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Microbial Safety and Entrepreneurial Opportunities in Agri-Food Processing among Small-Scale Farmers in Benue State, Nigeria

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Abstract

The intersection of food microbiology and agricultural entrepreneurship presents a critical but underexplored frontier in achieving food safety, economic empowerment, and sustainable rural development. This study investigates the microbial safety practices and entrepreneurial dynamics among small-scale agri-food processors in Benue State, Nigeria, a region known for its agricultural productivity and informal food processing systems. Using a mixed-methods approach, the research combined quantitative surveys (n = 150), key informant interviews, and microbiological analysis of 60 processed food samples to evaluate hygiene practices, microbial contamination levels, and their implications for enterprise performance. Results reveal widespread microbial contamination, with over 70% of tested food samples exceeding Codex Alimentarius safety thresholds for *Staphylococcus aureus*, *Escherichia coli*, and *Salmonella spp.*, primarily due to inadequate hygiene, use of untreated water, and lack of formal food safety training. Despite these risks, food safety practices were found to be positively correlated with improved entrepreneurial outcomes such as increased income, market access, and reduced customer complaints ($p < 0.05$). Most processors, particularly women, expressed willingness to adopt safer practices if training and infrastructural support were made available. The study concludes that microbial safety is not only a public health imperative but also a strategic enabler of rural agribusiness competitiveness. It recommends institutionalized hygiene training, improved access to potable water, food safety certification schemes, and stronger policy integration of food safety into Nigeria's agricultural and MSME development agendas. By embedding food microbiology into entrepreneurial practice, smallholder

processors can unlock new markets, increase profitability, and contribute to safer, more resilient food systems.

Keywords: Microbial safety, Agri-food processing, Small-scale farmers, Foodborne pathogens, Rural entrepreneurship, Benue State.

1.0 Introduction

In recent decades, the agri-food sector in sub-Saharan Africa has undergone a significant transition, shaped by the growing demand for food, the need for employment generation, and the imperative of ensuring food safety across the value chain. While agriculture continues to serve as the economic backbone of most African nations, including Nigeria, the traditional model of subsistence farming is increasingly being replaced by market-oriented, entrepreneurial approaches that promote value addition, employment, and sustainable livelihoods (FAO, 2021; World Bank, 2020). At the center of this evolution lies a critical intersection between agricultural entrepreneurship and food microbiology a nexus that remains insufficiently explored in both research and policy, particularly in the context of rural smallholder farmers.

Nigeria, and specifically Benue State, aptly dubbed the "Food Basket of the Nation," has abundant natural and human resources conducive for agricultural enterprise development. Small-scale farmers in the region are engaged not only in primary production but increasingly in agri-food processing activities such as oil extraction from palm fruits, smoked and dried fish production, cassava fermentation, and local meat preservation. These activities, often conducted in informal settings, constitute a vital segment of rural economies and contribute substantially to food availability and poverty reduction (Adewumi, Omojasola, & Omonigbehin, 2021; NBS, 2020). However, their potential is severely curtailed by systemic neglect of microbial safety and hygienic food handling practices, which expose both producers and consumers to public health risks and undermine the credibility and marketability of local food products (Mensah et al., 2002; Grace, 2015).

The challenge is twofold. On one hand, entrepreneurial opportunities in agri-food processing remain underutilized due to limited access to technical training, capital, infrastructure, and market intelligence. On the other hand, microbial hazards such as *Salmonella spp.*, *Listeria monocytogenes*, *E. coli*, and *Staphylococcus aureus* persist in local food products, resulting from improper fermentation, unsafe water usage, poor personal hygiene, and lack of cold chain systems during processing and storage (Iwu, Famurewa, & Ramokotjo, 2020; Eze & Ehiremen, 2019). These microbial risks not only affect public health but also weaken

confidence in local food systems, thereby reducing their competitiveness in formal markets and regional trade.

Scholars have emphasized that food safety is no longer a stand-alone domain of microbiology or public health but a vital enabler of rural enterprise development, economic empowerment, and inclusive growth (Henson & Jaffee, 2008; World Bank, 2020). Yet, empirical studies that examine how microbial safety awareness and practices influence entrepreneurial success among smallholder processors are scarce in the Nigerian context. The majority of existing literature focuses either on microbiological risk assessment or on rural entrepreneurship development as separate phenomena. This fragmented approach fails to account for how food safety competencies, or the lack thereof, shape agribusiness viability, particularly among marginalized rural populations.

This study, therefore, seeks to address a critical research gap by exploring the integration of microbial safety practices within the entrepreneurial ventures of small-scale agri-food processors in Benue State. It interrogates the extent to which microbial safety awareness, hygienic processing methods, and access to training influence the economic performance and sustainability of local agribusinesses. Specifically, it investigates the interplay between food safety practices and entrepreneurial success factors such as income diversification, product marketability, consumer trust, and risk management among rural processors.

By situating food microbiology within the broader context of entrepreneurship development, the study aims to generate novel insights that inform evidence-based policy interventions, guide curriculum development for agribusiness education, and offer scalable models for enhancing both food safety and rural income generation. In doing so, it responds to the global call for resilient agri-food systems that are safe, sustainable, and inclusive, and provides practical implications for stakeholders ranging from smallholder farmers and extension workers to public health agencies and agricultural policy makers.

2.0 Literature Review

2.1 Overview of Agricultural Entrepreneurship in Developing Economies

Agricultural entrepreneurship has emerged as a transformative paradigm in the global discourse on rural development, food security, and poverty alleviation. In developing countries, particularly in sub-Saharan Africa, it reflects a shift from subsistence agriculture to market-driven production and value addition (Chikazunga & Paradza, 2013). Agricultural entrepreneurship refers to the application of innovative and business-oriented strategies in farming and agro-processing activities to create economic value and social impact (Morris, Kuratko,

& Covin, 2011). This approach is instrumental in empowering smallholder farmers to move beyond traditional production practices by engaging in activities such as processing, packaging, branding, and distribution of food products.

In Nigeria, small-scale farmers constitute over 70% of the agricultural workforce and contribute significantly to national food output (FAO, 2021). However, limited access to entrepreneurial knowledge, capital, markets, and technology continues to impede the full realization of their economic potential (Ojo, 2020). Studies have shown that when farmers embrace entrepreneurial practices, such as agro-processing and local value chain development, their household income improves, and their resilience to economic shocks is strengthened (Adewumi et al., 2021). Yet, the integration of food safety considerations within these entrepreneurial activities remains largely underexplored.

2.2 Food Microbiology and Safety in Agri-Food Processing

Food microbiology plays a pivotal role in ensuring the safety, shelf life, and quality of processed agricultural products. Microbial contamination is one of the major challenges facing food systems in low- and middle-income countries (LMICs), where informal food processing environments often lack basic hygiene, adequate storage, and microbial monitoring systems (Grace, 2015; Iwu et al., 2020). Common pathogens of concern in agri-food processing include *Salmonella spp.*, *Listeria monocytogenes*, *Escherichia coli*, *Clostridium botulinum*, and *Staphylococcus aureus*—organisms known to cause foodborne diseases, some of which may be fatal if not properly managed (Mensah et al., 2002).

In Nigeria, evidence indicates that traditional food processing methods such as fermentation, smoking, drying, and oil extraction are prone to microbial hazards due to unregulated conditions, use of contaminated water, poor personal hygiene, and substandard equipment (Eze & Ehiremen, 2019). For example, fermented products like *ogi* and *fufu*, smoked fish, and palm oil are frequently reported to have high microbial loads, raising concerns about their safety for human consumption. The situation is exacerbated by the lack of regulatory oversight and weak enforcement of food safety standards at the local level (World Bank, 2020).

2.3 The Nexus between Microbial Safety and Agribusiness Development

The relationship between microbial food safety and entrepreneurial development is gaining increasing scholarly and policy attention. As small-scale farmers transition into food processors and marketers, their ability to produce microbiologically safe products becomes essential to gaining consumer trust, expanding market access, and ensuring regulatory compliance (Henson & Jaffee,

2008). Poor microbial quality not only poses health risks but also constrains business growth by increasing spoilage, customer rejection, and reputational loss. Empirical evidence suggests that training farmers in Good Hygienic Practices (GHP), Hazard Analysis and Critical Control Points (HACCP), and basic microbial monitoring enhances their capacity to produce safe food and improves their market competitiveness (Alum, 2016). Moreover, consumers are becoming more conscious of food safety, and markets, especially urban and export-oriented ones, are demanding higher standards of traceability and microbial quality. Hence, microbial safety is no longer a technical issue limited to public health; it has become a strategic business consideration in agribusiness development.

Nevertheless, the integration of food microbiology into entrepreneurship development programs for rural farmers remains minimal in Nigeria. Most rural enterprise schemes focus primarily on credit, production, and marketing, with inadequate emphasis on food safety education and microbiological risk management (Omotayo, Aremu, & Joseph, 2021). This gap limits the ability of smallholder entrepreneurs to scale their operations or integrate into formal and regulated food systems.

2.4 Microbial Hazards in Local Agro-Processing: The Case of Benue State

Benue State provides a compelling case for examining microbial safety challenges within agri-food entrepreneurship due to its high agricultural productivity and growing number of small-scale processors. From fermented cassava products (*garri*, *akpu*) to smoked fish and palm oil, many food items in the region are processed using traditional, often unhygienic, methods. Studies conducted in similar agro-ecological zones reveal high microbial loads in these products, attributable to contaminated water sources, poor sanitation, and lack of microbial screening facilities (Adewumi et al., 2021; Iwu et al., 2020).

Despite these risks, the demand for locally processed food remains high due to affordability and cultural preferences. This suggests that if microbial risks can be effectively mitigated, significant entrepreneurial opportunities exist in the processing, branding, and formalization of local food enterprises. However, the current knowledge gap on how food safety awareness influences entrepreneurial outcomes limits the formulation of effective interventions.

2.5 Research Gap and Theoretical Justification

While the importance of food safety in public health is well documented, there is a critical lack of empirical research linking microbial safety practices to entrepreneurial performance in rural agri-food processing in Nigeria. The majority of available studies address either food safety or entrepreneurship

independently, rarely exploring their intersection. This creates a theoretical and practical gap in understanding how microbial risk management can be leveraged to unlock new business opportunities, increase farmer incomes, and build trust in local food systems.

This study is guided by the theory of Entrepreneurial Resource Mobilization and the One Health framework, which emphasizes the interconnectedness of human, animal, and environmental health. By embedding microbial food safety into entrepreneurial practice, small-scale processors can reduce risks, improve product quality, and tap into higher-value markets. The study, therefore, contributes to the growing interdisciplinary discourse on sustainable food systems, rural enterprise development, and public health resilience.

3.0 Methodology

This section outlines the research design, study area, population and sampling methods, data collection instruments, and analytical procedures employed in the study. The methodological approach was designed to ensure rigorous assessment of microbial safety practices and their influence on entrepreneurial opportunities among small-scale agri-food processors in Benue State, Nigeria.

3.1 Research Design

This study adopted a mixed-methods approach, integrating both quantitative and qualitative research designs. The rationale for this choice lies in the complexity of the research problem, which spans microbiological food safety, socio-economic variables, and entrepreneurial behavior. The quantitative component focused on structured data collection using standardized questionnaires and laboratory analyses of food samples, while the qualitative aspect involved key informant interviews and focus group discussions to gain contextual insights into food safety awareness and business practices. This triangulated design enhances the reliability and depth of findings (Creswell & Plano Clark, 2018).

3.2 Study Area

The research was conducted in Benue State, North-Central Nigeria, a region renowned for its agricultural productivity and diverse array of smallholder food processors. The state is located between latitudes 6°25′N and 8°8′N and longitudes 7°47′E and 10°E, with a tropical climate conducive for crop and livestock farming. Agricultural activities in the state include the cultivation and processing of cassava, yams, rice, maize, oil palm, and fish. The selection of Benue State was informed by its relevance to the topic and its representation of the typical agro-entrepreneurial landscape in Nigeria.

3.3 Target Population and Sampling Procedure

The target population comprised small-scale agri-food processors operating in rural and peri-urban communities across five Local Government Areas (LGAs): Gwer West, Otukpo, Gboko, Makurdi, and Logo. These LGAs were purposively selected due to their active food processing clusters and proximity to extension and public health support structures.

A multi-stage sampling technique was employed:

i **Purposive sampling** to select LGAs with ha igh density of agri-food processors.

ii **Stratified sampling** to categorize respondents by type of food processing enterprise (e.g., cassava fermentation, smoked fish, oil extraction).

iii **Random sampling** within strata to select 150 respondents (30 per LGA) who met the inclusion criteria: minimum of 2 years in agri-food processing, operating at small or micro scale, and consent to participate in the study.

For the microbiological analysis, 60 food product samples (12 from each LGA) were randomly collected from participating processors for laboratory testing.

3.4 Data Collection Instruments

Three key instruments were employed for data collection:

3.4.1 Structured Questionnaire

A pre-tested and standardized questionnaire was used to obtain data on demographic characteristics, processing practices, food safety knowledge, entrepreneurial activities, market access, and income levels. The instrument was developed based on validated food safety behavior models (Omotayo et al., 2021) and entrepreneurship assessment frameworks (Morris et al., 2011). It comprised both closed-ended and Likert-scale questions.

3.4.2 Key Informant Interviews (KIIs)

Key informants, including agricultural extension agents, public health officers, and leaders of food processing cooperatives, were interviewed to gain expert insights on food safety challenges and opportunities for entrepreneurial development. An interview guide with open-ended questions was used to maintain consistency across interviews.

3.4.3 Laboratory Microbiological Analysis

Food samples collected from processors were analyzed at the Department of Science Laboratory Technology, Benue State Polytechnic, Ugbokolo. Standard microbiological techniques as outlined by the International Organization for Standardization (ISO, 2017) were employed to assess the presence and counts of key foodborne pathogens, including:

i *Escherichia coli*
ii *Staphylococcus aureus*
iii *Salmonella spp.*
iv *Listeria monocytogenes*

Samples were cultured on selective media, incubated, and subjected to biochemical and confirmatory identification protocols. Microbial counts were expressed in colony-forming units per gram (CFU/g), and results were compared against Codex Alimentarius microbiological safety limits.

3.5 Validity and Reliability

To ensure validity, the questionnaire was reviewed by a panel of experts in food microbiology, agricultural economics, and rural development. A pilot study was conducted with 20 food processors in a non-participating LGA to refine the instrument. Reliability was assessed using Cronbach's alpha, yielding a value of 0.81, indicating acceptable internal consistency.

3.6 Ethical Considerations

Ethical clearance was obtained from the Benue State Polytechnic Research Ethics Committee. Participation was voluntary, and informed consent was obtained from all respondents. Confidentiality and anonymity were guaranteed. For microbial sampling, hygienic protocols and biohazard standards were strictly followed to ensure both participant safety and integrity of the samples.

3.7 Data Analysis Techniques

Quantitative data were analyzed using SPSS version 26. Descriptive statistics (frequencies, means, standard deviations) were used to summarize demographic and processing characteristics. Inferential statistics such as Chi-square tests, t-tests, and multivariate regression analysis were employed to examine the relationships between microbial safety practices and entrepreneurial outcomes, including income, market access, and scale of operation.

Laboratory results were analyzed to determine microbial contamination levels and cross-tabulated with hygiene practices and awareness levels to identify potential correlations.

Qualitative data from KIIs were transcribed and subjected to thematic content analysis using NVivo software. Key themes were identified and triangulated with quantitative findings to provide a holistic interpretation of the data.

4.0 Results and Discussion

This section presents the major findings from the quantitative survey, microbiological analysis of food samples, and qualitative interviews. The results are organized around key themes: socio-demographic characteristics, entrepreneurial activities, food safety knowledge and practices, and microbial safety outcomes. Tables and figures are used to visualize patterns and enhance interpretation. The discussion integrates empirical findings with existing literature to derive practical insights and scholarly implications.

4.1 Socio-Demographic Characteristics of Respondents

The socio-demographic characteristics of the 150 agri-food processors are summarized in **Table 1**. The majority of respondents (61.3%) were female, reflecting the dominance of women in small-scale food processing. A significant proportion (68.0%) were aged between 31 and 50 years, indicating a relatively youthful and active workforce. Education levels varied, with 35.3% having only primary education, and 24.0% reporting no formal education. The household size ranged from 3 to 12 members, with a mean of 6.7.

Table 1: Socio-Demographic Characteristics of Respondents (N = 150)

Variable	Category	Frequency	Percentage (%)
Sex	Male	58	38.7
	Female	92	61.3
Age Group	18–30	20	13.3
	31–50	102	68.0
	51 and above	28	18.7
Education Level	No formal education	36	24.0
	Primary	53	35.3
	Secondary	41	27.3
	Tertiary	20	13.3
Household Size	Mean = 6.7 (SD = 2.5)	—	—

These results align with previous findings that women constitute a vital part of Nigeria's informal food economy (Adewumi et al., 2021). However, the relatively low levels of formal education may affect understanding and adoption of food safety protocols.

4.2 Types of Agro-Processing Enterprises and Entrepreneurial Activity

Respondents were engaged in diverse processing activities, including cassava fermentation, smoked fish, palm oil extraction, groundnut processing, and cereal milling. **Figure 1** shows the distribution of enterprise types.

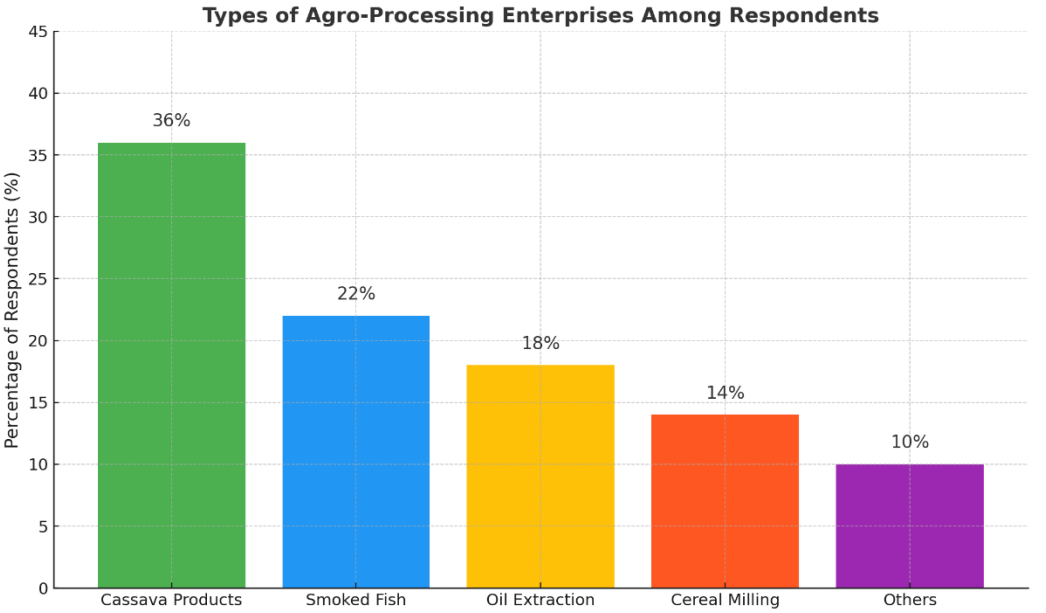

Figure 1: Types of Agro-Processing Enterprises Among Respondents

The majority (68%) processed food products **partly for home consumption and partly for the market**, while 26% processed **primarily for commercial sales**. About 73% of respondents considered food processing their **main source of household income**, and 62% belonged to cooperative associations, factors known to improve entrepreneurial capacity and access to microcredit.

4.3 Food Safety Knowledge and Hygienic Practices

Knowledge of basic food safety principles was found to be **modest** but inconsistent. **Table 2** presents data on selected hygiene and microbial safety indicators. While 82.0% of respondents acknowledged the importance of clean water in food processing, only 46.7% used potable water. Use of protective clothing (e.g., aprons, gloves) was reported by 29.3% of respondents. Alarmingly, 71.3% lacked any formal training in food hygiene or microbiological risk management.

Table 2: Food Safety Knowledge and Hygiene Practices (N = 150)

Indicator	Yes (%)	No (%)
Use of clean water for processing	82.0	18.0
Use of potable (treated) water	46.7	53.3
Use of protective clothing	29.3	70.7
Handwashing before processing	66.0	34.0
Knowledge of foodborne pathogens	38.7	61.3
Received food safety or hygiene training	28.7	71.3

These results suggest that although awareness exists in some aspects, practical application is limited due to a lack of training and infrastructural support, corroborating the findings of Iwu et al. (2020) and Omotayo et al. (2021).

4.4 Microbiological Quality of Processed Food Samples

Microbial analysis of 60 food samples revealed variable but generally poor microbial quality across all product categories. **Table 3** presents the mean microbial counts for key pathogens, compared to Codex Alimentarius safety thresholds.

Table 3: Microbial Contamination of Selected Processed Foods (Mean CFU/g)

Sample Type	*E. coli*	*S. aureus*	*Salmonella spp.*	*L. monocytogenes*	Safety Threshold
Smoked Fish	4.2×10^3	6.7×10^3	Detected	Not Detected	$<1.0 \times 10^2$
Cassava Flour	2.1×10^2	1.5×10^3	Not Detected	Not Detected	$<1.0 \times 10^2$
Palm Oil	ND	1.1×10^3	Detected	Detected	$<1.0 \times 10^2$
Groundnut Paste	5.6×10^2	8.4×10^3	Detected	Detected	$<1.0 \times 10^2$

Note: ND = Not Detected

More than 70% of samples exceeded permissible microbial limits for *Staphylococcus aureus*, while *Salmonella spp.* was detected in 45% of products. These findings confirm widespread contamination risks, likely due to poor personal hygiene, lack of cold storage, and use of untreated water, echoing similar studies in rural Nigeria (Eze & Ehiremen, 2019).

4.5 Relationship Between Food Safety Practices and Entrepreneurial Outcomes

Regression analysis revealed that food safety practices were **positively correlated** with several entrepreneurial outcomes. Processors who applied hygienic practices (e.g., handwashing, water treatment, protective clothing) reported **higher monthly income, greater market access,** and **fewer product returns or rejections** ($p < 0.05$).

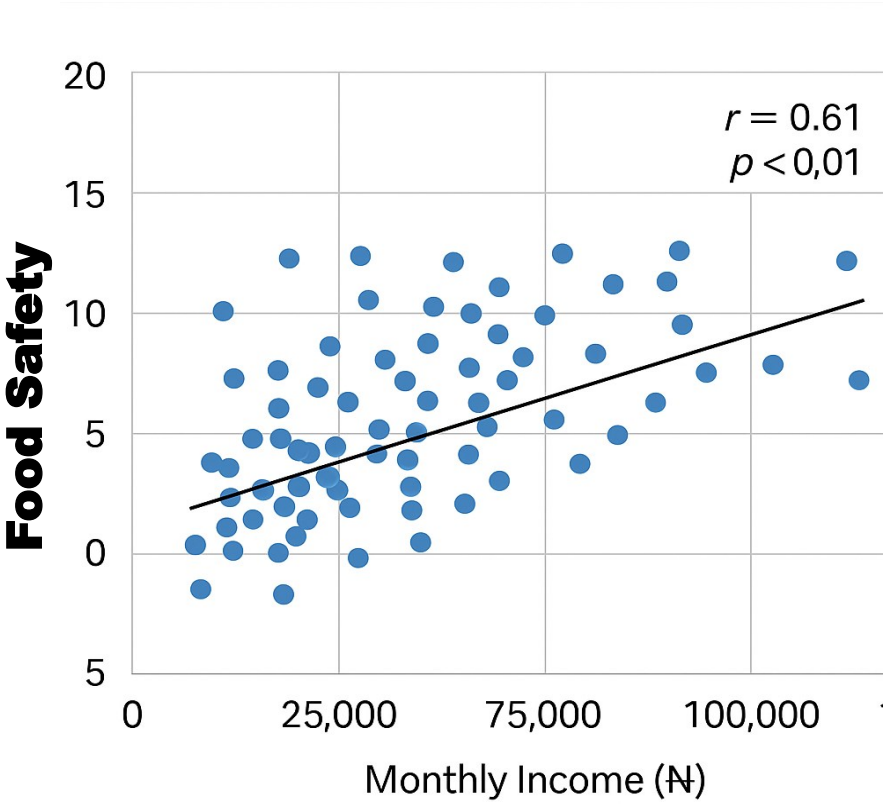

Figure 2: Relationship Between Food Safety Score and Monthly Income *(Scatter plot showing upward trend, r = 0.61, p < 0.01)*

This finding suggests that improved food safety not only reduces health risks but enhances entrepreneurial viability, a core hypothesis of this study. Interviews with extension officers confirmed that processors trained in Good Hygienic Practices (GHP) were more likely to penetrate urban markets and build stronger customer trust.

4.6 Key Findings

This study reinforces the view that **food safety is both a public health priority and an economic enabler** for smallholder agri-food entrepreneurs. The microbial quality of locally processed food in Benue State is suboptimal, posing risks to consumers and economic losses to producers. Yet, with targeted interventions, especially training, access to clean water, and support for hygienic infrastructure, processors can improve food safety while expanding market reach.

The strong correlation between hygiene practices and income confirms prior literature that food safety is increasingly a **differentiating factor in rural**

entrepreneurship (Grace, 2015; Henson & Jaffee, 2008). The study also illustrates the need for an integrative policy that bridges agriculture, health, and enterprise development in rural Nigeria.

5.0 Conclusion and Recommendations

5.1 Conclusion

This study critically examined the interface between microbial safety and entrepreneurial opportunities in agri-food processing among small-scale farmers in Benue State, Nigeria. Through a combination of field surveys, microbiological analysis, and stakeholder interviews, it has revealed significant gaps in food safety knowledge, poor hygienic processing practices, and widespread microbial contamination across a variety of local food products. These conditions not only pose public health risks but also hinder the economic viability and market expansion of small-scale agri-food enterprises.

Despite these challenges, the study found that improved food hygiene practices, such as proper handwashing, use of potable water, and adoption of protective clothing, were positively associated with increased income, wider market access, and reduced consumer complaints. This underscores the critical role of microbial food safety not only as a health imperative but also as a strategic tool for business development and value creation in rural food systems.

The findings further confirm that most small-scale processors, particularly women, operate with limited education and lack formal training in microbiological risk management. Yet, their willingness to adopt safer practices if properly trained and supported highlights the untapped potential to transform these microenterprises into scalable, profitable, and safe food ventures. By integrating food safety education into rural agribusiness development and strengthening support structures, there is a compelling opportunity to foster inclusive growth, enhance public health outcomes, and build resilient local food economies.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed:

i. **Institutionalize Food Safety Training for Rural Agri-Food Processors**

   Government agencies, NGOs, and agricultural extension services should embed practical food microbiology and hygiene training into all agribusiness support programs. Modules should include Good Hygienic Practices (GHP), basic microbial risk identification, and low-cost mitigation techniques suitable for small-scale settings.

ii. **Facilitate Access to Clean Water and Sanitary Infrastructure**
Policy efforts should prioritize investments in rural water sanitation and hygiene (WASH) facilities, especially near food processing hubs. Community-based water purification systems, low-cost boreholes, and hygienic processing sheds will directly reduce microbial contamination risks.

iii. **Promote Food Safety Certification for Microenterprises**
A simplified, locally adapted food safety certification scheme should be introduced to encourage compliance and enable access to urban and formal markets. Certification can act as both a marketing tool and a mechanism to raise product quality standards.

iv. **Strengthen Cooperative Models for Knowledge and Resource Sharing**
Support the formation and capacity-building of food processing cooperatives, particularly among women. These groups can facilitate pooled resources for training, joint product branding, and collective access to microcredit and inputs necessary for hygienic operations.

v. **Mainstream Food Safety into National Agricultural and MSME Policies**
Policymakers should revise national agriculture and entrepreneurship development frameworks to explicitly recognize food safety as a core component. Funding schemes (e.g., Anchor Borrowers Programme, BOA loans) should include conditional food hygiene assessments and incentives for best practices.

vi. **Support Community-Based Microbiological Surveillance and Research**
Universities and research institutes should be funded to conduct regular microbial risk assessments of locally processed food and collaborate with communities to implement early-warning and rapid-response systems to foodborne disease outbreaks.

Therefore, achieving food security and economic empowerment in Nigeria's rural communities requires more than increasing productivity; it requires producing **safe, marketable, and trusted food**. This study provides evidence that food safety, when linked with entrepreneurial development, holds transformative potential for public health, livelihoods, and sustainable development in the agri-food sector.

Declarations

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Conflicts of Interest

The authors declare that there are no known financial, professional, or personal conflicts of interest that could have influenced the outcome or interpretation of this research.

Ethical Approval

Ethical clearance for this study was obtained from the Benue State Polytechnic Research Ethics Committee. All procedures performed in this study were in accordance with ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

Informed Consent

Written informed consent was obtained from all individual participants included in the study. Participants were assured of anonymity, voluntary participation, and the right to withdraw at any stage without penalty.

Author Contributions

Lead Author: Conceptualization, methodology, field data collection, microbiological analysis coordination, and manuscript drafting.

Co-Author(s): Supervision, literature review support, data analysis, and critical revision of the manuscript.
All authors read and approved the final version of the manuscript.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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