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THE IMPACT OF MODERN TECHNOLOGICAL INNOVATIONS ON FOOD SECURITY IN NIGERIA: A CUTTING-EDGE TECHNOLOGY FROM AN AGROPRENEURSHIP PERSPECTIVE

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ABSTRACT

This study empirically examines how modern technological innovations affect food security in Nigerian technology-based farming organizations. The goal of this study is to ascertain the nature of connections between modern technological innovation and food security. It's also aimed at identifying modern technological innovations that guarantee food security and determining their effectiveness and profitability for the food security business. This study used a cross-sectional survey research design to examine a few technology-based and digital-farming organizations in Delta State that were reachable by the study population. From the managers who were the study objects, 60 of the remaining managerial personnel were reported. To assess the data from the respondents, Spearman's rank-order correlation coefficient was used. The findings demonstrated a strong positive connection between food security and modern technological innovations. The study identified the modern technological innovations that guarantees food security such as nanotechnology in agriculture, Artificial Intelligence (AI) in Quality Control, Robotics in Food Processing, The Blockchain Technology and Supply chain management, The Use of Drones in Agriculture, Internet of Things (IoT) in Food Safety, Climate-Resilient Crops, Automated Harvesting using Robot and Post-Harvest Technologies, digital farming, responsible innovation, Vertical Farming, Precision Agriculture, micro-innovation. This study concludes that all the identified modern technological innovations are effective and profitable for the food security business. The study recommends that farmers adopt modern technological innovations to ensure food security and, to a greater extent, sustain the economy.

Keywords: Food security, AI in quality control, Blockchain technology, Vertical farming, Technological Innovation, Responsible Innovation, Digital farming, Poly-innovation, Robotics in Food Processing.

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1. INTRODUCTION

Food insecurity has gotten worse over the past decade, and hunger rates are at their highest level since 1970 (European Commission, 2020). According to the FAO 2020 report, about one in seven people do not now have access to enough food, even though food production has increased significantly over the past 50 years. The Food and Agriculture Organization of the United Nations (OECD/FAO, 2021), estimates that 1.02 billion people worldwide suffered from undernourishment in 2009, a rise of more than 37% in just 20 years. Despite significant improvements in food security in many of these countries, 98% of them are in developing countries, and their share of the world's hungry has been increasing recently (Imide et al., 2025).

According to an FAO study from 2025, 673 million people (8.2% of the world's population) were hungry in 2024; nonetheless, this is a drop from prior years rather than a situation where more than one in seven people do not have enough food. Over 3.1 billion individuals were unable to buy a nutritious meal, and 2.33 billion people experienced moderate to severe food insecurity, according to FAO (2024) statistics. About 3.7 billion people, or more than half of the world's population, suffer from starvation, while environmental degradation is responsible for

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more than 40% of deaths globally, according to other studies (Ericksen, 2008). It has been demonstrated that the global economic crisis and high local food costs are the main reasons of the growth in global food insecurity (European Commission, 2019). Even worse, joblessness makes it harder for those in need to get food when prices rise and wages fall. A pattern of rising hunger and food insecurity existed even before the current food and financial crises, raising concerns about the efficacy of agricultural policies and poverty-reduction efforts implemented over the past 40 years (United Nations Millennium Development Goals, 2010). The resilience of agrifood systems, or food security, is a hot topic in policy and research (Fadillah et al., 2024). Academics link the adaptability of agrifood systems to a number of difficult issues, including food loss (Ashkenazy et al., 2018), nutritional security (BajŽelj et al., 2020), public health emergencies (European Commission, 2020) and rural poverty (Lal, 2003).

Policy documents usually stress the importance of building resilience in agrifood systems to attain food security. The year 2020 emphasized the need to create more resilient farming systems that should be reproduced in many regions after the COVID-19 pandemic. Before the pandemic, the European Commission (2018) had pushed for a targeted shared agricultural strategy to promote resilient farming methods. Because of climate shocks, including destructive floods, ongoing conflicts, unstable economies, and high food costs, over 33 million Nigerians may experience acute food insecurity by 2027.

According to FAO (2024) forecast, the situation is dire; it is estimated that nearly three times as many people will experience emergency levels of food insecurity, especially in the North-East and North-West regions in Nigeria. About 33.1 million people are on malnutrition and food insecurity (FAO, 2024), and they will experience severe food insecurity during the upcoming lean season, which runs from June to August. The Nigerian government leads Cadre Harmonisé, which has partners. Due to economic hardship, record-high inflation, the consequences of climate change, and persistent conflict in Nigeria's northeastern states, the population has increased by an astounding seven million people over the same period last year. Even during the busiest harvest season, 25.1 million people are projected to face severe food insecurity between October and December of 2024. The northeastern states are home to 3.8 million of them. This figure is anticipated to increase to five million (Iyamah & Chukwuka, 2024).

One million people nationally experienced Emergency-level (Phase 4) food insecurity during the height of the 2024 lean season; by 2025, that figure is predicted to have risen by a startling 80% to 1.8 million. 800,000 pregnant and lactating women and 5.4 million children in six of the worst afflicted states—Borno, Adamawa, and Yobe in the northeast, and Sokoto, Katsina, and Zamfara in the northwest—are at risk of acute malnutrition or wasting. A startling 1.8 million of these children may be at danger for Severe Acute Malnutrition (SAM) and need urgent nutritional support.

The notion of enhancing social resilience and concentrating on agroecosystem resilience is endorsed by other organizations (OECD/FAO, 2021). Resilience is the ability of a system to withstand, adapt, and reorganize itself in the face of disruptive occurrences (Walker et al., 2004). When a system has this kind of knowledge, it can function consistently and stay true to itself even when its surroundings change and produce disturbances. The two types of resilience that are usually discussed in the literature are "engineering" and "ecological" resilience (Lal, 2003).

The first assumes that equilibrium is present and discusses a system's capacity to return to a steady state following external shocks or perturbations. Resilience in this sense refers to how a system interacts with both the external environment and its component parts. According to Mendelsohn (2009), resilience is a relational notion that subtly emphasizes how crucial a healthy relationship is between a system, its surrounding our adoption of the ecological perspective on resilience in this article is consistent with the notion that a system can achieve a different equilibrium even in the event of structural changes without losing the ability to perform its essential functions, the existence of multiple equilibria, and dynamic interactions among system components (Pimentel et al., 1995) and any revolutionary changes made to ensure the system's continued existence. The word "future" is useful in this context (Fytsilis et al., 2024). As per Godfray et al. (2010), resilience is a characteristic that enables any system to tackle a sustainable future by improving its capacity to handle continuous change and to resist, recover, and adapt as necessary (European Commission, 2020). The structure and characteristics of agrifood systems must be taken into account to understand the concept of resilience.

According to Ashkenazy et al. (2018), agrifood systems are defined by the human-nature couplings that arise in these intricate configurations, which also give them the characteristics of social-ecological systems. Agrifood systems consist of both social and physical components. Natural resources and ecological elements are included in the first group, whilst all social entities engaged in the production, processing, distribution, and consumption of agrifoods are included in the second. Since innovations open up new possibilities, Chukwuka & Imide (2025b) contend that they are essential to a business's existence, prosperity, and economic growth. Generating fresh ideas is one of the primary drivers of innovation, promoting corporate reinvention.

Sometimes, innovation is confused with simple ideas. The majority of businesses have formalized procedures for generating ideas, but they don't fully capitalize on the opportunity to pool the expertise of intelligent individuals (Chukwuka & Imide, 2025b). The majority of businesses find it difficult to develop new customer offers or go-to-market products, or to turn concepts into value propositions and introduce them. Furthermore, being innovative

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does not always entail coming up with the biggest concept imaginable. A tactical "tinkering" strategy may involve an ongoing process of problem detection and operational and delivery level repair (Chukwuka & Nwomiko, 2018; Chukwuka et al., 2026).

It all comes down to our ability to keep an eye on, comprehend, and react to the behaviors of our clients and other stakeholders, as well as their needs, both explicit and implicit. Using existing technologies to produce data analytics and prototypes in order to gain insights is one approach to accomplish this. In this instance, though, technology is only as good as the information it offers (Lemmens, 2015). More significantly, if we want to improve experiences for both internal and external consumers, we need to have a culture of constant experimentation and development based on the insights we obtain. Innovation efforts should, for the most part, be intentional, methodical, and integrated into the company's core procedures and organizational culture to maintain competitiveness and promote ongoing renewal (World Commission on Environment and Development, 1987; Imide & Chukwuka, 2025).

1.1. Problem Statement and Justification for this Study

Over 33 million Nigerians could experience severe food insecurity by 2025 due to climate shocks such as catastrophic floods, protracted conflicts, unstable economies, and high food prices, according to a UN FAO (2024) assessment. The situation is dire; it is estimated that nearly three times as many people will experience emergency-level food insecurity, especially in the North-East and North-West regions. These problems can be resolved by implementing climate-resilient agriculture and enhancing the transformation of the food system through modern technological advancements. Because humans cannot survive without food, despite their ability to tolerate poor governance and other problems, this study is required to reduce food insecurity in Nigeria. World Food Program (WFP, 2025) predicts that 33.1 million Nigerians will experience food insecurity by 2027 as a result of the country's economic difficulties, the climatic crisis, and unrest in the northeast. According to a recent study, 33 million Nigerians are expected to experience acute food insecurity by 2025, and the number of those in critical need is expected to nearly triple. 33.1% of the population would experience severe food insecurity during the upcoming lean season (June–August), according to Cadre Harmonize, a food insecurity and malnutrition analysis conducted by the Nigerian government in collaboration with partners. Due to economic hardship, record-high inflation, the consequences of climate change, and persistent conflict in Nigeria's northeastern states, the population has increased by an astounding seven million people over the same period last year. Even during the busiest harvest season, 25.1 million people are projected to face severe food insecurity between October and December of 2024. The northeastern states are home to 3.8 million of them. This figure is anticipated to increase to five million. It is projected that the number of people experiencing hardship in the nation will rise by an alarming 80%, from 1 million during the peak of the 2024 lean season to 1.8 million during the same period in 2025. 800,000 pregnant and lactating women and 5.4 million children in six of the worst afflicted states—Borno, Adamawa, and Yobe in the northeast, and Sokoto, Katsina, and Zamfara in the northwest—are at risk of acute malnutrition or wasting. A startling 1.8 million of these children may be at danger for Severe Acute Malnutrition (SAM) and need urgent nutritional support.

This study's objectives are based on solving Nigeria's food crisis, hunger, and food insecurity issues. To determine and identify the cutting-edge technology advancement that ensures food security. The Objective is also to ascertain the applicability, profitability and validity of the identified modern technological innovations in food security. The specific aim of the study is to determine the exact nature of connection between food security and the use of contemporary technology innovation and advancements.

1.2. Theoretical Framework

A comprehensive theoretical framework for contemporary innovations in food security integrates models of economic growth, like the Endogenous Growth Theory, with theories unique to agriculture, like the Innovation Diffusion Theory, within the four acknowledged pillars of food security (availability, access, utilization, and stability). This framework illustrates how farmers' adoption of technological advancements—from precision agriculture to artificial intelligence in supply chains—is influenced by knowledge and investment, with the ultimate goal of increasing food production, improving distribution efficiency, enhancing nutritional value, and fostering resilience against shocks.

1.2.1. Frameworks for Economic Growth: **Endogenous Growth Theory (EGT):** This strategy emphasizes that, even in the agricultural sector, internal factors like knowledge, creativity, and people capital are what propel long-term success. Investments in agricultural research and development (R&D) are seen to be significant sources of innovation that increase productivity and hence promote food security. Paul Romer and Robert Lucas made major contributions to the development of Endogenous Growth Theory (EGT) in the mid-1980s, despite the fact that key early notions were present in the 1960s. Romer's groundbreaking 1986 paper, "Increasing Returns and Long-Run

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Growth," laid the groundwork by introducing concepts of knowledge and human capital with growing returns, setting it apart from previous neoclassical growth models.

1.2.2. Frameworks Particular to Innovation: Everett Rogers created the Innovation Diffusion Theory (IDT): A framework that explains the slow integration of new technology into a social structure. It provides a lens through which to examine how farmers and other stakeholders embrace agricultural innovations in order to successfully incorporate them into food systems. The Innovation Diffusion Theory (IDT) was first presented in Everett Rogers' seminal book Diffusion of Innovations, which was released in 1962. This theory, which is central to communication studies, explains how new ideas and technologies progressively seep into a social structure.

2. MATERIALS AND METHODS

2.1. Experimental Site

This cross-sectional study was in the technologically driven farms in Delta State, Nigeria. In order to study some digital and modern technologically based farms and farming organizations in Nigeria, this study used a cross-sectional survey research design. These farms and organizations will be accessible as the population of study

2.2. Parameters Studied

The study units include the managerial employees of agropreneurship and digital and technologically operated farms, as our unit of analysis is organizational, and these employees will serve as a proxy for the organization. Within the agropreneurship organization, the data on functional departments was supplied by the human resources department. A total of 250 managerial personnel were reported by the managers who served as the study's subjects. 60 respondents from the questionnaire returned from the 100 questionnaires shared to the study areas utilizing the Spearman's Rank order coefficient of correlation statistical tool, the questionnaire will be used to examine the data from the respondents.

2.3. Data Analysis

Descriptive statistics (frequency distribution, tables, percentages, and averages) were utilized to study the data that was gathered, and the questionnaire was used to analyze the data from the respondents using the Spearman's Rank order coefficient of correlation statistical tool.

2.4. Analysis from Questionnaire

2.4.1. Analysis of Research Data: Research Question 1: What are the modern Technological Innovations that are effective in Food Security in your agropreneurship firm?

From Table 1: Responses for identifying the Modern Technological Innovations used in food Security by technology-based farms in Asaba, Delta State, 45 (75%) of the respondents strongly agreed that Artificial Intelligence (AI) in Quality Control is one of the modern technological innovations used in food security in their technology-based farms.Also, question 2 showed that 83% (50) of respondents strongly agreed that Nanotechnological Application in food security and in agriculture is one of the modern technological innovations used for food security in their technology-based farms in Asaba, Delta State. While the third question revealed that 78% (47) of respondents believe that Digital Farming Technology, Vertical Farming, Precision Agriculture, Responsible Technology, Micro-Innovation, and Poly-Innovation in Food Security are all modern technological innovations in food security in their technology-based farms in Asaba, Delta State. 83% (50) of respondents strongly agreed that Robotics in Food Processing, The Blockchain Technology and Supply chain management, The Use of Drones in Agriculture, Internet of Things (IoT) in Food Safety, Climate-Resilient Crops, Automated Harvesting using Robot and Post-Harvest Technologies are all modern technological innovations in food security their technology based farms in Asaba and Nigeria.

Research Question 2: What is the Effectiveness and Profitability of these Identified Modern Technological Innovations in Food Security

From Table 2 it is clear that the Effectiveness and the Profitability of Applications of the identified Modern Technological Innovations in Food Security. 83% (50) strongly agreed from question 5, that Artificial Intelligence (AI) in Quality Control is highly effective and profitable in food security business in Asaba and in Nigeria. 70% (42) strongly agreed that Nanotechnological Application in food security and agriculture is highly effective and leads to profitability in food security business in Asaba and in Nigeria.75% (45) strongly agreed that Digital Farming Technology, Vertical Farming, Precision Agriculture, Responsible Technological, Micro-Innovation, Poly-Innovation in Food Security, is highly effective, and it is profitable in the food security business. 83% (50) strongly agreed that Robotics in Food Processing, The Blockchain Technology and Supply chain management, The Use of

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Drones in Agriculture, Internet of Things (IoT) in Food Safety, Climate-Resilient Crops, Automated Harvesting using Robot and Post-Harvest Technologies are all highly effective and profitable in food security business.

Table 1: Responses for identifying the Modern Technological Innovations used in food Security

S/NO	Statement	SA 5	A 4	D 3	SD 2	U 1
1	Artificial Intelligence (AI) in Quality Control is one of the modern technological innovations used in food security in your technology based farms.	45	10	2	2	1
2	Nanotechnological Application in food security and agriculture is one of the modern technological innovations used for food security in your technology based farms.	50	4	2	2	2
3	Digital Farming Technology, VerticalFarming, PrecisionAgriculture, ResponsibleTechnological, Micro-Innovation Innovation, Poly-Innovation in Food Security are all modern technological innovations in food security in your technology based farms	47	3	4	3	3
4	Robotics in Food Processing, The Blockchain Technology and Supply chain management, The Use of Drones in Agriculture, Internet of Things (IoT) in Food Safety, Climate-Resilient Crops, Automated Harvesting using Robot and Post-Harvest Technologies are all modern technological innovations in food security	50	5	2	1	2

Source: Analysis of Field Survey, 2026; Likert Scale meaning above: *SA=Strongly Agree. A=Agree. D=Disagree. SD: Strongly Disagree. U=Undecided.*

Table 2: The Effectiveness and the Profitability of Applications of the identified Modern Technological Innovations in Food Security

S/No	Statement	Scale				
		SA 5	A 4	D 3	SD 2	U 1
5	Is Artificial Intelligence (AI) in Quality Control effective and profitable in food security business?	50	5	2	3	-
6	Nanotechnological Application in food security and agriculture is highly effective and leads to profitability in food security business	42	6	-	10	2
7	Digital Farming Technology, Vertical Farming, Precision Agriculture, Responsible Technological, Micro-Innovation, and Poly-Innovation in Food Security are highly effective and they are profitable in food security business	45	10	3	-	2
8	Robotics in Food Processing, The Blockchain Technology and Supply Chain Management, The Use of Drones in Agriculture, Internet of Things (IoT) in Food Safety, Climate-Resilient Crops, Automated Harvesting using Robots and Post-Harvest Technologies are all highly effective and profitable in the food security business.	50	3	5	2	-

Source: Analysis of Field Survey, 2026; Likert Scale meaning above: *SA=Strongly Agree. A=Agree. D=Disagree. SD: Strongly Disagree. U=Undecided.*

3. RESULTS

Using data from sixty (60) study objects, Table 3 presents Spearman's rank order correlation run to ascertain the nature of the relationship between food security and modern technological innovations, as well as the opportunities created by agropreneurs and technologically based farming organizations in Nigeria, in an emerging economy. A statistically significant, strong positive correlation coefficient (rho = .883**, P<0.001) across variables indicates a substantial relationship between food security and the criterion variable. Furthermore, there were noteworthy connection values (rho =.769**, P<0.001) between the use of the identified modern or cutting edge technologies such as nanotechnology in agriculture, Artificial Intelligence (AI) in Quality Control, Robotics in Food Processing, The Blockchain Technology and Supply chain management, the Use of Drones in Agriculture, Internet of Things (IoT) in Food Safety, Climate-Resilient Crops, Automated Harvesting using Robot and Post-Harvest Technologies, digital farming, responsible innovation, Vertical Farming, Precision Agriculture, micro-innovation and food security in technology-based farming organizations in Nigeria (Table 4).

Table 3: Spearman's rho correlation coefficient: A test of association between the variables

			Food Security	Modern Technological Innovations	Cutting-Edge Technological Innovations on Food Security
Spearman's rho	Food Security	Correlation Coefficient	1.000	.790**	.883**
		Sig. (2-tailed)	.	.000	.000
		N	60	60	60
	Modern Technological Innovations	Correlation Coefficient	.613**	1.000	.769**
		Sig. (2-tailed)	.000	.	.000
		N	60	60	60
	Cutting-Edge Technological Innovations on Food Security	Correlation Coefficient	.883**	.769**	1.000
		Sig. (2-tailed)	.000	.000	.
		N	60	60	60

**.At the 0.05 level, the correlation is significant (2-tailed); SPSS output, Version 20 – Field Survey, 2026.

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Decision: We declare that there is a substantial relationship or connection between the elements of food security and the modern technological innovations of technology-based farms in Nigeria, and that the null hypotheses provided are rejected.

Table 4: Sets of Technologies, Related Avenues for Innovation, Connections to the Resilience of Agrifood Systems and Food Security and Unresolved Issues

	Technologies	Innovation route	Favorable effects on agrifood systems' resilience and food security	Open Issues
1	Megatrends in technology, such as nanotechnologies and digital farming	Responsible technological innovation	- Recognizing threats or hazards - Adjusting innovation paths as necessary - Cooperative innovation governance	Challenges in: - Implementing responsible innovation concepts in real-world situations, - Deciding who ought to be involved inside or not included in the procedure of conscientious innovation governance, - Expecting the effects of technologies that are impartial
2	Technologies for internetworking that link participants and make Transactions	Poly-innovation	- A focus on resilience - Encouragement of social behaviors that strengthen resilience	- Possibility of inequality propagating - Disruptions to agrifood systems' niches
3	easier Small-scale Jugaad technologies that are frequently created using bricolage	Micro-innovation	- Establishing robust subsystems inside the larger agrifood system	- Little to no funding for pertinent initiatives - Insufficient institutional and technical assistance

Technological Innovation and Agrifood Systems Resilience: The Potential and Perils of Three Different Strategies.

4. DISCUSSION

The findings demonstrated a strong positive correlation between food security and contemporary technological advancements, such as nanotechnology in agriculture, digital farming, responsible innovation, and micro-innovation. This is consistent with Eastham & Leman (2024). This empirical result demonstrates that mega-technological innovations such as digital farming and nanotechnology help ensure food security. Responsible technical innovation has also developed to preserve food security. This finding is in agreement with Bukchin-Peles (2024). It is a hopeful development since it can avoid the paradoxical effects of technology on resilience, despite the fact that responsible technological innovation is far from simple and that there are gaps between theoretical goals and innovative praxis. Modern technological advancements that have been shown to ensure food security and environmental sustainability are included in this study, such as technological innovation, poly-innovation, micro-innovation, nanotechnology, and digital farming. This paper outlines the connections between these innovation paths and the resilience of agrifood systems.

This study also discovered eleven (11) other modern technological innovations that can guarantee food security globally. These include: Precision Agriculture, Artificial Intelligence (AI) in Quality Control, Vertical farming, Robotics in Food Processing, the use of drones in agriculture, the Blockchain Technology and Supply chain management, automated harvesting, Internet of Things (IoT) in Food Safety, post-harvest technologies, Climate-Resilient Crops, and environmental Sensors.

4.1. Concept of Food Security and Modern Technological Innovations

According to the European Commission (2020), food security is defined as "all people have physical and economic access to sufficient food to meet their dietary needs and food preferences for a productive and healthy life". According to Ashkenazy et al. (2018), food security comprises access to a sufficient diet, a clean environment, drinking water, medical care, and appropriate food preparation. According to the European Commission 2020, food security is the ability of households and individuals to purchase adequate food of sufficient nutritional quality, whether imported or produced domestically, and to have access to enough food in sufficient amounts. By their very nature, the three dimensions are hierarchical. To ensure that hungry households have access to enough food, availability is a necessary but insufficient need (Ye et al., 2022).

Food may be produced in sufficient quantities, but individuals may not be able to afford it for social and cultural reasons, as well as because of distribution, cost, and income level.

Just having access to food does not ensure optimal consumption; it also requires the safe and proper preparation of food and the nutritional value of meals eaten at home. The fourth element of food security, stability, is defined by FAO (1996) as the result of cyclical occurrences, such as seasonal food shortages or quick shocks, like economic or climatic disasters.

The two primary factors influencing food security in most developing countries are the continuous provision of ecosystem services and the sustainable use of natural resources.

Ecosystem functions have a direct and indirect impact on all aspects of food security by supplying ecosystem services that boost agricultural output, create opportunities for income generation, and supply energy for cooking; therefore, preserving these functions is crucial to ensuring global food security (Pimentel et al., 1995). Ecosystem services have an impact on the three pillars of food security: the development of resources for safe and hygienic

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food preparation (i.e., consumption), the production of food (i.e., availability), and the provision of resources for enhancing lives and generating income. Conversely, low-income and food-insecure households have been associated with unhealthful coping mechanisms that cause environmental disturbances (Lal, 2003). Population growth and economic expansion are the main factors threatening global food security because of their increased dependence on the planet's finite resources. As competition for these resources increases, the already challenging targets of ending hunger and extreme poverty will become considerably more challenging (Georgescu-Roegen, 1971). To reaffirm the highest political level commitment to the 2015 eradication of hunger, food insecurity, and malnutrition, the FAO held the Food Summit in 1996, which coincided with the World Cup.

In 2000, the United Nations formed a worldwide partnership with the time-bound goal of accomplishing eight distinct objectives, such as guaranteeing environmental sustainability and ending hunger and poverty by 2027. These objectives have been called the Millennium Development Goals by the European Commission (2019). Unfortunately, 1990 was selected as the baseline year for these goals because, by most measures, food insecurity has increased since then (Ashkenazy et al., 2019). Given the global increase in greenhouse gas emissions and deforestation since the targets were established, it appears doubtful that these goals will be fully met in the upcoming five years. The notion that generating biofuels from grain harvests boosts competitiveness is also supported by data.

Furthermore, studies show that the production of biofuels from grain crops exacerbates the global hunger issue by increasing competition for land, water, and energy—all of which are necessary for food production (European Commission, 2020). Concerns regarding the effects of population growth and economic expansion on global food security are raised by the grave threat posed by climate change and the predicted harm it will cause to every aspect of food production and distribution (Godfray et al., 2010; Chukwuka & Dibie, 2024b)

4.2. Technological Innovations in Food Security

Since the advent of highly innovative and often radical technologies and the recent focus on sustainable transformations of agrifood systems through technological escalation, scholars and policymakers have added the topic of responsibility in the technological innovation process to their agendas. Even though some new perspectives, like the needs, values, and the effects of technology on society, must be taken into account, technological innovations like genome editing, 3D food printing, sensors, Internet of Things platforms, autonomous robots and vehicles, big data, drones, and other technology-mediated tools like food biofortification technologies could support the resilience of agrifood systems (Arnaldi et al., 2015; Mirsalami & Mirsalami, 2024a).

One of the main reasons for concern is the inability to predict how high-tech innovation would affect agrifood systems in the long run. Expectations and reality can sometimes diverge significantly. Additionally, there can be unintended or negative long-term effects. An example of how the introduction of improved BT cotton varieties increased cotton production in the United States and had some positive effects on system resilience is provided by Antonova (2015). But it also brought forth ecological hazards and new power dynamics that threatened the system's long-term viability (Jareonsin et al., 2024).

According to additional data, while new technologies have been demonstrated to boost output, they may also have a negative impact on the environment, leading to water pollution and biodiversity loss (Asveld et al., 2019) or deteriorating the quality of natural resources (Burget et al., 2017). According to Ashkenazy et al. (2018), technological developments at the farm level may enhance farmers' immediate financial results, but they do not ensure the long-term sustainability of their enterprises. Investments in technical advancement must lead to debt that is challenging to repay, especially for small-scale farmers (Bronson, 2019).

Technological dependence (Bhadur & Talat, 2020), power concentration among key supply chain participants and technology providers (Bolz & deBruin, 2019), divisions and inequalities within agrifood systems (Arthur, 2009), disruptions of established norms regarding production, collaboration, or competition (Asveld et al., 2019), and established conditions of producing, competing, or collaborating (Bronson, 2019) are just a few of the socio-ethical issues that novel technologies may cause. It has long been known that some participants in agrifood systems may find the change to a new status quo abrupt or painful, even when benefits outweigh drawbacks (Brozen, 1951).Because of the ambiguity surrounding new technologies' revolutionary potential (Arthur, 2009) and potentially dangerous nature (Espig et al., 2021), appropriate techniques for promoting them are necessary.

4.2.1. Nanotechnological Application in Food Security and Agriculture: Nanotechnology is the study, development, and application of systems, technologies, and structures through the manipulation of atoms and molecules at the nanoscale, or with one or more dimensions of the order of 100 nanometers (100 millionth of a millimeter) smaller, according to Eastwood et al. (2019). It has only recently become possible to actively use nanoscale structures, despite the fact that they are ubiquitous in nature and have long been employed inadvertently in a variety of technologies. Consumer goods have been impacted by food nanotechnology in a number of areas, including food preservation, packaging, and additives. Since the recognition of this novel approach, food processing and storage have been enhanced to ensure food safety (Mirsalami & Mirsalami, 2024b). It has also been shown that

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some common substances used in packaging or as food additives exist partially at the nanoscale. For example, it has recently been shown that up to 40% of TiO2 NPs suitable for food usage are nanoscale in size (Koirala & Anal, 2021).

The one-way results of scientific research help government agencies create laws and regulations and food manufacturers develop their products (Fig. 1). Unfortunately, there are now very few laws and regulations governing product marketing and proper waste disposal worldwide. Because the public mostly learns from government organizations (rules and regulations) and manufacturers (products and marketing), scientists and manufacturers typically ignore public awareness and acceptability. Customers will ultimately decide if food nanotechnology is actually present on the dishes (Xiaojia et al., 2022; Fig. 2).

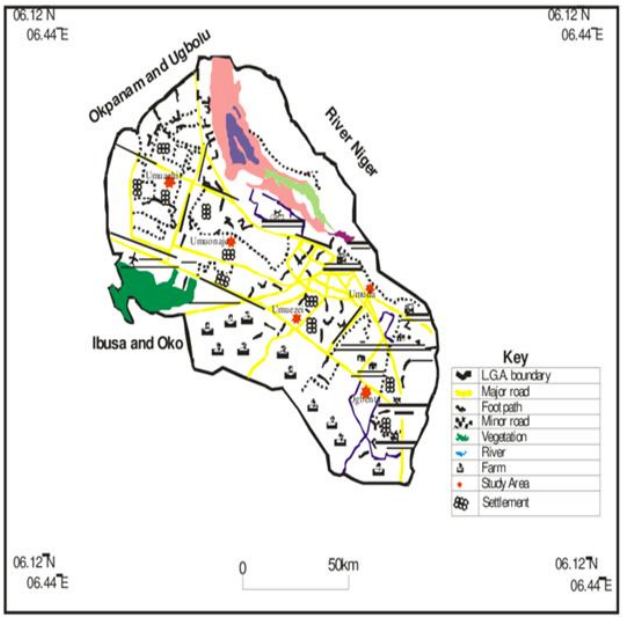

Fig. 1: Map of the Study Area in Asaba, Delta State, Nigeria.

Nanotechnology has the ability to decrease the use of pesticides by developing novel agrochemical agents and innovative delivery systems to increase agricultural productivity. Among the applications of nanotechnology are:
(1) Crop protection through the use of nano-sensors to detect diseases and agrochemical residues
(2) Crop improvement through the use of nano-formulations of agrochemicals
(3) Plant genetic engineering using nanodevices
(4) The diagnosis of plant diseases
(5) The production of poultry, animal breeding, and animal health
(6) Postharvest management. The application of nanotechnology may lead to higher agricultural production. It is possible to increase agricultural output without endangering the land or water by using precision farming techniques. Additionally, it can lessen soil microbes and nitrogen loss through emissions and leaching (Xiaojia et al., 2022; Mhlanga & Ndhlovu, 2023).

Food processing and storage, extending product shelf life, and transferring genes or DNA into plants via nanoparticles to produce insect-resistant cultivars are a few uses for nanotechnology. Nanotechnology has the potential to speed up biomass-to-fuel production (Lv et al., 2021; Mariano, 2024). There is currently research, testing, and sometimes even use of nanotechnology in food technology; experts recommend weighing the potential benefits of nanotechnology for food, agriculture, fisheries, and aquaculture against concerns about the environment, soil, water, and worker occupational health; (7) and (8) It is believed that nanomaterials have unique physical, chemical, and mechanical characteristics (Hanlon & Sewalt, 2021). Agricultural waste products have recently attracted attention as a renewable raw material source that may be processed to replace a variety of purposes and used as non-material.

4.2.2. Digital Farming Technology: To boost agricultural productivity, digital farming makes use of digital technologies like sensors, drones, GPS mapping, and machine learning. By adopting digital farming to collect and analyze data on soil quality, crop health, weather patterns, and other aspects in real-time, farmers can make better decisions regarding planting, irrigation, fertilization, and pest and disease control (Buitenhuis et al., 2020). By using agricultural inputs more effectively, farmers can increase crop yield and quality while saving time and money. Changes could result from agriculture's digitization (Eastwood et al., 2022). In order to feed the world's growing population in a sustainable and resource-efficient manner, farmers can produce better and larger yields by making the most of the quantity of arable land that is now available. Digitalization in agriculture has enormous potential because it may reach a large number of farmers, especially those in less developed countries. Digital farming offers crucial support to conserve limited natural resources, promote sustainability, and reduce environmental impacts on global food production by enhancing understanding of on-farm sustainability, helping to adapt farming practices to the unique agronomic conditions of different countries and enabling a more precise application of crop protection products (Buitenhuis et al., 2020).

4.2.3. Responsible Technological Innovation in Food Security and Agrifood Resilience: Scholars and decision-

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makers have been forced to address the issue of accountability in the process of technological innovation due to the introduction of extremely creative and even radical innovations as well as the recent focus on the sustainable changes that technological advancements can bring about in agrifood systems and food security. Since technologically enabled innovations like genome technology for food biofortification, 3D printing, or editing seem perceptive and capable of promoting the sustainable intensification of production with a strong potential for resilience of agrifood systems, some new perspectives, such as the needs, values, and effects of technology on society, must be taken into consideration (Antonova, 2015). These include sensors, robotics, drones, big data, autonomous cars, and digital tools like Internet of Things platforms. Scholars and decision-makers have been inspired to integrate the accountability problem into technological innovation methods by the emergence of highly innovative and often radical technologies, as well as the recent emphasis on the sustainable transformation of agrifood systems through technological advancement. Numerous other elements, such as the needs, values, and the necessity of considering the impact of technology on society, appear instructive and able to promote the sustainable intensification of generating a lot of opportunities for resilient agrifood systems (Battaglino et al., 2020).

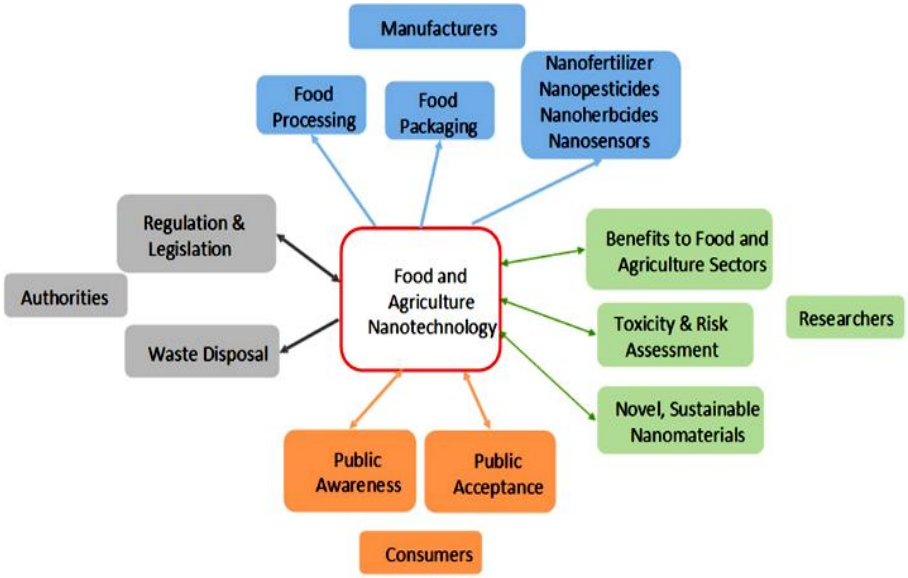

Fig. 2: From a commercial product to a customer's plate, this depicts the scientific investigation of food nanotechnology (Xiaojia et al., 2022).

The inability to forecast the long-term effects of high-tech innovation on agrifood systems is one of the primary causes for concern. Expectations and reality might not align at all. However, unexpected or adverse long-term consequences can occasionally occur. The European Training Foundation and European Bank (2021) give an example of how the introduction of superior forms of Bt cotton increased cotton agricultural output in the United States with some positive effects on system robustness. But this also led to new power dynamics inside the system and environmental risks, which threatened the system's long-term viability. According to additional data, while innovative technologies may help boost production, they may also exacerbate environmental deterioration and the resulting biodiversity loss (Bocker & Silva, 2022; Ugbah et al., 2025; Moemeka & Chukwuka, 2026).

Modernizing agricultural technology can assist farmers in improving their short-term financial outcomes, but it cannot guarantee the long-term viability of their businesses, as Ashkenazy et al. (2018) and Chukwuka (2025) make evident. Technological advancements require financial investments that small-scale farmers in particular may find difficult to repay (Bronson 2019). Technological dependence (Edwards-Schachter, 2018), power concentration among technology providers and significant supply chain participants (Espig et al., 2021), divisions and inequality within agrifood systems (Lemmens, 2015), disruptions of established norms regarding production, collaboration, or competition (Burget et al., 2017), and established conditions of producing, competing, or collaborating (Arthur, 2009) are some additional socio-ethical issues that novel technologies may bring with them.

It is commonly known that the shift to a new status quo for agrifood systems can be difficult or even traumatic for some participants, even when the benefits of technical advancements outweigh any potential drawbacks (Lemmens, 2015). The promotion of new technologies necessitates appropriate measures due to their risky nature, as there is a significant deal of uncertainty around their revolutionary potential (Arthur, 2009; Buitenhuis et al., 2020; Sadeghzadeh et al., 2024). Realizing that technological advancement involves some social hazards led to the emergence of a new paradigm that emphasizes accountability in the innovation process (Holling, 2001).

Following previous attempts to highlight ethical principles and provide guidelines for innovating within and for society (Edwards-Schachter, 2018; Igweh et al., 2025), responsible innovation (Rosenzweig & Hillel, 1998;

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Bronson, 2019) or responsible research and innovation (Burget et al., 2017) opened up a new and lively scientific debate with the aim of countervailing economic with socio-cultural and environmental aspects in innovation processes (Uche & Chukwuka, 2025). In order to ascertain what players may do with new technologies and for what purpose, Responsible Research and Innovation (RRI) seeks to address concerns about the potential advantages of new technologies as well as the normative consequences of technological innovation, including what it should achieve and for whom.

Emphasizing the necessity of accepting accountability for the outcomes of an innovation path selected after carefully weighing the different values that underpin the creation and use of new technologies is one of the fundamental tenets of the RRI philosophy (Bronson, 2019). Before using such a method, a thorough examination of the anticipation, reflexivity, inclusion, and responsiveness of the ARIR sequence is necessary (Chukwuka & Igweh, 2025b). As defined by Espig et al. (2021) and Nazzaro et al. (2024), RRI "is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society) (Chukwuka & Igweh, 2025a).

4.2.4. Micro-Innovation in Food Security and Agrifood resilience: Bolz & deBruin (2019) define micro-innovating as "informal changes," or incremental, modest enhancements created by user groups instead of by outsiders and subsequently disseminated through official channels. Asveld et al. (2019) and Igweh & Chukwuka (2025a) posit that the production methods directly lead to these kinds of innovative results. While the technique is being used, actors and/or organizations observe its efficacy and determine that certain modifications are needed. Either developing new technology or modifying existing ones can do this. It's interesting to note that even when individuals are happy with how technology is working to better meet their ever changing wants, they still change. As an alternative, they develop their own technologies, either separately or together (Bhadur & Talat, 2020). This kind of "micro-innovation" is mostly independent since players can independently generate creative ideas through repeated trial and error processes. It manifests as an attempt to address issues and shortcomings (Bahadur & Doczi, 2019). The prevalent paradigm in technical innovation studies, which stresses the development of novel solutions to issues that many performers encounter, is influenced by the diffusion of innovations hypothesis. The core concept states that social groups, or sectors, are composed of individuals who deal with comparable issues, have similar characteristics, and share concerns. Farmers who grow the same crop in a certain location are an illustration of this.

The vast majority of technical advancements at the farm level are made to cater to the requirements or issues of a nearly nonexistent demographic: the typical farmer. Tractors, irrigation systems, and insecticides are a few examples of historical technologies whose primary goal was to help farmers increase the efficiency of their produce. These technologies were successful in this endeavor. However, in addition to offering distinct opportunities for innovation, different locations also provide unique difficulties and worries (Espig et al., 2021). Despite their structural distinctions, farms can range greatly in terms of soil fertility, microclimate, water availability, and quality even within the same location (Okoduwa et al., 2026).

As a result, whereas some farmers may gain more from technology than others, others may not see the anticipated impact. Furthermore, technologies might not be appropriate for the current technical infrastructure, the symbolic representations of certain agricultural types (Lemmens 2015), or the "local way of doing things" (Ashkenazy et al., 2018). To bridge the gap between their needs and the technology that is now available, farmers have always modified technological advancements to suit their particular operating conditions. For example, Arthur (2009) talks about how Australian farmers might have modified grain harvesters to make them more compatible with other pieces of machinery. In 2021, the European Training Foundation and the European Bank briefly launch a modified drum seeder made by Indian farmers.

4.2.5. Poly-Innovation in Food Security and Agrifood Resilience: This study uses the term "poly-innovation," which refers to a blend of the aforementioned forms of production. In order to boost a company's worth and the value to society, it explains the use of creative concepts that leverage modern technology to assist creative organizational and/or marketing elements. One of the first to argue that a new paradigm in innovation was required (Dubé et al., 2012). With a primary focus on the welfare of underserved or socially marginalized populations that are ignored by mainstream innovation methodologies, this paradigm would blend elements of organizational, social, and technological innovation. They believe that advances in technology, organizations, and society may combine to produce "convergent outcomes for precisely targeted, achieved." In order to help achieve social and economic objectives, this strategy—dubbed "convergent innovation" by Dubé et al. (2012)—involves multiple sectors in the innovation process without depending on centralized planning and control systems. In the process of creating socially acceptable technical advances, RRI frameworks often focus heavily on marketing technology innovations. Accordingly, the "techno-fication" of production is prioritized over other

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creative avenues (Arnaldi et al., 2015). Due to this, RRI has struggled to fully incorporate social innovation into its agenda, even though policymakers have recently placed greater emphasis on it, particularly in the European Union (Dubé et al., 2012).

Additionally, through a range of strategies and business models, firms have attempted in the past to link organizational and social innovation with economic and technological innovation. For instance, the Nigerian start-up Hello Tractor (https://hellotractor.com/) created a digital network that links small-scale farmers and tractor owners to exchange agricultural equipment. The requirement or encouragement of organizational changes (Eastwood et al. 2019; Chukwuka & Igweh, 2026) and the function of some technologies as mediators in organizational innovations (Edwards-Schachter, 2018) are two examples of the obvious connections between organizational and technical innovation. As a result, the relevant discourse also ignores the organizational dimension of innovation.

4.3. Cutting-Edge Technological Innovations on Food Security

In order to increase productivity and lessen their negative effects on the environment, this study discovered recent cutting-edge technological advancements in food production have focused on AI-driven automation, sustainable farming practices, and alternative proteins. Global issues like population increase and climate change are addressed by these developments.Innovative technical developments are causing a dramatic change in the way we produce, prepare, and distribute food. These developments are guaranteeing better and safer products for consumers in addition to increasing the sustainability and efficiency of food production. Here are eleven (11) discovery of how modern technology innovations are having a big impact on food security are as follows:

4.3.1. Precision Agriculture: This method employs sensors, GPS, and data analytics to precisely monitor and manage crops. Farmers may maximize yields, minimize waste, and lessen their impact on the environment by carefully adjusting irrigation, fertilizer application, and insect management. An excellent illustration of this is the Australian business by name 'Precision Ag'. By using sensors, drones, and artificial intelligence (AI) to track crop health and soil conditions, precision agriculture enables farmers to make accurate decisions about fertilization, irrigation, and pest control, increasing yields while using fewer resources.

4.3.2. Artificial Intelligence (AI) in Quality Control for food security: AI-powered systems can anticipate crop yields, oversee farm operations, keep an eye on animals, and improve inventory control and food demand forecasts to cut waste and boost supply chain effectiveness. AI reduces faults by up to 80% and increases equipment effectiveness by 45% in food processing through predictive maintenance, quality control, and real-time changes. Collaborative robotics reduces injuries while increasing production by 35–50% when used in conjunction with humans. Product releases are shortened by 45% thanks to digital twins that optimize production lines.AI-powered tools can quickly analyze data and photos to find flaws, impurities, and other problems with food goods' quality. This guarantees that consumers only receive the best produce. One business that uses AI in its grading system is Clarifruit (Chukwuka & Dibie, 2024a).

4.3.3. Vertical Farming: Usually indoors, vertical farms grow crops in layers that are piled vertically. Regardless of climate, this creative approach maximizes space, saves water, and enables year-round output. Vertical farms are transforming the industry's approach to crop growing; OnePointOne is just one example of companies doing vertical farming.

4.3.4. Robotics in Food Processing: Additionally, processing facilities are using robots to automate operations like packaging, grading, and sorting. This lowers the possibility of contamination, boosts efficiency, and enhances consistency. A great example of an Apple grading machine that runs on a packhouse line is Tomra.

4.3.5. The Blockchain Technology and Supply chain management: Builds customer trust and improves traceability by offering a clear and safe way to track food items from farm to table. Blockchain record all transactions, from farm to fork, in an unchangeable and transparent manner. Consumer confidence in the food supply is increased, fraud is decreased, and traceability is improved. IBM Food Trust is one use case for blockchain in food supply chain management.

4.3.6. The Use of Drones in Agriculture: Drones are being utilized for pesticide and fertilizer applications, field surveys, and crop health monitoring. This airborne viewpoint offers insightful information that can optimize operations and assist farmers in making well-informed decisions. One business that makes use of drone spraying technology is Rantizo.

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4.3.7. Internet of Things (IoT) in Food Safety: The supply chain's temperature, humidity, and other elements that impact food quality can be monitored using IoT sensors. Food safety and spoiling prevention are ensured by proactive action made possible by this real-time data. One example of how IoT is being used in food safety is through food management software such as FoodReady.

4.3.8. Climate-Resilient Crops: In direct reaction to environmental challenges, climate-resilient crops are being developed that can tolerate harsh weather events and shifting climatic circumstances.

4.3.9. Automated Harvesting*:* Robots with cameras and sensors are harvesting crops fast and accurately. This allows for harvesting at the optimal ripeness, reduces crop damage, and saves labor costs.An example of this is the robots used by farms to harvest strawberries.

4.3.10. Post-Harvest Technologies*:* During processing and storage, advancements like cold plasma technology and ozone treatment aid to preserve food, minimize spoiling, and get rid of harmful bacteria.

4.3.11. Environmental Sensors*:* The several stages involved in managing and storing fresh produce products as they travel from suppliers to retailers necessitate ideal storage conditions. You may increase shelf life, minimize losses, and guarantee the best possible quality and freshness of product when it arrives at retail shelves by carefully managing the climate in storage facilities.A fine example of an environmental sensor is Atmos.

5. CONCLUSION

The findings of this study demonstrated a strong positive connection between food security and modern technological innovations. The study identified the modern technological innovations that guarantees food security such as nanotechnology in agriculture, Artificial Intelligence (AI) in Quality Control, Robotics in Food Processing, The Blockchain Technology and Supply chain management, The Use of Drones in Agriculture, Internet of Things (IoT) in Food Safety, Climate-Resilient Crops, Automated Harvesting using Robot and Post-Harvest Technologies, digital farming, responsible innovation, Vertical Farming**,** Precision Agriculture, micro-innovation. This study concludes with the confirmation that all the identified modern technological innovations in this study are proven to be effective and profitable to the food security business. Based on the empirical findings, this study recommends that farmers or agropreneurs should adopt modern technological innovations that guarantee food security and, to a larger extent, sustain the environment.

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Ethics Statement: Since no live animals or humans were used in the investigation, ethical approval was not necessary.

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Generative AI Statements: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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