Bioresources Development Conference (BDC26)
NABDA
Journal of Biotechnology Research
ISSN: 1119-0531
Special Issue Vol. 5(3): (2026)

Characterization Of Regional/Agroecological Bioresources For Food Security

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Article ID: NJBR-BDC26-B002 | Received:6 May, 2026 | Accepted: 18 August, 2026

ABSTRACT

Food security remains a critical global challenge, particularly in regions facing climate variability, population growth, and resource constraints. The characterization of regional and agroecological bioresources offers a strategic pathway to enhancing sustainable food systems. This study explores the characterization of regional/agroecological bioresources for food security and functional potential of bioresources such as indigenous crops, livestock breeds, and soil microorganisms. By integrating ecological, genetic, and socio-economic data, the research identifies underutilized and resilient species that can contribute to improved nutrition, productivity, and environmental sustainability. Agroecological characterization enables a deeper understanding of how local conditions including soil type, rainfall patterns, and traditional farming practices influence the performance and adaptability of bioresources. This approach supports the development of location-specific interventions, reducing reliance on external inputs while promoting biodiversity conservation. Furthermore, documenting indigenous knowledge systems enhances the sustainable management and utilization of these resources. The findings highlight the importance of diversifying food sources to mitigate risks associated with climate change and market instability. Enhanced characterization also facilitates breeding programs, value chain development, and policy formulation aimed at strengthening local food systems. Ultimately, leveraging regional bioresources through systematic characterization contributes to resilient agricultural practices, improved livelihoods, and long-term food security.

Key words: Agroecology, Food Security, Bioresource, Sustainability, Utilization, Global Challenges.

INTRODUCTION

Food security remains one of the most pressing global development challenges of the 21st century, particularly in developing countries where agricultural systems are highly vulnerable to environmental and socio-economic shocks. The Food and Agriculture Organization defines food security as a condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs for an active and healthy life (FAO, 2021). Despite global efforts, food insecurity continues to rise, driven by factors such as rapid population growth, climate change, land degradation, and inefficient agricultural practices (FAO, 2021; World Bank, 2022).

In Nigeria, the situation is particularly concerning. Nigeria's population, estimated to exceed 200 million, places enormous pressure on available food systems and natural resources. Agricultural production, which is largely rain-fed, is increasingly affected by erratic rainfall patterns, flooding, desertification, and declining soil fertility (Ojo *et al.*, 2020). These challenges are further compounded by overdependence on a narrow range of staple crops such as rice, maize, and cassava, which reduces dietary diversity and increases vulnerability to crop failure (Nnamani *et al.*, 2018).

Paradoxically, Nigeria is endowed with vast agroecological diversity that supports a wide range of biological resources. The country is characterized by multiple agroecological zones—including mangrove forests, freshwater swamps, tropical rainforests, derived savannah, Guinea savannah, Sudan savannah, and Sahel regions each harbouring unique bioresources adapted to specific environmental conditions (Iloeje, 2001; FMARD, 2016). These bioresources include indigenous crops, local livestock breeds, and diverse soil microorganisms that possess inherent resilience to

local stresses such as drought, pests, and poor soil conditions.

Agroecological bioresources refer to the biological components of agricultural ecosystems that interact with ecological processes to sustain productivity and environmental balance. These resources are shaped by natural factors such as climate, soil type, and biodiversity, as well as human factors including traditional farming practices and indigenous knowledge systems (Altieri, 1995; Gliessman, 2015). The concept of agroecology emphasizes the integration of ecological principles into agricultural production systems, promoting sustainability, resilience, and resource efficiency.

Characterization of agroecological bioresources involves the systematic identification, documentation, and evaluation of their genetic, phenotypic, ecological, and functional attributes. This process provides critical information on the adaptability, productivity, and utilization potential of these resources under varying environmental conditions (FAO, 2012). It also enables the identification of underutilized and resilient species that can contribute significantly to food security, especially in the face of climate variability and resource constraints. One of the major limitations of modern agricultural systems is the neglect of indigenous and underutilized species. These species, often referred to as neglected and underutilized species (NUS), have historically played important roles in local diets and livelihoods but have received limited attention from research, policy, and market systems (Padulosi *et al*., 2013). Many of these bioresources are rich in essential nutrients, tolerant to harsh environmental conditions, and require minimal external inputs, making them highly suitable for sustainable agriculture (Oloyede *et al*., 2015).

Furthermore, indigenous knowledge systems are integral to the effective management and utilization of agroecological bioresources. Local farmers possess extensive knowledge of crop varieties, soil management practices, and ecological interactions, which have been developed over generations through observation and experience (Berkes, 2012). However, this knowledge is increasingly threatened by modernization, urbanization, and the erosion of cultural practices. The importance of characterizing regional and agroecological bioresources extends beyond agricultural productivity. It plays a crucial role in biodiversity conservation, climate change adaptation, and sustainable development. By understanding the interactions between bioresources and their environments, it becomes possible to design location-specific interventions that enhance productivity while minimizing environmental degradation (Tittonell, 2014). Moreover, the diversification of food systems through the inclusion of a wider range of bioresources can reduce dependence on a limited number of crops and improve resilience against market and climatic shocks. This approach aligns with global efforts to promote sustainable agriculture and achieve the Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 13 (Climate Action) (United Nations, 2015).

Despite the recognized importance of agroecological bioresources, there remains a significant gap in their characterization and utilization in Nigeria. Limited research, inadequate policy support, and poor market integration have hindered the development and adoption of these resources. As a result, many valuable species remain underexploited, while others face the risk of extinction. Therefore, this study seeks to address these gaps by focusing on the characterization of regional and agroecological bioresources for food security. Specifically, the study aims to:

- Identify and categorize key agroecological bioresources in Nigeria
- Examine their ecological and functional characteristics
- Assess their contributions to food security and sustainability
- Analyze challenges associated with their utilization
- Propose strategies for their sustainable management and integration into food systems

By providing a comprehensive understanding of agroecological bioresources, this research contributes to the development of resilient and sustainable food systems capable of addressing current and future food security challenges.

MATERIALS AND METHODS

This study adopts a systematic literature review approach to examine the characterization of

regional and agroecological bioresources for food security. A systematic review method is appropriate for synthesizing existing knowledge, identifying research gaps, and providing a comprehensive understanding of the subject matter through the integration of findings from multiple scholarly sources (Snyder, 2019).

The research is qualitative in nature and is based on the analysis of secondary data obtained from a wide range of academic and institutional sources. The qualitative approach enables an in-depth exploration of the ecological, genetic, and socio-economic dimensions of agroecological bioresources, as well as their implications for food security (Creswell, 2014).

Sources of Data

Data for this study were collected from credible and authoritative sources, including:

- Peer-reviewed journal articles
- Books and academic publications
- Reports from international organizations such as the Food and Agriculture Organization and the World Bank
- National policy documents and agricultural reports from Nigeria
- Conference proceedings and research theses

These sources were selected to ensure a balanced representation of global perspectives and region-specific insights, particularly within the Nigerian context.

Data Analysis

The collected data were analyzed using a thematic content analysis approach. This involved:

- Categorizing information into themes such as bioresource types, agroecological factors, and food security contributions
- Identifying patterns and relationships among variables
- Synthesizing findings to develop a coherent narrative

The thematic approach allows for the systematic interpretation of complex information and facilitates the identification of key insights relevant to the study objectives (Braun & Clarke, 2006).

Scope and Limitations of the Study

The study focuses primarily on the characterization of agroecological bioresources within Nigeria, while drawing comparative insights from other regions where necessary. It emphasizes plant, animal, and microbial resources relevant to food systems.

However, the study is limited by:

- Dependence on secondary data, which may not capture recent field-level developments
- Variability in data quality across sources
- Limited availability of documented information on certain underutilized bioresources

Despite these limitations, the systematic approach adopted ensures that the findings are reliable and provide valuable insights into the role of agroecological bioresources in enhancing food security.

Conceptual Framework

The concept of agroecological bioresources is rooted in the interdisciplinary field of **agroecology**, which integrates ecological science with agricultural practices to promote sustainable and resilient food systems. Agroecology emphasizes the interactions between plants, animals, humans, and the environment within agricultural systems, aiming to optimize these relationships for long-term productivity and environmental sustainability (Altieri, 1995; Gliessman, 2015).

At the core of this study is the linkage between agroecological bioresources and food security, which can be understood through three interconnected dimensions:

- **Ecological Dimension**
  This dimension focuses on how environmental factors such as climate, soil properties, water availability, and biodiversity influence the distribution, adaptation, and productivity of bioresources. Agroecological systems rely on natural processes such as nutrient cycling,

biological pest control, and symbiotic relationships to sustain agricultural productivity (Tittonell, 2014).

- Genetic and Biological Dimension
  This involves the inherent characteristics of bioresources, including their genetic diversity, physiological traits, and adaptive capacities. Genetic diversity is critical for resilience, as it enables species to withstand environmental stresses such as drought, pests, and diseases (FAO, 2010). The characterization of these traits is essential for identifying species with high potential for food security.
- Socio-economic Dimension
  Agroecological bioresources are deeply embedded in local socio-economic systems. Factors such as traditional knowledge, cultural practices, market access, and policy frameworks influence how these resources are utilized and managed (Berkes, 2012). Smallholder farmers, who dominate agricultural production in Nigeria, rely heavily on indigenous bioresources for their livelihoods.

Definition and Scope of Agroecological Bioresources

Agroecological bioresources refer to living biological components within agricultural ecosystems that contribute directly or indirectly to food production and environmental sustainability. These include:

- Plant species (crops, trees, wild edibles)
- Animal species (livestock, poultry, fish)
- Microorganisms (bacteria, fungi, algae)

These resources are distinguished by their **adaptation to specific agroecological zones** and their ability to function within natural ecological processes. Unlike conventional agricultural inputs, agroecological bioresources often require minimal external inputs and are better suited to local environmental conditions (Gliessman, 2015). The scope of agroecological bioresources extends beyond food production to include:

- Soil fertility enhancement
- Climate regulation
- Biodiversity conservation
- Livelihood support

Characteristics of Agroecological Bioresources

Agroecological bioresources possess distinct characteristics that make them valuable for sustainable food systems. These include:

- Ecological Adaptability: These bioresources are naturally adapted to local environmental conditions such as rainfall variability, soil types, and temperature fluctuations. This adaptability enhances their survival and productivity under changing climatic conditions (Altieri & Nicholls, 2017).
- Genetic Diversity: Agroecological systems are rich in genetic diversity, which provides a buffer against environmental stresses. Diverse genetic traits enable crops and livestock to resist pests, diseases, and extreme weather conditions (FAO, 2010).
- Low Input Requirements: Many indigenous bioresources require minimal use of synthetic fertilizers, pesticides, and irrigation. This makes them cost-effective and environmentally sustainable, particularly for resource-poor farmers.
- Nutritional Value: Several underutilized bioresources are rich in essential nutrients, including vitamins, minerals, and proteins. Their inclusion in diets can help address malnutrition and improve public health outcomes (Nnamani *et al.*, 2018).
- Cultural and Traditional Relevance: These resources are often deeply rooted in local cultures and traditions. Indigenous knowledge systems guide their cultivation, harvesting, and utilization, contributing to their sustainability (Berkes, 2012).
- Environmental Sustainability: Agroecological bioresources support ecological processes such as nutrient cycling, soil formation, and biodiversity conservation. They play a crucial role in maintaining ecosystem balance and reducing environmental degradation (Tittonell, 2014).

Importance of Characterization

Characterization is a critical step in unlocking the full potential of agroecological bioresources. It involves:

- Identifying species and their traits
- Understanding ecological interactions
- Evaluating productivity and resilience
- Documenting traditional knowledge

Through characterization, it becomes possible to:

- Select suitable species for specific environments
- Improve agricultural productivity
- Support breeding and conservation programs
- Enhance sustainable utilization

The Food and Agriculture Organization emphasizes that proper characterization of genetic resources is essential for ensuring their conservation and effective use in agriculture (FAO, 2012).

Agroecological Factors Influencing Bioresource Performance

The performance, adaptability, and productivity of agroecological bioresources are largely determined by the complex interaction between biological traits and environmental conditions. These interactions occur within specific agroecological zones and are influenced by both natural and anthropogenic factors. Understanding these factors is essential for effective characterization, as it enables the identification of bioresources best suited for particular environments and production systems (Gliessman, 2015; Tittonell, 2014). Agroecological factors can be broadly categorized into climatic, edaphic (soil-related), topographical, and management-related factors, each playing a critical role in shaping bioresource dynamics.

Classification of Agroecological Bioresources

Agroecological bioresources can be broadly classified into three major categories: plant, animal, and microbial bioresources. Each category contributes uniquely to food security and ecosystem sustainability.

Plant Bioresources

Plant bioresources form the backbone of food systems and are the primary source of human nutrition. They can be further categorized into:

a. Indigenous Food Crops

These include locally adapted crops such as:

- Millet (*Pennisetum glaucum*)
- Sorghum (*Sorghum bicolor*)
- Bambara groundnut (*Vigna subterranea*)

These crops are characterized by:

- High drought tolerance
- Low input requirements
- Nutritional richness

They are particularly important in semi-arid regions where conventional crops may fail (Padulosi *et al.*, 2013).

b. Tree Crops and Agroforestry Species

Examples include:

- Oil palm (*Elaeis guineensis*)
- African locust bean (*Parkia biglobosa*)
- African pear (*Dacryodes edulis*)

These species provide multiple benefits, including food, income, and environmental services such as carbon sequestration and soil conservation.

c. Wild and Underutilized Edible Plants

These include species that are not widely cultivated but are important for local diets, such as:

- *Dialium guineense*
- *Detarium microcarpum*

ISSN: 1119-0531
Special Issue Vol. 5(3): (2026)

These plants contribute to dietary diversity and serve as food sources during periods of scarcity (Oloyede *et al.*, 2015).

Animal Bioresources

Animal bioresources provide essential nutrients such as protein and play significant roles in livelihoods and cultural practices.

a. Indigenous Livestock Breeds

Examples include:

- White Fulani cattle
- West African Dwarf goats
- Local sheep breeds

These animals are characterized by:

- Adaptation to harsh environmental conditions
- Resistance to local diseases
- Ability to thrive on low-quality feed

Such traits make them highly valuable in low-input farming systems (FAO, 2015).

b. Poultry and Small Animals

Local poultry species and small animals such as rabbits and guinea fowl are widely reared in rural communities due to their:

- Low maintenance requirements
- Rapid reproduction rates
- Contribution to household nutrition

c. Aquatic Bioresources

Fish species such as catfish and tilapia are important components of agroecological systems, particularly in wetland and riverine areas. They contribute significantly to protein supply and income generation.

Microbial Bioresources

Microbial bioresources are often overlooked but are critical for ecosystem functioning and agricultural productivity.

a. Soil Microorganisms

These include:

- Nitrogen-fixing bacteria (e.g., *Rhizobium*)
- Mycorrhizal fungi

They enhance soil fertility by improving nutrient availability and uptake (Smith & Read, 2008).

b. Decomposers

Microorganisms involved in decomposition break down organic matter, releasing nutrients back into the soil and maintaining nutrient cycles.

c. Biocontrol Agents

Certain microbes act as natural pest control agents, reducing the need for chemical pesticides and promoting sustainable agriculture.

Functional Roles of Agroecological Bioresources in Food Systems

The classification of bioresources is closely linked to their functional roles, which include:

- **Food Provision:** Supplying essential nutrients for human consumption
- **Soil Fertility Enhancement:** Through nitrogen fixation and organic matter decomposition
- **Climate Regulation:** Carbon sequestration and resilience to climate stress
- **Economic Support:** Income generation and livelihood sustainability

The Food and Agriculture Organization emphasizes that diversified bioresources are critical for building resilient and sustainable food systems (FAO, 2018).

Implications of Characterization for Food Security

Effective characterization and classification enable:

- Identification of resilient and high-performing species
- Development of targeted agricultural interventions

- Conservation of genetic resources
- Enhancement of food system diversity and stability

In the context of Nigeria, leveraging characterized bioresources can significantly improve food availability, accessibility, and utilization, thereby strengthening national food security.

Importance of Agroecological Bioresources for Food Security

The role of agroecological bioresources in enhancing food security is increasingly recognized in both academic discourse and global development policy. Food security encompasses not only the availability of food but also access, utilization, and stability over time. Agroecological bioresources contribute to all these dimensions by promoting sustainable production systems, enhancing resilience, and supporting diversified diets (FAO, 2018; HLPE, 2017). In regions such as Nigeria, where agricultural systems are predominantly smallholder-based and highly dependent on natural resources, the effective utilization of agroecological bioresources is essential for achieving long-term food security.

Enhancement of Food Availability: Agroecological bioresources increase food availability by supporting diverse and resilient production systems. Indigenous crops, livestock, and microorganisms adapted to local conditions tend to perform better under environmental stress, thereby ensuring more stable yields compared to highly specialized, input-dependent systems (Altieri & Nicholls, 2017).

Improvement of Nutritional Security: Beyond quantity, agroecological bioresources play a vital role in improving the nutritional quality of diets. Many underutilized and indigenous species are rich in essential micronutrients, including vitamins, minerals, and amino acids, which are often lacking in diets dominated by a few staple crops (Nnamani *et al.*, 2018).

Climate Change Resilience and Adaptation: One of the most significant contributions of agroecological bioresources is their role in enhancing resilience to climate change. Climate variability manifested through droughts, floods, and temperature extremes poses a major threat to food production systems globally. Agroecological bioresources, particularly indigenous species, possess adaptive traits such as:

- Drought tolerance
- Pest and disease resistance
- Ability to thrive in marginal soils

These traits enable farming systems to withstand environmental shocks and maintain productivity under adverse conditions (Tittonell, 2014). By reducing dependence on climate-sensitive monocultures, agroecological systems enhance the stability of food supply over time.

Economic Empowerment and Livelihood Support: Agroecological bioresources contribute to food security by supporting **rural livelihoods and income generation**. Smallholder farmers rely on a variety of biological resources for subsistence and commercial purposes. The cultivation, processing, and marketing of indigenous crops and livestock create economic opportunities and reduce poverty levels. The World Bank notes that agricultural diversification is a key driver of economic growth and poverty reduction in developing countries (World Bank, 2020).

Biodiversity Conservation and Ecosystem Stability: Agroecological bioresources play a central role in maintaining **biodiversity**, which is essential for ecosystem stability and long-term agricultural sustainability. Diverse ecosystems are more resilient to disturbances and provide critical services such as pollination, soil fertility maintenance, and pest control (Gliessman, 2015).

Reduction of External Input Dependency: Agroecological systems that utilize local bioresources tend to rely less on external inputs such as synthetic fertilizers, pesticides, and irrigation. This reduces production costs and minimizes environmental impacts, making agriculture more sustainable and accessible to resource-poor farmers (Altieri, 1995).

Strengthening Food System Stability: Food system stability refers to the ability of a system to maintain consistent food supply despite shocks and stresses. Agroecological bioresources

contribute to this stability by promoting diversification and risk reduction.

Integration of Indigenous Knowledge Systems: The effective utilization of agroecological bioresources is closely linked to indigenous knowledge systems, which provide valuable insights into resource management, crop selection, and adaptation strategies. These knowledge systems have evolved over generations and are tailored to local environmental conditions (Berkes, 2012).

Policy and Development Implications: The importance of agroecological bioresources extends to policy and development planning. Governments and development agencies are increasingly recognizing the need to support agroecological approaches as part of sustainable food system transformation.

The Food and Agriculture Organization advocates for the integration of agroecology into national agricultural strategies as a pathway to achieving sustainable development goals (FAO, 2018).

Challenges to the Characterization and Utilization of Agroecological Bioresources

Despite the recognized importance of agroecological bioresources in enhancing food security, their effective characterization and utilization remain significantly constrained by a combination of scientific, institutional, socio-economic, and environmental challenges. These constraints are interrelated and often reinforce one another, thereby limiting the integration of these resources into mainstream agricultural systems, particularly in developing countries such as Nigeria.

Inadequate Scientific Characterization and Data Deficiency

One of the most critical barriers is the limited scientific characterization of many agroecological bioresources, especially underutilized and indigenous species. Comprehensive data on genetic diversity, physiological traits, ecological adaptability, and nutritional composition are often lacking or fragmented (Padulosi *et al.*, 2013).

Erosion of Genetic Diversity and Biodiversity Loss

Agroecological bioresources are increasingly threatened by **genetic erosion**, driven by the expansion of monoculture systems and the dominance of a few high-yielding crop varieties. This trend reduces the diversity of genetic resources available for adaptation and resilience (FAO, 2010). In many parts of Nigeria, traditional crop varieties and indigenous livestock breeds are being replaced by improved or exotic species that are often less adapted to local conditions. This shift not only undermines ecological resilience but also leads to the loss of valuable traits such as drought tolerance, pest resistance, and nutritional richness. The long-term implication is a narrowing of the genetic base of food systems, which increases vulnerability to environmental shocks and reduces the capacity for future agricultural innovation.

Weak Institutional and Policy Frameworks

The absence of coherent and well-implemented policies significantly hampers the development and utilization of agroecological bioresources. In many developing countries, agricultural policies tend to prioritize high-input, industrial farming systems over agroecological approaches (HLPE, 2017).
Key institutional challenges include:

- Limited funding for agroecological research
- Weak coordination among research institutions
- Inadequate extension services to disseminate knowledge to farmers
- Lack of national databases on bioresources

Although initiatives exist, their impact is often constrained by poor implementation and insufficient political will. The World Bank has noted that policy neglect of smallholder-centered and biodiversity-based agriculture limits sustainable agricultural transformation (World Bank, 2020).

Loss of Indigenous Knowledge Systems

Indigenous knowledge systems are essential for the identification, management, and utilization of agroecological bioresources. However, these knowledge systems are increasingly being lost due to urbanization, modernization, and generational shifts (Berkes, 2012).
Younger generations are less engaged in traditional farming practices, leading to:

ISSN: 1119-0531
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- Decline in knowledge of local species and their uses
- Reduced capacity for sustainable resource management
- Disconnection between cultural practices and agricultural systems

This erosion of knowledge undermines the holistic understanding required for effective agroecological characterization and limits the integration of traditional and scientific approaches.

Market Constraints and Low Commercialization

Another major challenge is the **limited market development for agroecological bioresources**, particularly underutilized species. These resources often lack:

- Standardized production systems
- Processing technologies
- Market visibility and consumer awareness

As a result, farmers have little economic incentive to cultivate or conserve them. The dominance of global value chains centered around a few staple crops further marginalizes local bioresources (Padulosi *et al*., 2013).

Limited Access to Technology and Research Infrastructure

The effective characterization of bioresources requires advanced tools and technologies, including molecular techniques, geographic information systems (GIS), and data management platforms. However, access to such technologies is often limited in developing regions.

Research institutions in Nigeria frequently face:

- Inadequate laboratory facilities
- Insufficient funding for field studies
- Limited collaboration with international research networks

This technological gap restricts the ability to conduct comprehensive characterization and hinders innovation in agroecological systems.

Environmental Degradation and Climate Change

Environmental degradation manifested through deforestation, soil erosion, pollution, and habitat loss poses a significant threat to agroecological bioresources. These processes reduce the availability and productivity of biological resources and disrupt ecological interactions.

Climate change further exacerbates these challenges by altering:

- Rainfall patterns
- Temperature regimes
- Species distribution

While agroecological bioresources are generally more resilient, extreme and unpredictable climate conditions can still exceed their adaptive capacity (Lobell et al., 2011). This creates uncertainty in their performance and complicates efforts at characterization and utilization.

Socio-economic Constraints and Farmer-Level Limitations

At the farm level, several socio-economic factors limit the adoption and utilization of agroecological bioresources:

- Limited access to credit and financial resources
- Small landholdings and land tenure insecurity
- Labor constraints
- Risk aversion among farmers

Farmers often prioritize short-term productivity over long-term sustainability, especially under conditions of poverty and food insecurity. Without adequate support, the transition to agroecological systems may be perceived as risky or unprofitable.

Strategies for Sustainable Characterization and Utilization of Agroecological Bioresources

Addressing the multifaceted challenges associated with the characterization and utilization of agroecological bioresources requires a coordinated, multi-level, and interdisciplinary approach. Sustainable strategies must integrate scientific innovation, policy reform, institutional strengthening, and community participation to unlock the full potential of these resources for food security. The following strategic directions are proposed based on current scholarly and policy frameworks.

1. **Strengthening Research and Comprehensive Characterization Systems**

A fundamental priority is the expansion of systematic and integrated research efforts aimed at the comprehensive characterization of agroecological bioresources. This includes:

- Morphological, genetic, and physiological profiling
- Nutritional and functional evaluation
- Ecological adaptability assessments

Investment in modern tools such as molecular markers, genomic sequencing, and geographic information systems (GIS) will enhance the accuracy and scalability of characterization processes. Establishing national and regional databases for bioresources will facilitate data sharing, improve accessibility, and support evidence-based decision-making.

The Food and Agriculture Organization emphasizes the importance of strengthening national capacities for the characterization and documentation of plant and animal genetic resources as a foundation for sustainable agriculture (FAO, 2012).

2. **Development of Enabling Policy and Institutional Frameworks**

Effective policy support is essential for mainstreaming agroecological bioresources into national food systems. Governments should develop and implement comprehensive agroecological policies that:

- Recognize the value of indigenous and underutilized species
- Provide funding for research and conservation programs
- Promote sustainable land-use practices
- Integrate agroecology into national agricultural development plans

Institutional coordination among ministries, research institutes, and extension services must also be strengthened to ensure policy coherence and effective implementation. In Nigeria, aligning agricultural policies with sustainability goals will be critical for long-term food security.

3. **Conservation and Sustainable Management of Genetic Resources**

The sustainability of agroecological bioresources depends on the **conservation of genetic diversity** through both in-situ and ex-situ approaches.

- **In-situ conservation:** Protection of natural habitats and on-farm conservation of indigenous species
- **Ex-situ conservation:** Establishment of seed banks, gene banks, and botanical gardens

These strategies ensure the preservation of valuable genetic traits for future use in breeding and adaptation programs. Community-based conservation initiatives can further enhance local participation and ownership.

Integration of Indigenous Knowledge Systems with Scientific Research

Sustainable utilization requires the integration of indigenous knowledge systems with modern scientific approaches. Local farmers possess valuable knowledge on species selection, cultivation practices, and ecological interactions that can complement scientific findings (Berkes, 2012).

Strategies should include:

- Documentation of traditional knowledge
- Participatory research involving local communities
- Co-creation of knowledge between scientists and farmers

This integration enhances the relevance, acceptance, and effectiveness of agroecological interventions.

4. **Capacity Building and Extension Services**

Human capacity development is critical for the adoption and effective utilization of agroecological bioresources. This involves:

- Training farmers on sustainable agricultural practices
- Strengthening agricultural extension systems
- Building technical expertise in research institutions

Extension services should be reoriented to promote agroecological principles, including biodiversity management, soil health improvement, and climate-resilient farming practices. The World Bank highlights the role of knowledge dissemination and capacity building in driving agricultural transformation (World Bank, 2020).

ISSN: 1119-0531
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5. Development of Inclusive and Sustainable Value Chains

Enhancing the economic viability of agroecological bioresources requires the development of robust value chains. This includes:

- Processing and value addition technologies
- Improved storage and transportation infrastructure
- Market access and commercialization strategies

Promoting local and international markets for underutilized species will create economic incentives for farmers to cultivate and conserve these resources. Certification schemes and branding of indigenous products can further enhance market competitiveness.

6. Promotion of Agroecological Farming Practices

The adoption of agroecological practices is essential for optimizing the use of bioresources. These practices include:

- Crop diversification and intercropping
- Agroforestry systems
- Organic soil fertility management
- Biological pest control

Such practices enhance ecosystem services, reduce dependence on external inputs, and improve resilience to environmental stress (Altieri & Nicholls, 2017).

7. Leveraging Technology and Innovation

Technological innovation plays a key role in advancing the characterization and utilization of bioresources. This includes:

- Use of digital tools for data collection and analysis
- Remote sensing and climate modeling
- Biotechnology for crop improvement

Integrating technology with traditional practices can significantly improve productivity and sustainability while maintaining ecological balance.

8. Strengthening Multi-Stakeholder Collaboration

Sustainable management of agroecological bioresources requires collaboration among multiple stakeholders, including:

- Government agencies
- Research institutions
- Non-governmental organizations
- Farmers and local communities
- Private sector actors

Public-private partnerships can facilitate investment, innovation, and market development, while community participation ensures inclusivity and sustainability.

9. Mainstreaming Agroecology into Development Agendas

Finally, agroecological bioresources should be integrated into broader development frameworks, including national and global agendas. This aligns with the Sustainable Development Goals (SDGs), particularly those related to food security, climate action, and biodiversity conservation. The Food and Agriculture Organization advocates for scaling up agroecology as a transformative pathway toward sustainable food systems (FAO, 2018). Incorporating agroecological principles into development planning will ensure long-term sustainability and resilience.

DISCUSSION

This study has examined the characterization of regional and agroecological bioresources as a strategic pathway to enhancing food security, with particular emphasis on their ecological, genetic, and socio-economic dimensions. The findings underscore a central paradox: while agroecological bioresources possess immense potential to support resilient and sustainable food systems, they remain significantly under-characterized, underutilized, and inadequately integrated into mainstream agricultural development frameworks.

A key insight emerging from this study is that agroecological diversity represents an untapped asset

ISSN: 1119-0531
Special Issue Vol. 5(3): (2026)

for food system transformation. In ecologically diverse regions such as Nigeria, a wide array of indigenous crops, livestock breeds, and microbial resources have evolved adaptive traits that enable them to thrive under local environmental conditions. These traits—including drought tolerance, pest resistance, and low input requirements—are particularly relevant in the context of climate change and resource constraints. This aligns with the broader agroecological argument that resilience is best achieved through diversification rather than intensification based on uniform systems (Gliessman, 2015; Altieri & Nicholls, 2017).

However, the study also reveals that the potential of these bioresources is constrained by systemic gaps in characterization and knowledge generation. The lack of comprehensive data on genetic and functional traits limits their inclusion in breeding programs, policy frameworks, and market systems. This finding supports earlier observations by the Food and Agriculture Organization that inadequate documentation and characterization of biological resources remain major barriers to their sustainable utilization (FAO, 2012). Without robust scientific evidence, these resources continue to be marginalized in favor of well-documented, high-input agricultural systems.

Another important dimension highlighted in this study is the disconnect between indigenous knowledge systems and formal scientific research. While local communities possess extensive knowledge of agroecological bioresources, this knowledge is often not systematically documented or integrated into research and policy processes. The erosion of such knowledge due to socio-cultural changes further exacerbates the problem (Berkes, 2012). Bridging this gap is essential for achieving a more holistic understanding of bioresource systems and for designing context-specific agricultural interventions.

The analysis also demonstrates that agroecological bioresources contribute to multiple dimensions of food security simultaneously. Unlike conventional approaches that prioritize yield maximization, agroecological systems emphasize diversity, sustainability, and resilience. This multidimensional contribution includes improved nutritional outcomes, enhanced ecosystem services, and increased livelihood opportunities. Such findings reinforce the perspective of the High Level Panel of Experts that diversified agroecological systems are fundamental to achieving sustainable food security (HLPE, 2017).

Despite these advantages, the study identifies significant structural and institutional barriers that hinder the scaling of agroecological approaches. Weak policy frameworks, limited research funding, inadequate extension services, and underdeveloped markets collectively create an environment in which agroecological bioresources are undervalued and underexploited. These constraints are not merely technical but reflect broader political and economic priorities that favor industrial agricultural models (World Bank, 2020).

Furthermore, the study highlights the interconnected nature of challenges and opportunities within agroecological systems. For instance, poor market development reduces the economic incentives for farmers to cultivate indigenous species, which in turn leads to reduced conservation and further loss of genetic diversity. Similarly, weak research systems limit characterization efforts, which affects policy formulation and investment decisions. This cyclical pattern suggests that isolated interventions are unlikely to produce meaningful change; instead, integrated and systemic approaches are required.
From a policy perspective, the findings suggest that mainstreaming agroecological bioresources into national agricultural strategies is not optional but imperative. The increasing impacts of climate change, coupled with rising food demand, necessitate a shift toward more resilient and sustainable production systems. Agroecological bioresources provide a viable pathway for achieving this transition, particularly in resource-constrained environments.

Moreover, the study contributes to ongoing academic discourse by reinforcing the argument that food security should be approached as a systems issue rather than a production problem. While increasing food production remains important, equal attention must be given to factors such as biodiversity conservation, resource efficiency, and socio-economic equity. Agroecological bioresources, when properly characterized and utilized, address these multiple dimensions

simultaneously.

In summary, the discussion highlights that the effective characterization and utilization of agroecological bioresources require a paradigm shift in agricultural research, policy, and practice. This shift involves moving away from narrow, input-intensive models toward diversified, knowledge-intensive systems that leverage local resources and ecological processes. Such a transition holds significant promise for enhancing food security, promoting sustainability, and improving livelihoods, particularly in countries like Nigeria.

CONCLUSION

This study has demonstrated that the characterization of regional and agroecological bioresources is a critical pathway for achieving sustainable food security, particularly in ecologically diverse and resource-constrained environments such as Nigeria. By integrating ecological, genetic, and socio-economic dimensions, agroecological bioresources provide a robust foundation for building resilient, diversified, and sustainable food systems.

The findings reveal that indigenous crops, livestock breeds, and microbial resources possess inherent adaptive traits that make them highly suitable for addressing contemporary challenges, including climate variability, soil degradation, and nutritional deficiencies. However, their full potential remains largely untapped due to inadequate characterization, weak institutional support, limited market development, and the erosion of indigenous knowledge systems.

The study further establishes that food security cannot be sustainably achieved through conventional, input-intensive agricultural models alone. Rather, it requires a paradigm shift toward agroecological approaches that prioritize biodiversity, resource efficiency, and local adaptability. Effective characterization serves as a foundational step in this transition, enabling the identification, conservation, and strategic utilization of bioresources tailored to specific agroecological contexts.

Ultimately, the sustainable management and integration of agroecological bioresources into food systems offer a viable and necessary strategy for enhancing agricultural productivity, improving nutritional outcomes, and strengthening resilience against environmental and socio-economic shocks. Realizing this potential will depend on coordinated efforts across research, policy, and practice, supported by inclusive frameworks that recognize the value of both scientific innovation and indigenous knowledge.

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How to Cite This Article
Enaregha, E. B., and Prefa, C. A. (2026). Characterization of regional/agroecological bioresources for food security. NABDA Journal of Biotechnology Research, 5(3), 8-21.