practicality, eco-friendliness, health benefits, and novelty. Using Likert-scale items, respondents indicated their levels of agreement with statements about the product's features and overall appeal. This approach enabled the researchers to quantify consumer perceptions, providing measurable insights into the product's attractiveness and its alignment with consumer expectations for herbal and eco-innovative products.

The fourth section, Purchase Intention and Price Sensitivity, explored respondents' willingness to purchase BE-BOMB, the price range they considered acceptable, and their perceived value of eco-innovative products. This section was critical for assessing the product's market feasibility, guiding potential pricing strategies, and evaluating how price considerations might influence consumer adoption of sustainable personal care items. By combining purchase intention with price sensitivity, the study provided a more nuanced understanding of the economic potential of BE-BOMB in the target market.

The fifth and final section, Qualitative Feedback, allowed respondents to share open-ended opinions on the product's fragrance, packaging design, and formulation. This section captured rich, descriptive insights that could not be fully represented in structured scales, offering valuable guidance for product refinement and future development. Participants' suggestions highlighted consumer preferences and areas for improvement, complementing the quantitative findings and ensuring a holistic understanding of user perceptions.

Before the questionnaire was distributed, it underwent content validation by experienced lecturers to ensure clarity, relevance, and alignment with the research objectives. Feedback from this review led to minor revisions, such as simplifying technical terms for accessibility and refining the phrasing of Likert-scale items to avoid bias. These steps ensured that the questionnaire was both user-friendly and methodologically sound, capable of producing reliable data to assess consumer awareness, acceptance, and willingness to purchase BE-BOMB effectively.

Data Analysis

The quantitative data collected from the structured questionnaire were analysed using a combination of descriptive and inferential statistical techniques to provide a comprehensive understanding of consumer awareness, perceptions, and purchase intention toward BE-BOMB. Descriptive statistics, including frequency distributions, means, and percentages, were first employed to summarize respondents' demographic characteristics, levels of awareness about bath bombs and betel leaves, perceptions of the product's eco-friendliness, health benefits, and overall acceptance. These analyses provided a clear overview of general trends and patterns within the sample, such as the proportion of respondents familiar with herbal skincare products or the percentage expressing interest in purchasing the bath bomb.

To explore the relationships between demographic variables and purchase intention, cross-tabulation analysis was conducted. This allowed the researchers to identify which consumer segments, based on age, gender, education, or income, were more likely to adopt BE-BOMB. For example, the analysis could reveal whether younger consumers or those with higher environmental awareness showed higher willingness to purchase, helping to segment the target market and inform marketing strategies. This approach provided actionable insights into which demographic groups represented the most promising early adopters for eco-innovative products.

Further, correlation analysis was conducted to measure the strength and direction of associations between key variables. In particular, the analysis examined the relationship between respondents' perceptions of eco-friendliness and their willingness to pay for BE-BOMB. By quantifying these relationships, the study identified potential drivers of consumer adoption, offering evidence for how sustainability-related attributes influence purchase decisions. This information is critical for pricing strategies, product positioning, and communication of eco-innovation benefits to target consumers.

For the qualitative data collected through open-ended questions, thematic analysis was applied. Responses were carefully reviewed, coded, and categorized to identify recurring themes and patterns related to fragrance preferences, packaging appeal, and suggestions for product formulation.

This analysis provided nuanced insights into consumer expectations and desires, complementing the quantitative findings. For instance, while descriptive statistics could show overall acceptance of BE-BOMB, thematic analysis revealed specific aspects consumers valued or wished to improve, such as scent variety, visual aesthetics, or product usability. These insights are particularly valuable for guiding product development and refinement, ensuring that the final offering aligns closely with consumer preferences.

By integrating quantitative and qualitative analyses, the study produced a holistic understanding of both measurable trends and personal consumer experiences. The statistical results offered a broad view of acceptance, willingness to pay, and market potential, while the thematic analysis provided depth and context to these findings, highlighting areas for innovation and product enhancement. Collectively, these analytical approaches ensured that the research findings were both empirically robust and practically relevant, providing actionable guidance for the commercial development, marketing, and sustainability positioning of BE-BOMB in the Malaysian beauty and wellness market.

Expert Evaluations

To ensure product safety, quality, and market readiness, BE-BOMB underwent a series of expert evaluations conducted by reputable institutions and industry professionals. Nano Lab Analytical Sdn. Bhd. performed comprehensive laboratory analyses to verify the product's safety and chemical stability. These tests included assessments of microbial content, pH balance, and the safety of all active ingredients, confirming that BE-BOMB met hygiene and regulatory standards suitable for consumer use. This scientific validation was critical in ensuring that the herbal bath bomb was free from contaminants and safe for regular external application.

In addition to laboratory testing, practical evaluations of consumer appeal were conducted by Chanteque Beauty & Spa and Najwa Pharmacy. Experts examined key sensory and usability factors, including the product's fragrance, texture, dissolvability, and overall tactile experience during use.

They also evaluated packaging design, visual aesthetics, and consumer-friendliness, offering professional feedback on how the product might be received in retail and wellness settings. These assessments provided valuable insights into the product's market readiness, highlighting areas for potential improvement, such as enhancing packaging appeal or modifying fragrance intensity to better suit target consumers.

Together, these evaluations provided external validation of BE-BOMB's feasibility, reinforcing the credibility of the consumer survey findings. By combining laboratory safety verification with expert assessments of usability and market potential, the study ensured that BE-BOMB was not only safe and effective but also aligned with consumer expectations and industry standards. This multi-layered validation strengthened confidence in the product's commercial viability, supporting its positioning as a safe, eco-innovative, and market-ready herbal bath bomb in Malaysia's beauty and wellness industry.

Ethical Considerations

The study strictly adhered to standard ethical research practices to ensure the protection and rights of all participants. Participation was entirely voluntary, and all respondents were required to provide informed consent prior to completing the survey. The research team clearly communicated the study's objectives, emphasizing that the collected data would be used solely for research and product development purposes. Respondents were assured of their confidentiality, with no personally identifiable information collected beyond basic demographic details such as age, gender, education, and income. These ethical measures fostered a trustworthy research environment, encouraging honest and candid responses from participants.

In summary, the methodological design of this study enabled a comprehensive and multi-dimensional examination of consumer awareness, acceptance, and economic potential for the betel leaf bath bomb (BE-BOMB). The study employed a quantitative survey design, capturing broad trends in consumer perceptions, purchase intentions, and price sensitivity through structured questionnaires.

This approach allowed for statistical analysis using descriptive techniques, cross-tabulation, and correlation measures, providing insights into demographic influences on purchasing behaviour and the relationship between eco-friendly perceptions and willingness to pay.

Complementing the quantitative component, qualitative feedback was collected via open-ended questions, giving participants the opportunity to share personal opinions on fragrance, packaging, and product formulation. This enriched the data by highlighting practical areas for product improvement, ensuring that consumer preferences and expectations were directly incorporated into BE-BOMB's design and marketing strategy. The integration of qualitative and quantitative methods provided a holistic understanding of consumer behaviour, combining measurable trends with contextual, experiential insights.

Further strengthening the study's reliability, expert evaluations were conducted to verify BE-BOMB's safety, quality, and market readiness. Nano Lab Analytical Sdn. Bhd. confirmed the product's chemical stability, microbial safety, and pH balance, while Chanteque Beauty & Spa and Najwa Pharmacy assessed fragrance, texture, usability, and packaging appeal. These evaluations not only validated laboratory safety but also ensured that BE-BOMB met industry standards and consumer expectations for wellness and beauty products. The expert feedback complemented the consumer survey data, providing a robust, multi-layered assessment of product feasibility and commercial potential.

By integrating survey-based quantitative data, qualitative insights, and expert assessments, this methodology offered a comprehensive framework for evaluating both the consumer acceptance and economic viability of eco-innovative, herbal-based bath products in Malaysia. It enabled identification of key drivers for adoption, such as perceived eco-friendliness, health benefits, affordability, and cultural uniqueness, while also addressing practical considerations for market readiness, product development, and sustainability practices.

Ultimately, this methodological approach provided a strong foundation for actionable recommendations. Insights from demographic analyses, purchase intention patterns, and qualitative themes informed strategies for pricing, packaging, fragrance selection, and marketing.

The combination of consumer perspectives and expert validation ensures that BE-BOMB is positioned not only as a safe and effective herbal bath product but also as a market-ready, eco-innovative solution aligned with sustainability principles and the circular economy.

The ethical, rigorous, and multi-faceted design of the methodology underscores its relevance for researchers, entrepreneurs, and policymakers interested in green entrepreneurship, herbal product innovation, and sustainable consumer goods. By systematically linking consumer behaviour, product safety, and market feasibility, the study provides valuable insights into the development and commercialisation of eco-friendly wellness products, supporting both economic viability and responsible environmental practices.

3. RESULTS AND FINDINGS

The survey results indicate a strong consumer interest in the Betel Leaf Bath Bomb (BE-BOMB) as a natural, safe, and affordable personal care product. Respondents consistently highlighted the product's herbal ingredients, eco-friendly formulation, and potential health benefits, suggesting that BE-BOMB resonates with the growing consumer preference for sustainable and culturally inspired wellness products. These findings align with global trends in eco-innovation within the beauty and personal care industry, emphasizing the increasing demand for products that are both environmentally responsible and health-conscious.

Demographic Profile of Respondents

The study captured responses from a total of 111 participants, revealing that the sample was predominantly male (72%) compared to female respondents (28%). The majority of participants (approximately 77%) were aged 18 to 24 years, representing a youthful consumer segment that is both trend-conscious and environmentally aware. This demographic is particularly relevant for new product adoption, as young consumers are more likely to engage with eco-friendly and novel personal care products. Educational and income data indicated that most respondents were students or early-career individuals, which has implications for price sensitivity and purchase decision-making, as discussed in later sections.

Table 1. Results and Findings

Aspect	Findings	Interpretation
Consumer Interest	Majority of respondents expressed strong interest in BE-BOMB as a natural, safe, and affordable bath product.	Indicates positive market acceptance and consumer curiosity toward eco-innovative skincare products.
Demographics	72% male, 28% female; 77% aged between 18-24 years.	Reflects participation mainly from young adults, the key target market for sustainable beauty products.
Purchase Intention	78% of respondents were "interested" or "very interested" in purchasing BE-BOMB.	Suggests strong potential for market entry and product acceptance among youth consumers.
Price Preference	49.5% preferred RM5-RM10; 28% preferred RM10-RM15.	The ideal selling price range is between RM5-RM15, supporting affordability and accessibility.
Perceived Benefits	Respondents viewed BE-BOMB as healthier, eco-friendly, and culturally unique due to the use of betel leaves.	Highlights consumer appreciation for traditional herbal ingredients and sustainability values.
Laboratory Analysis	pH level recorded at 8.50; no microbial contamination detected.	Confirms product safety and suitability for external use.
Expert Evaluation	BE-BOMB found to be microbiologically safe and commercially viable; recommendations for improved visual design and packaging.	Validates product feasibility with minor improvements needed for better market presentation.

Consumer Awareness and Acceptance

The survey findings indicate that BE-BOMB enjoys a high level of awareness and acceptance among the target consumer segment. Approximately 78% of respondents reported being "interested" or "very interested" in purchasing the product, demonstrating a strong curiosity and readiness among Malaysian youth for herbal-based and eco-innovative bath products. This level of acceptance suggests that consumers are increasingly receptive to natural, sustainable, and culturally meaningful personal care items, highlighting a favourable market environment for BE-BOMB.

Several factors contributed to the positive perception of BE-BOMB. First, health and safety considerations played a critical role. Respondents viewed the product's natural, chemical-free composition as a safer alternative to conventional bath products, alleviating concerns about skin irritation, allergic reactions, or long-term exposure to synthetic chemicals. This perception aligns with broader trends in the beauty and wellness industry, where consumers prioritize safety, transparency, and clean formulations when selecting personal care products. By offering a non-toxic and gentle alternative, BE-BOMB successfully positions itself as a product that addresses functional health needs while promoting daily self-care routines.

Second, eco-friendliness was a significant factor influencing acceptance. Consumers appreciated that BE-BOMB was created from discarded betel leaves, effectively transforming an agricultural by-product into a value-added skincare solution. This sustainable approach resonates with circular economy principles, demonstrating how waste reduction and resource efficiency can be integrated into product innovation. Respondents recognized that using herbal residues reduces environmental impact, including waste disposal issues, and supports responsible consumption. The combination of sustainability with tangible product benefits enhanced BE-BOMB's attractiveness to environmentally conscious consumers, particularly younger generations who are highly aware of ecological issues and the environmental footprint of their purchasing choices. Third, the cultural uniqueness of BE-BOMB contributed to its appeal. The inclusion of betel leaves (Piper betle), a plant widely used in traditional Malaysian remedies for its antibacterial and refreshing properties, added local and cultural relevance to the product.

Respondents noted that this cultural connection not only made the product more distinctive but also reinforced trust and authenticity. By integrating traditional herbal knowledge into a modern, convenient bath format, BE-BOMB bridges heritage and innovation, appealing to consumers who value products that are both effective and meaningful in a local context. Overall, these findings suggest that BE-BOMB successfully meets both functional and symbolic consumer needs. Functionally, it delivers on safety, efficacy, and eco-friendly production; symbolically, it communicates cultural identity, sustainability, and conscientious consumption.

The alignment of these factors indicates that BE-BOMB is not only a practical personal care product but also a strategically positioned eco-innovative offering that resonates with consumer values and lifestyle preferences. This combination of health, environmental responsibility, and cultural authenticity underscores its potential to penetrate the Malaysian wellness market, particularly among youth and environmentally conscious consumers seeking sustainable alternatives to conventional bath products.

Purchase Intention and Price Sensitivity

Price emerged as a key factor in consumer willingness to adopt BE-BOMB. Survey results revealed that nearly 50% of respondents preferred a price range between RM5 and RM10, while 28% were willing to pay RM10-RM15. This indicates that BE-BOMB is perceived as an affordable eco-innovative product, suitable for mass-market adoption in the Malaysian context. The remaining respondents were less willing to pay beyond RM15, highlighting the price sensitivity of young consumers, particularly for newly introduced herbal and sustainable products. The data suggest that pricing strategies for BE-BOMB should focus on accessibility and value perception. By setting a competitive price that aligns with consumer expectations, marketers can enhance adoption rates while positioning the product as a cost-effective, sustainable alternative to chemical-based bath bombs.

Perceived Benefits

Survey responses underscored several distinct advantages of BE-BOMB that set it apart from conventional bath products, highlighting the product's potential to meet both functional and symbolic consumer needs. A primary motivator for respondents was the healthier and safer profile of BE-BOMB. Participants emphasized that the natural, chemical-free formulation significantly reduces exposure to synthetic additives, parabens, and artificial fragrances commonly found in traditional bath products. This perceived safety not only addresses concerns about skin irritation or long-term chemical exposure but also reinforces the product's positioning as a wellness-oriented, responsible choice.

By prioritizing natural ingredients, BE-BOMB appeals to health-conscious consumers who are increasingly selective about the products they use in their personal care routines. In addition to health benefits, respondents highlighted the product's eco-conscious attributes as a key factor influencing acceptance. Consumers appreciated that BE-BOMB incorporates discarded betel leaves (Piper betle), an agricultural by-product, aligning with sustainable practices and circular economy principles. This upcycling approach transforms waste into a value-added product, minimizing environmental impact while demonstrating innovation in resource utilization. For environmentally aware consumers, the eco-friendly aspect of BE-BOMB enhances its appeal and adds a sense of moral satisfaction, as purchasing the product contributes to responsible consumption and environmental stewardship. This finding aligns with studies indicating that sustainability and ethical production practices are increasingly important drivers of purchase intention among millennial and Gen Z consumers in Malaysia and globally (Ooi & Wong, 2024; García-González et al., 2025).

Another notable advantage cited by respondents was unique cultural identity and authenticity. The inclusion of betel leaves, well-known in Malaysian traditional medicine for their antibacterial and aromatic properties, added a distinctive cultural and symbolic dimension to the product. Consumers recognized the integration of traditional knowledge into a modern self-care product as both novel and meaningful, enhancing the product's differentiation in a competitive beauty and wellness market. By combining local herbal heritage with contemporary eco-innovative design, BE-BOMB provides a culturally resonant experience that strengthens consumer attachment and perceived value. This combination of efficacy, sustainability, and cultural authenticity positions BE-BOMB as a product that fulfils both practical wellnesses need and aspirational lifestyle preferences.

Collectively, these perceived advantages indicate that BE-BOMB successfully addresses multiple dimensions of consumer demand. Functionally, it provides a safe and effective bathing experience; environmentally, it embodies sustainability through resource reuse; culturally, it connects consumers with local traditions and herbal knowledge.

By integrating these three dimensions, BE-BOMB appeals to consumers seeking personal care products that are not only effective but also aligned with broader values of health, environmental responsibility, and cultural appreciation. These findings suggest that BE-BOMB has strong market potential, particularly among young, trend-conscious, and eco-aware consumers, who are increasingly prioritizing products that deliver both functional benefits and symbolic meaning. Furthermore, the convergence of safety, sustainability, and cultural distinctiveness provides a robust foundation for branding, marketing, and product differentiation strategies, enabling BE-BOMB to stand out in Malaysia's rapidly growing herbal and eco-friendly personal care sector.

Laboratory and Expert Evaluation

To complement consumer insights, BE-BOMB underwent laboratory and professional assessment to validate its safety, quality, and market readiness:

- Laboratory analysis by Nano Lab Analytical Sdn. Bhd. confirmed that BE-BOMB maintains a pH of 8.50, within a safe range for external use. Microbiological tests demonstrated no microbial contamination, ensuring the product meets hygiene and safety standards for personal care items.
- Expert evaluation by Chanteque Beauty & Spa and Najwa Pharmacy assessed the product's fragrance, texture, usability, and packaging appeal. Experts confirmed that BE-BOMB is microbiologically safe and commercially viable, while recommending enhancements in visual appeal and packaging design to improve market competitiveness.

The combination of laboratory validation and expert evaluation reinforces the credibility and reliability of BE-BOMB as a consumer-ready herbal product.

Integrated Interpretation of Results

The findings of this study provide a comprehensive perspective on the consumer acceptance, market potential, and strategic positioning of BE-BOMB as a natural, eco-innovative bath product.

Taken together, several key insights emerge that not only highlight the product's immediate feasibility but also indicate pathways for commercialization, sustainability, and cultural resonance.

First, the study demonstrates high market interest among the target segment of young Malaysian consumers. Approximately 78% of respondents expressed interest or strong interest in purchasing BE-BOMB, reflecting a substantial openness to trying herbal-based, sustainable bath products. This level of receptivity suggests that eco-innovative personal care items have strong appeal among environmentally conscious youth, who are increasingly influenced by health, sustainability, and lifestyle trends. The findings align with global research showing that Generation Z and millennial consumers prioritize natural, chemical-free, and environmentally responsible products in their personal care routines (Ooi & Wong, 2024). The high interest levels also indicate potential for BE-BOMB to gain traction in urban and semi-urban markets, where awareness of herbal and sustainable wellness products is generally higher.

Second, affordability emerges as a critical factor in market adoption. Survey results show that nearly half of respondents (49.5%) prefer a price range of RM5-RM10, while 28% are willing to pay between RM10-RM15. This demonstrates that while consumers value eco-friendly and herbal products, price sensitivity remains a significant determinant of purchase behaviour. For BE-BOMB to achieve widespread adoption, it should be strategically positioned as an accessible, affordable product without compromising quality or safety. Offering the product within the RM5-RM10 range would likely maximize market penetration and appeal to budget-conscious young consumers while reinforcing the perception of value for money. These findings are consistent with prior studies on eco-innovative products, which indicate that high prices can be a barrier even for environmentally motivated consumers (Yusoff et al., 2023; Business Today, 2025).

Third, BE-BOMB provides both functional and symbolic value to consumers, which strengthens its market positioning. Functionally, the product's chemical-free, herbal formulation offers clear health benefits, such as reduced risk of skin irritation, antibacterial effects, and overall safety for personal care use.

Symbolically, BE-BOMB resonates with environmentally conscious and culturally aware consumers by embodying sustainability and local heritage. The upcycling of discarded betel leaves demonstrates environmental responsibility, aligning with circular economy principles, while the use of a culturally significant herb, widely recognized in traditional Malaysian remedies, adds authenticity and local relevance. This dual appeal enhances consumer motivation to adopt the product, as it fulfils both practical needs and aspirational values. By bridging efficacy, sustainability, and cultural identity, BE-BOMB stands out as a product that caters to contemporary wellness trends while leveraging local natural resources for competitive differentiation.

Fourth, safety and quality assurance emerged as a critical enabler of consumer confidence. Laboratory analyses by Nano Lab Analytical Sdn. Bhd. confirmed that BE-BOMB is microbiologically safe, chemically stable, and suitable for external use with a pH of 8.50. Additionally, expert evaluations from Chanteque Beauty & Spa and Najwa Pharmacy validated the product's texture, fragrance, usability, and commercial viability. These objective assessments not only substantiate claims made in marketing communications but also enhance consumer trust, a key factor in promoting adoption of herbal and eco-friendly products. By ensuring safety, quality, and professional validation, BE-BOMB addresses one of the main barriers often associated with herbal and natural cosmetics, that concerns regarding efficacy and product safety (Gambardella et al., 2025). Collectively, these findings provide a holistic understanding of consumer perceptions, purchase intention, and potential market positioning for BE-BOMB.

The data suggest that the product is well-poised to capture interest in Malaysia's growing herbal and eco-friendly personal care segment, particularly among younger consumers who value sustainability, cultural relevance, and affordability. To strengthen its commercial success, attention should be given to packaging aesthetics, fragrance options, and multi-purpose functionality, which could broaden the appeal to a wider consumer base, including those without bathtubs who may use it for foot soaks or spa treatments. Furthermore, the study highlights the economic and social implications of BE-BOMB as an eco-innovative product.

By transforming discarded betel leaves into a value-added skincare item, the product exemplifies circular economy practices, reduces waste, and promotes sustainable resource use. At the same time, the project supports local entrepreneurship and community empowerment by creating opportunities for small-scale producers, herbal farmers, and wellness retailers, fostering inclusive economic growth. These outcomes contribute directly to several United Nations Sustainable Development Goals (SDGs), including SDG 3 (Good Health and Well-being), SDG 8 (Decent Work and Economic Growth), and SDG 12 (Responsible Consumption and Production). In doing so, BE-BOMB not only addresses consumer needs but also aligns with global sustainability objectives, enhancing its relevance in both local and international markets.

In conclusion, the integrated interpretation of results indicates that BE-BOMB combines consumer readiness, economic feasibility, product safety, and sustainability in a single, marketable innovation. Its acceptance is driven by a combination of health-conscious, environmentally aware, and culturally informed consumer preferences. Affordability and perceived value are key factors supporting adoption, while laboratory validation and expert assessments ensure credibility and safety. Strategically, BE-BOMB demonstrates significant potential to establish itself in Malaysia's herbal and eco-friendly beauty market, offering a scalable model for eco-innovation that integrates traditional herbal knowledge with modern product development.

This synthesis suggests that the next steps for commercialization should focus on enhancing product differentiation, diversifying offerings, improving packaging, and exploring partnerships with local suppliers and wellness retailers. By doing so, BE-BOMB can strengthen its market position, maximize consumer engagement, and serve as a practical example of sustainable entrepreneurship that bridges heritage, innovation, and environmental responsibility.

CONCLUSION

The findings of this study indicate that the Betel Leaf Bath Bomb (BE-BOMB) successfully addresses the increasing consumer demand for natural, chemical-free, and sustainable skincare products, particularly among young, environmentally conscious consumers. The results support previous research showing that Generation Z and millennial consumers are highly aware of environmental issues and increasingly prefer personal care products that align with eco-friendly principles (Ooi & Wong, 2024). The high level of acceptance and willingness to purchase BE-BOMB at an affordable price range suggests that the product has significant potential to penetrate the Malaysian beauty and wellness market as a competitive eco-innovative product.

From a sustainability perspective, BE-BOMB embodies the principles of the circular economy by transforming discarded betel leaves (Piper betle), an agricultural by-product, into a value-added personal care solution. This upcycling approach not only minimizes environmental waste but also mitigates issues such as open burning of agricultural residues, which can contribute to air pollution and greenhouse gas emissions. Similar initiatives in the cosmetic industry have been recognized for promoting waste valorization and fostering sustainable innovation (Mancini et al., 2024). By repurposing unused herbal resources, BE-BOMB demonstrates responsible production and aligns with global sustainability practices, emphasizing both environmental stewardship and resource efficiency (García-González et al., 2025).

Economically, BE-BOMB promotes local entrepreneurship by encouraging collaboration with small-scale farmers and microbusinesses. This model supports inclusive economic growth, providing rural communities with opportunities for income generation and capacity building. Such an approach aligns with existing research highlighting the role of green entrepreneurship in emerging economies, where eco-innovative products can simultaneously address environmental, social, and economic objectives (Gambardella et al., 2025). By linking product development to local agricultural resources, BE-BOMB also strengthens supply chain sustainability and enhances community participation in the green economy.

The project contributes directly to several United Nations Sustainable Development Goals (SDGs). It addresses SDG 3 (Good Health and Well-being) by providing a safe, chemical-free skincare product; SDG 8 (Decent Work and Economic Growth) by offering entrepreneurial opportunities to local producers; and SDG 12 (Responsible Consumption and Production) by encouraging resource reuse, eco-friendly packaging, and waste reduction. Collectively, these outcomes demonstrate that BE-BOMB integrates sustainability, social responsibility, and innovation within a single product concept, exemplifying how eco-innovation can generate multi-dimensional impact in both local and global contexts.

From a product development standpoint, BE-BOMB illustrates that traditional herbal ingredients can be effectively translated into modern wellness applications. Laboratory analyses confirmed that the product is safe for consumer use, with a pH of 8.50 suitable for external application and no detectable microbial contamination. Expert evaluations further validated the product's commercial feasibility, recommending improvements in visual appeal and packaging to enhance market competitiveness. These findings highlight the importance of combining scientific validation with consumer-centric design, ensuring that herbal-based innovations meet both safety standards and aesthetic expectations.

The study also underscores the economic feasibility of eco-innovative herbal products in Malaysia. BE-BOMB not only expands consumer choices for safer and sustainable skincare but also contributes to community empowerment, environmental protection, and cultural preservation by integrating traditional herbal knowledge into modern product applications. This approach aligns with research emphasizing the potential of eco-innovations to drive both sustainable consumption and local entrepreneurship while meeting global sustainability objectives (Niinimäki, 2015; Ooi & Wong, 2024).

Despite these positive findings, several limitations should be acknowledged. First, the sample size of 111 respondents, predominantly young adults aged 18-24, limits the generalizability of the results to other age groups. Second, most participants resided in urban and semi-urban areas, potentially excluding insights from rural populations with differing consumption behaviours and preferences.

Third, the reliance on self-reported data may introduce social desirability bias, potentially inflating interest or acceptance levels. Lastly, the pricing analysis was based on perceived willingness to pay rather than observed market transactions, which may not fully reflect actual purchasing behaviour. Addressing these limitations in future research would strengthen the validity and applicability of the findings.

To enhance BE-BOMB's commercial potential and long-term sustainability, several practical recommendations are proposed:

- Product diversification: Introducing new colours, shapes, and fragrances would expand appeal to different consumer segments and encourage repeat purchases.
- Packaging improvements: Utilizing biodegradable, moisture-resistant materials align with current trends in sustainable packaging, improving both functionality and environmental responsibility.
- Optimizing product formulation: Adjusting the pH closer to natural skin levels would enhance user comfort and skin compatibility.
- Expanding product use cases: Marketing BE-BOMB as a multi-purpose product, such as a foot soak or spa treatment, would attract consumers without bathtubs and broaden market applicability.
- Sustainable sourcing and partnerships: Collaborating with local herbal farms and wellness retailers ensures consistent quality, supports rural economies, and strengthens supply chain sustainability.
- Market research expansion: Conducting further studies with diverse demographics, including older consumers and rural populations, would provide insights into broader acceptance and long-term purchase behaviour.

By implementing these strategies, BE-BOMB can solidify its position as a market-ready eco-innovative product, demonstrating tangible benefits in terms of sustainability, entrepreneurship, and cultural relevance. The study's findings reinforce the notion that integrating traditional herbal knowledge with modern eco-innovations can create products that are both commercially viable and socially responsible.

In conclusion, BE-BOMB represents a successful example of how eco-innovation can be applied in the beauty and wellness industry to address environmental, economic, and social objectives simultaneously. The product combines safety, sustainability, affordability, and cultural significance, appealing to environmentally conscious consumers while supporting local entrepreneurship. Future research and product refinement, guided by consumer preferences and expert evaluations, can further strengthen its commercial potential, ensuring that BE-BOMB contributes to responsible consumption, sustainable business growth, and broader environmental stewardship within Malaysia and beyond.

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CHAPTER 4
FOOD IRRADIATION FOR MITIGATING POST-HARVEST LOSSES IN NIGERIA

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INTRODUCTION

Following the axiom of 'no food no life', food is considered an elixir for healthy and productive life (Bolarin & Bosa, 2015; Oladimeji, 2019). According to Ashaye et al. (2019), ensuring access to quality, nutritious, and safe food for a burgeoning global population is a pressing challenge. With the global population expected to hit 9 billion by 2050, up from 7 billion plus in 2012, food production needs a massive boost of a whopping 70% increase to meet future demand. Realistically, high post-harvest losses (PHLs) occasioned by poor post-harvest management of agricultural produce may pose a setback to the projected food production. PHLs are a great concern especially in Nigeria due the losses of majority of farm produce to pest, rodents, and to deterioration triggered by inappropriate post-harvest process and storage (Bolarin & Bosa, 2015). Achieving SDG 2 in Nigeria demands focus on cutting post-harvest food losses, alongside other key strategies (Ogundele, 2022). It's a vital move for food security, otherwise, according Asaye et al. (2019) the resultant effect may increase food insecurity capable of exacerbating the existing cases of protein-energy malnutrition (PEM) and the various micronutrient deficiency disorders (MDDs) of vitamin A deficiency (VAD), nutritional anaemia due to deficiencies of iron, folic acid and vitamin B12, and iodine deficiency disorders (IDDs) which remain important public health problems. Furthermore, PEM, VAD and IDD have profound consequences on growth and mental development of children, and especially VAD has a damaging consequences on the eye (xerophthalmia and night blindness), as well as contributing majorly to the high rates of child and maternal morbidity and mortality (Ashaye et al., 2019).

One modern pragmatic way to achieving a reduction in PHLs and hence to ensure food availability all the year round is the practice of food preservation (Oladimeji, 2019). Despite so, indigenous technologies and knowledge of preservation of food from spoilage, in the submission of Oluyi (2023), have fallen short in the face of contemporary realities, such as escalating population at an unprecedented rate, rendering antiquated methods ineffective in addressing modern challenges. For instance, the techniques employed when Nigeria's population stood at a mere 10 million cannot suffice for a nation of over 200 million today. Ipso-facto, attempting to solve 21st century problems with 14th century solutions is a futile endeavour (Oluyi, 2023).

Food preservation has been a human pursuit for ages, and food irradiation is a solid associate in this quest. By tackling ripening, sprouting, pests, microbes, and pathogens, this technique extends the shelf-life of fresh produce, and thus reducing waste (Gautam & Tripathi, 2016; Lokuna, 2017).

Irradiated food has gotten a clean bill of health, as research confirms that when done right, irradiation keeps food safe and nutritious, even at doses above 10 kGy for certain foods (Farkas & Mohácsi-Farkas, 2011). Though, food irradiation was among the extensively studied techniques of 20th century much of the research was limited to the laboratory levels, and its commercial use is still relatively limited and underutilised perhaps due to misconceptions spread by activists and some serious political or/and psychological response (Farkas & Mohácsi-Farkas, 2011). In Nigeria currently, there are challenges of food security due to high post-harvest losses of about 20-60% of total food production (Ashaye et al., 2019; Okojie, 2021; Onyedinefu, 2023), farmers are facing significant economic hardship and reduced income (George, 2024). Food irradiation technology is promising at mitigating these losses and increasing farmers' income, increasing food availability and improving food safety (Koutchma et al., 2018; Sambo et al., 2024). It is against this premise that this study was undertaking to come up with evidence-based findings focusing on sensitising and promoting the applications of food irradiation among relevant stakeholders in Nigeria for food preservation to reducing PHLs, which can ensure food security improvement that may lead to the attainment of SDG 2.

1. MATERIALS AND METHODS

This narrative review is a synthesis that systematized and interpreted current literature to offer a broad overview of a subject rather than a statistical meta-analysis (Ferrari, 2015). The approach was selected to permit for the integration of diverse study types and grey literature, offering a broad, contextualized overview on the subject. The search strategy involved a systematic appraisal of research publications from institutional databases especially PubMed, Google Scholar, Scopus, and African Journals Online (AJOL). The search was supplemented by a review of institutional reports from a global organization such as International Atomic Energy Agency (IAEA).

Studies and reports from print media were included if they focused on food irradiation, preservation, and post-harvest losses in Nigeria.

2. POST-HARVEST LOSSES AND ECONOMIC IMPLICATION IN NIGERIA

In the explanation of Ashaye et al. (2019), post-harvest starts when the process of collecting or separating food of edible quality from immediate production site has been completed, and food loss is the decreasing in the quantity and quality of crops produced after harvest until consumption (Ibrahim et al., 2022). Ashaye et al. (2019) further explained that food's journey from source to plate involves deliberate human effort, and ends when ingested, and Nigeria's agri-sector's biggest challenge is post-harvest losses, causing a huge 60% of crops lost yearly. This thus suggested poor storage facility, unreliable distribution, and market access issues are the factors. Bad roads, lack of cold storage facilities, processing factories make tomatoes and other perishables decay before reaching the market (Ashaye et al., 2019). Use of improper packaging worsens this problem, as smallholder farmers usually sell their produce in rough raffia baskets, in place of smooth plastic crates, which cause them to bruise and spoil (Ashaye et al., 2019). This challenge always result in the shortage of more than 13 million metric tonnes of tomatoes, vegetables and other agricultural produce (Onyedinefu, 2023), representing an annual loss of about $9 billion (14 trillion Nigeria Naira, based on 1,520 official exchange rate), in value, in the agricultural sector (Gambo, 2020; Okojie, 2021; AgencyReport, 2022). Due to poor processing and handling of tomatoes in Nigeria, for instance, there is an increasing post-harvest loss which causes huge economic loss annually, as shown in Figure 1, resulting in impoverishing Nigeria farmers for a very long time with long-standing lamentation without getting meaningful assistance (Ogundele, 2022).

Similarly, grains, tubers, fresh fruits and vegetable and other perishable food commodities suffer post-harvest losses of huge economic significance, as shown in Table 1, adapted from Ashaye et al. (2019) and Okojie (2021).

Tomato farmers in Nigeria harvested 1.5 million metric tons.

Post-harvest loss, over 0.7 M metric tons

Revenue loss, over $176 M (268 bn Nigeria Naira, based on 1,520 official exchange rate).

Figure 1. Tomato harvest, loss in post-harvest and economy in Nigeria
Source: (Ojewale, 2019; Gambo, 2020; Okojie, 2021)

Table 1. Yearly post-harvest loss of some agricultural produce in Nigeria

Produce Type	Percentage Loss	General comment
Grains	5 - 20	Losses are higher in rural communities due to lack of adequate basic infrastructure and facilities.
Fish	20	
Roots and Tubers	35	
Fruits and Vegetables	50 - 60	

3. FOOD PRESERVATION

Food preservation is a specifically food processing technique that is used to keep food from spoilage, whilst spoilage is either a microbial or chemical or physical action or all that makes foods unsuitable for consumption, and can be accompanied with bruising and browning; infestation by insects or other pests or growth of such germs as bacteria, yeast and moulds (Oladimeji, 2019). Oladimeji (2019) explained further that food processing and preservation is a branch of food technology that is concerned with the transformation of raw animals, vegetables, or marine materials into tasty, nutritious, safe food products, and also providing a means of creating products that are convenient for consumers, especially ready-to-eat foods or those that require minimal preparation and cooking (Oladimeji, 2019). With the combination of processing, preservation, and modern logistics seasonal crops become a year-round thing (Urugo et al., 2024). In the explanation of Oladimeji (2019), food preservation usually involves preventing the growth of bacteria, fungi like yeasts, or other micro-organisms, as well as retarding the oxidation of fats that causes rancidity.

Furthermore, according to Oladimeji (2019), preservation may also include processes that inhibit visual deterioration, such as the enzymatic browning reaction in apples when cut during food preparation. Maintaining or creating nutritional value, texture and flavour is an important aspect of food preservation, although, historically, some methods drastically altered the character of the food being preserved, which in many cases those changes have displayed desirable qualities with such foods as cheese, yogurt and pickled onions (Oladimeji, 2019). Mechanistically, food preservation is based on killing of microbes, keeping new ones out, stop unwanted chemical reactions within the food, and inactivates those enzymes (Shankar-Tumuluru, 2023).

Why food preservation?

Preservation of foods is for preventing spoilage; avoiding wastage, especially when in surplus during harvest season; prolonging shelf life; allowing for use of foods during the off-season; enhancing food affordability when most expensive; ensuring balanced food within the household; enabling care of emergency situations; and others (Oladimeji, 2019; Angelan, 2024).

4. CAUSES OF FOOD SPOILAGE

Food spoilage, an undesirable physical or chemical change taking place in the food which leads eventually to its rejection, can be elicited by action of insects, enzymes, occurring chemical reactions, actions of such micro-organisms as bacteria, yeast and moulds which cause physical change, and others (Shankar-Tumuluru, 2023). The existence of globally employed conventional drying, freezing, chilling, pasteurization, and chemical preservations, and the modern ionizing radiation, high-pressure, and hurdle technologies (Amit et al., 2017), technology based on antimicrobial photodynamic therapy, antimicrobial peptides (Chu et al., 2024) and others are documented. Still, food irradiation holds a better option for food preservation than other methods due to its non-significant use of heat and its ability to improve food quality. It is effective against pathogens, reduces microbial contamination, and avoids the use of chemical preservatives that are environmentally injurious (Sambo et al., 2024; International Atomic Energy Agency, 2025).

In addition, food irradiation allows the use of cold treatment, further enhancing its suitability for modern food preservation systems (Home and Garden Information Center, 2020). Ionizing radiation is a game-changer for preserving fruits and vegetables because of ability to kill spoilage microbes, extend shelf life through delayed ripening and stopping tubers/bulbs from sprouting (Darré et al., 2022). Studies have demonstrated the effectiveness of food irradiation in preservation of foods: Son et al. (2022) examined the effect of low-energy X-rays on potatoes, and found that the X-rays killed microbes, kept potatoes fresh for 6 months with minimal DNA change, and the untreated ones sprouted in two months. Accordingly, the treatment effectively extended the potatoes shelf life.

The treatment of carrots and tomatoes with 1 kGy gamma rays as reported by Chu et al. (2024) showed a reduction in Salmonella populations compared with unirradiated samples. It was also observed that damage cells of carrots and tomatoes gradually healed themselves, on storage, after irradiation exposure. Furthermore, irradiation of chicken samples with instant low-energy electron beams showed a reduction in chicken meat contamination, and when samples were treated with up to 10 kGy, pathogenic microorganisms were potentially eliminated from the surface with concomitant stability in nutritional values (Vazirov et al., 2024; Damdam et al., 2023).

5. FOOD IRRADIATION

Food irradiation (Dhakal, 2023) is a technique, with non-significant heat use, for food preservation involving exposing foodstuffs or their products to specific amount of radiation for eliminating spoilage, pathogenic organism and inhibiting physiological process. Ionising radiations commonly used for food treatment are Gamma-rays emitted from radioisotopes Cobalt-60 (60Co) with 1.33 MeV or Caesium-137 (137Cs) with 0.662 MeV, electron beams with maximum 10 MeV kinetic energy and X-rays with maximum 7.5 MeV kinetic energy generated from electron and X-ray machines respectively (Akinloye et al., 2015; International Atomic Energy Agency, 2022; Dhakal, 2023).

The technique, otherwise called cold sterilization or pasteurization due to insignificant heat production compared to other thermal techniques of food preservation, results in the preservation of food nutritional and organoleptic properties (Dhakal, 2023). By principle (Chu et al., 2024), the process of food irradiation can be achieved, in one hand, by direct emission of high-energy electron rays into microbial cells, lipids, carbohydrates, amino acids, leading to ionization and chemical alterations, and on the other hand, by creating free radicals from water radiolysis within the food matrix to cause damage to cellular components. Co-jointly these steps disrupt cellular activities that leads to cell death (Chu et al., 2024).

The concept of food irradiation dates back to 1896 in Germany, where it first gained attention, and became operational in the early 1920s. Later, in the 1950s and 1960s, the US Army Natick Soldier Centre (NATICK) explored its potential for military rations, experimenting with both low-dose and high-dose irradiation (Oladimeji, 2019). Today, irradiation is widely used in various industries, including medical devices, plastics, and food packaging, with applications in tubes for gas pipelines, hoses for floor heating, shrink-foils for food packaging, automobile parts, wires and cables, tires, and gemstones (Akinloye et al., 2015). The list of approved irradiated products varies globally, typically encompassing spices, herbs, seasonings, select fresh and dried fruits and vegetables, seafood, meat and meat products, poultry, and egg products (Oladimeji, 2019). Despite decades of use for food disinfection and quarantine compliance, concerns linger regarding the toxicity of generated chemicals and irradiation's impact on nutritional quality (Oladimeji, 2019). Notably, research indicates that a unique family of chemicals formed through irradiation is non-toxic (Akinloye et al., 2015).

6. FOOD IRRADIATION USER COUNTRIES

The adoption of food irradiation is widespread, with over 70 countries having legislated its use for various food products (International Atomic Energy Agency, 2022). This endorsement is further supported by the esteemed scientific committees, including those in Denmark, Sweden, the United Kingdom, Canada, and the World Health Organization, all of which have guaranteed for the safety and efficacy of food irradiation (Bruhn, 2017).

In follow up, many countries are now selling irradiated foods, spices, onions, potatoes other food products, which has significantly contributed to their gross domestic or national product (Bruhn, 2017). Some of these countries where irradiated foods or products are sold and their economic scale are shown in Table 2 (Kume et al., 2009). Globally, the market size valued $229.9 M in 2025, and the estimative Growth rate at a compound average growth rate (CAGR) of 4.17% based on 2025-2033 forecast is expected to reach $318.8 M (Global Growths Insight, 2025).

Table 2. Countries, total irradiated foods and economic scale

S/No.	Country	Total Irradiated food per ton	Economic scale (M JPY)
1	Egypt	550	697
2	Vietnam	14,200	24,729
3	Brazil	23,000	218,519
4	China	146,000	232,130
5	France	3111	8,036
6	Japan	8096	1,255
7	India	1600	4,644
8	South Africa	18,185	165,784
9	USA	92,000	849,388
10	Ukraine	70,000	10,000

6.1 Various Foodstuffs Identified for Irradiation in Nigeria

The list, as outlined in Table 3 (Ajibola, 2020), provides valuable insights into the production tonnage, purpose of treatment, and recommended doses for each food item, highlighting the scope and potential benefits of irradiation in enhancing food safety and quality in the region.

Table 3. Some possible foodstuffs for ionizing radiation in Nigeria

S/No.	Produce	Yield ($t \cdot a^{-1}$) MMt	Benefit	RD (kGy)
1	Sorghum	6.500[a]	Disinfestations	1.0
2	Millet	1.550[a]	Disinfestations	1.0
3	Corn	11.200[a]	Disinfestations	1.0
4	Rice	5.765[a]	Disinfestations	1.0
5	Cocoa bean	0.304[b]	Disinfestation/microbe loss	1.0-5.0
6	Kola-nut	0.174[c]	Disinfestation/microbe loss	1.0-5.0
7	Yam	45.54[d]	inhibit sprouting	0.2
8	Potatoes	1.1[e]	inhibit sprouting	0.2
9	Onions	3.8[f]	inhibit sprouting	0.2
10	Tomatoes	4.1[g]	Inhibition of ripening	1.0
11	Citrus	3.5[h]	Inhibition of ripening	1.0
12	Fishes	1.07[i]	Disinfestations/shelf life	2.0-3.0
13	Meat	1.55[j]	Disinfestations/shelf life	2.0-3.0
14	Spices	1.04[k]	Disinfestations/loss pathogens	1.0-10.0

6.2 Exploring the Frontiers of Food Irradiation Technology in Nigeria

In Nigeria, food irradiation technology is still in its infancy, representing an alternative food preservation method that has yet to transition beyond the experimental phase (Oladimeji, 2019) This stagnation stems from inadequate equipment at the country's sole irradiation facility, rendering it inaccessible to potential users (Akinloye et al., 2015). Furthermore, a disconnect persists between government agencies, extension workers, and rural food producers, exacerbating ignorance about irradiation as a viable preservation method.

A study by Okoedo-Okojie & Onemolease (2009) underscores this, identifying lack of awareness as a primary barrier to adoption. Recognizing this, the Nigerian government, through the Nigeria Atomic Energy Commission (NAEC), is establishing frameworks to facilitate research and promote irradiation technology's adoption, aiming to unlock its potential for Nigerian food products (Oladimeji, 2019). According to Akinloye et al. (2015), the involvement of the Nigerian government in advocating for the use of irradiation technology as a food preservation method to reduce post-harvest losses is a positive indicator that this technology will soon reach its commercial stage in Nigeria, as Government agencies such as the Small and Medium Enterprise Development Agency of Nigeria (SMEDAN) and NAEC have concluded agreements that would pave way for the private sector to participate fully in the food irradiation industry.

Nigeria's sole Gamma Irradiation Facility (GIF), situated at the Nuclear Technology Centre (NTC) of the Nigeria Atomic Energy Commission (NAEC) in Sheda, Abuja, is a category IV multipurpose industrial irradiation facility with six operational modes. The facility features a robust irradiation room with 1.8 m thick steel-reinforced concrete walls, housing a Co-60 radioactive source with an activity of approximately 5.5 x 10^15 Bq (170 kCi) (Oladimeji, 2019). A continuous overhead conveyor system enables efficient processing of large products, with operational modes tailored to product type, quantity, shape, size, bulk density, and required dose. The facility ensures uniform irradiation and accurate dosage control, capable of handling up to 18 metric tons of products in a single batch using the four-path irradiation mode (Oladimeji, 2019). The GIF serves as a comprehensive research and development hub, targeting food and agricultural preservation, medical device sterilization, and enhancement of plastics' properties (Akinloye et al., 2015).

6.3 Unlocking Nigeria's Potential: The Future of Food Irradiation Technology

Addressing the pressing issue of population-food imbalance, particularly in developing countries where post-harvest losses claim a quarter of harvested food, necessitates effective strategies (Akinloye et al., 2015).

Nigerian researchers have explored food irradiation technology's efficacy in curbing spoilage and sprouting of staple foodstuffs, including fish, meat (Aworh et al., 2002), yam (Bawan & Abima, 2025), onions, garlic (Tyovenda et al., 2022), and cowpea seeds (Akaagerger & Tsavnande, 2024). Their findings affirm irradiation's potential, underscoring its promise for commercial adoption in Nigeria. The Nigeria Atomic Energy Commission (NAEC), established in 1976, has fostered research and development in nuclear science, including food irradiation. NAEC's Nuclear Technology Centre in Sheda houses a Co-60 Gamma Irradiation Facility (GIF), facilitating research. With this infrastructure and growing researcher interest, food irradiation may soon become more accessible for widespread use. Table 4 outlines food products treatable with gamma irradiation and achievable dose ranges (Akinloye et al., 2015).

Table 4. Gamma Irradiation in Food Preservation: Dose Ranges, Objectives, and Applications

Dose range	Objective of irradiation	Application on food products
Low dose (0.06 – 1) kGy	1. Inhibition of sprouting on potatoes and other foods. 2. Killing of insects and larvae found in wheat, flour, fruits and vegetables after harvesting. 3. Slowing of the ripening process.	Such food products as potatoes, onions, garlic, root ginger, bananas, mangoes, and select non-citrus fruits, alongside cereals, pulses, dehydrated vegetables, dried fish and meat, and fresh pork.
Medium dose (1 – 10) kGy	1. Elimination of certain microbes and parasites that cause spoilage of food. 2. Reducing the number of pathogenic microorganisms	A diverse range of perishables, including fresh fish, strawberries, grapes, dehydrated vegetables, fresh or frozen seafood, and raw or frozen poultry and meat,
High dose (10 – 50) kGy	1. Sterilization of food for a variety meal for hospital patients who suffer from immune disorders and can eat only bacteria-free foods. 2. Elimination of some viruses causing diseases. 3. Decontamination of certain food additives and ingredients	Meat, poultry, seafood and other food prepared for sterilized hospital diets, spices, enzyme preparations, natural gum.

With the adoption of commercial practices of food irradiation technology and the accompaniment effect in reducing postharvest losses of agricultural produce, it is hope that this may increase agricultural productivity that shall cause an increase in Nigeria gross domestic product (GDP) and perhaps assisting in making Nigeria currency valued through the exportation of quality and safe produce.

7. TOXICITY STUDIES OF IRRADIATED FOODS IN HUMANS AND ANIMALS

Extensive research since the 1950s has scrutinized the potential toxicological impacts of irradiated food consumption. A multitude of feeding trials have been undertaken, involving diverse laboratory diets and food components administered to humans and various animal species, including rats, mice, dogs, quails, hamsters, chickens, pigs, and monkeys, to rigorously assess irradiated food safety. These animal studies encompassed lifetime and multi-generation analyses, meticulously examining growth, blood chemistry, histopathology, and reproductive parameters for any discernible changes linked to irradiated food intake. The Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI) thoroughly evaluated data from these comprehensive trials (Center of Food Safety, 2009). Comprehensive evaluations culminated in the conclusion that irradiating food commodities up to an average dose of 10 kGy poses no toxicological, nutritional, or microbial risks (Ravindran & Jaiswal, 2019). Recent studies using laboratory diets sterilized by irradiation further corroborate irradiated food safety. Multiple animal generations fed diets irradiated at doses ranging from 25 to 50 kGy – significantly higher than those used for human food – exhibited no mutagenic, teratogenic, or oncogenic effects attributable to irradiated diet consumption (Oladimeji, 2019). Consequently, irradiating food with any dose intended to achieve a technological objective is deemed safe, provided it doesn't compromise nutritional value, rendering it safe for consumption (Ravindran & Jaiswal, 2019).

8. EXAMINATION OF BARRIERS TO FOOD IRRADIATION ADOPTION IN NIGERIA

The commercialization of food irradiation technology in Nigeria is still in the offing, and as such very little can be said concerning the problems faced during the use of this technology in Nigeria (Akinloye et al., 2015). However, the following are some factors that have limited the commercialization of food irradiation in Nigeria;

- Lack of adequate equipment: Food irradiation technology is yet to find widespread use in Nigeria, due to shortage irradiation facility. The only one presently in place is located at NTC of NAEC, Sheda Abuja, Nigeria (Ajibola, 2020).
- Lack of adequate education: A significant hurdle to food irradiation adoption in Nigeria stems from inadequate education and awareness. A disconnect persists between government agencies, extension workers, and rural food producers, hindering understanding and uptake of irradiation as a viable preservation method. Research by Akinloye et al. (2015) underscores this, identifying ignorance of improved preservation methods like irradiation as a primary barrier to adoption.
- Poor transport system: In the submission of Akinloye et al. (2015) and Ajibola (2020), a nation's infrastructure and transport systems are pivotal to its development. In Nigeria, road and rail networks serve as lifelines for agricultural produce distribution. Yet, these systems are crippled, with roads and rails in disrepair, and past investments largely squandered due to neglect. This dire state hampers supply chains and food distribution, often leaving perishables to rot. Trucks breakdowns, sometimes for days, exacerbate losses, as evident in cities like Jos, Kano, and Lagos, where spoiled produce piles starkly illustrate the transport system's failure. These challenges, coupled with the solitary Gamma Irradiation Facility (GIF) in Sheda, Abuja, will likely impede irradiation technology adoption in Nigeria.
- Economic consequence of irradiation: The economic dimension is pivotal in determining irradiation technology adoption. Drawing parallels with developed nations like the USA, where commercialization has led to marginal price hikes for irradiated products (Akinloye et al.,

2015), it's clear that costs may be counterbalanced by extended shelf life and enhanced safety. Moreover, widespread adoption is likely to drive costs down, making irradiated foods more accessible (Home and Garden Information Center, 2020).

- Lack of trained personnel: A critical prerequisite for irradiation technology adoption is the availability of skilled personnel to oversee operation, maintenance, and repairs of radiation equipment, particularly in developing nations like Nigeria. Equally crucial is ensuring a steady supply of spare parts to support equipment upkeep (Oladimeji, 2019).

9. RECOMMENDATION FOR ADOPTION OF RADIATION FOR FOOD PRODUCTS PRESERVATION IN NIGERIA

Resonating Farkas & Mohácsi-Farkas (2011), unlocking food irradiation's potential hinges on recognizing its role in curbing foodborne diseases and spoilage, coupled with consumers' willingness to invest in safer food processing. For widespread adoption in Nigeria, addressing implementation barriers is crucial. To this end, several recommendations are proposed:

- Adequate awareness education: Consumer acceptance of irradiated foods hinges on education and strategic communication, dispelling misconceptions that irradiation is a nuclear technology (Farkas & Mohácsi-Farkas, 2011). Demystifying irradiation can overcome hurdles posed by consumer skepticism and regulatory barriers, paving the way for wider adoption (Farkas & Mohácsi-Farkas, 2011). For adequate sensitizations on food irradiation, extension agents should use mass media, religious houses, market places, town-hall meetings to actively disseminate information to farmers and farmers groups, and consumers both in the rural and urban areas.
- Provision of facility: To align with developed nations in leveraging irradiation technology for food preservation, Nigeria must establish multiple facilities strategically across the country, ensuring accessibility. This necessitates a collaborative framework bridging public and private sectors. The Food Corporation of India's model, with its extensive

network, offers a viable blueprint (Akinloye et al., 2015). Concerted efforts from government agencies and private stakeholders can expedite facility construction in each state, making irradiation technology readily available to users.

- Subsidising cost arising from the actual service: According to Akinloye et al. (2015), if losses are targeted for reduction, government should, as a matter of responsibility, give production incentives in terms of favourable pricing linked with efficient marketing facilities. Also, government should give profitable or stable price assurance so that the farmer can increase production to levels that will ensure stability of supplies to meet both normal and emergency requirements. The subsidy can be in form where the federal government assists farmers in mopping up excess farm produce and storing them at strategic reserves, which are sold to people at reduced prices during periods of food scarcity.
- Construction of motorable roads: Feeder Roads should be constructed to convey the large amounts of farm produce, now wasting away in the fields because of lack of transport facilities, to the nearby irradiation facility.
- Sufficient personnel should be trained to manage the information, management and technical skill of irradiation technology.

CONCLUSION

In this study, it was found that there is high level of PHLs of agricultural produce in Nigeria, especially of perishable produce, food irradiation is a technique of food preservation that may cause not only postharvest losses reduction but also improve quality and safety of agricultural produce. It is a better technique of food preservation due to insignificant heat production compared to other thermal techniques, though it does replace others but offers one more protective step. For food and nutritional, health, economic, and export securities, over 70 countries have legislated the use of irradiation. Such international bodies as international atomic energy agency, food and agriculture organisation and world health organisation have endorsed it.

Commonly used sources of food irradiation are Cobalt-60 or Caesium-137 (137Cs), electron beam and X-ray. Currently, only one irradiation facility that houses Cobalt-60 radioactive source and operations under demonstration is available in Nigeria. The technique has been demonstrated for yam, water yam, onions, potatoes, garlic, tomatoes and cowpea seeds preservation without consequent toxic effect and changing of nutritional integrity. The commercialization of this technique has the potential to strengthening food and economic security in Nigeria that may raise GDP, cause attainment of SDG 2, as done in such countries as Egypt, China, Japan, USA and many others. The global market is increasing for irradiated foods, current it's valued at $229.9 M, and may reach $318.8 M by 2033. However, factors such as lack of adequate equipment, education and trained personnel, poor transport system, fear of economic consequence and others were discovered as hinderances for the commercial adoption of food irradiation in Nigeria. It is therefore recommended, for its quick commercial implementation, that the Nigeria government exercises the wiliness, politically, legislatively, structurally, educationally and economically.

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ISBN: 978-625-93129-9-6