ISSN: 2594-0252

AGRO PRODUCTIVIDAD

Strategy to improve the micropropagation of sugarcane plants using carbon dioxide injection

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Año 17 • Volumen 17 • Número 10 • octubre, 2024

Colegio de Postgraduados

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Agrobiodiversity and food security: challenges and sustainable solutions

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ABSTRACT

Objective: Agricultural biodiversity, also known as agrobiodiversity, encompasses the variety of plants, animals, and microorganisms that are directly or indirectly involved in agriculture. This diversity is the result of millennia of selection, management, and domestication of species, which has allowed societies to adapt to different environmental and cultural conditions. However, in recent decades, the loss of agrobiodiversity, accelerated by industrial agriculture, the expansion of monocultures, and the reduction of varieties, has put global food security at risk. This diversity is crucial to ensuring the resilience of agricultural systems in the face of challenges such as climate change, emerging pests, and the depletion of natural resources. This paper examines the importance of conserving agricultural biodiversity from the perspective of food security. It emphasizes how agrobiodiversity not only contributes to the stability of food production but also improves human diets by diversifying crops and providing essential micronutrients.

Design/Methodology/Approach: A search was conducted on the following scientific information platforms: Web of Science database and Google Scholar. A systematic search for publications related to agrobiodiversity systems was carried out in the WoS database and Google Scholar over the last 49 years (1975-2024).

Results: Genetic erosion is particularly concerning because genetic diversity is essential for crops to face environmental challenges such as climate change, pests, and diseases. The loss of traditional varieties, which are selected by local farmers to adapt to specific conditions, increases agriculture's vulnerability to external disruptions. These landraces, having been cultivated in genetically diverse mosaics, offer protection against catastrophic losses in the event of crop failures due to extreme conditions or diseases.

Findings/Conclusions: Genetic diversity allows for the development of sustainable solutions to pests and diseases, reducing dependence on pesticides and promoting more environmentally friendly farming practices. However, challenges related to biodiversity conservation persist, making it essential to implement public policies that promote agrobiodiversity and address the socioeconomic issues that limit its adoption.

Keywords: Agrobiodiversity, agri-food security, genetic resources, biodiversity and conservation.

Citation: Cadena-Zamudio, J. D., Ramírez-Mosqueda, M. A., Iñiguez-Luna, M. I., & Cadena-Zamudio, D. A. (2024). Agrobiodiversity and food security: challenges and sustainable solutions. *Agro Productividad*. https://doi.org/10.32854/agrop.v17i10.3084

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: June 05, 2024.
Accepted: September 16, 2024.
Published on-line: November 12, 2024.

Agro Productividad, 17(10). October. 2024. pp: 101-113.

INTRODUCTION

Agricultural biodiversity, also known as agrobiodiversity, refers to the variety of plants, animals, and microorganisms used directly or indirectly in agriculture, including wild-type crops as well as those that have been genetically modified (Matthies *et al.*, 2023). This

concept encompasses the different crop varieties and livestock breeds, as well as the natural systems that sustain them (Maxted *et al*., 2015). Agrobiodiversity is the result of thousands of years of selection, management, and domestication of species by humans, which has allowed societies to adapt to different environmental, climatic, and cultural conditions (Figure 1) (Agnoletti & Santoro, 2022).

In recent decades, there has been growing concern about the loss of agricultural biodiversity (Agnoletti & Santoro, 2022). Industrial agricultural practices, the expansion of monocultures, and the reduction in the number of crop varieties in production systems have accelerated this loss, putting global food security at risk (FAO, 1999). This biodiversity is key to maintaining a sustainable food system, capable of responding to future challenges such as climate change, the emergence of new pests and diseases, and fluctuations in the availability of natural resources (Jackson *et al*., 2007; Zimmerer, 2014).

For this reason, this paper explores the importance of conserving agricultural biodiversity from the perspective of food security, emphasizing how this diversity is essential for ensuring food production, addressing environmental challenges, and promoting the resilience of agricultural systems.

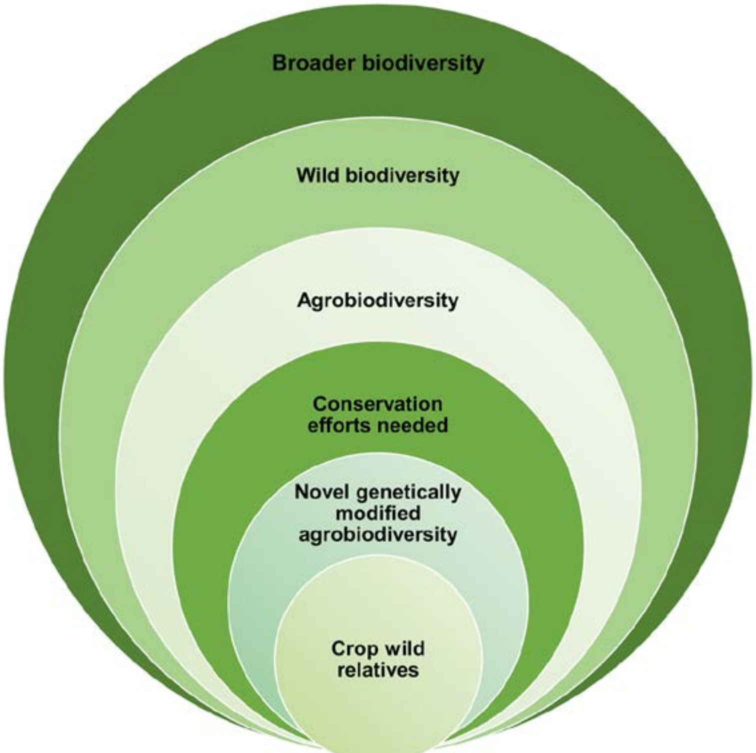

Figure 1. Agrobiodiversity is defined as the subset of broader biodiversity that is used for food and agriculture. Defining Broader biodiversity as: The variety of living organisms from different sources including wild and agricultural landscapes. Agrobiodiversity: as the variety of domesticated animals, plants and microorganisms used for food and agriculture. Novel genetically modified agrobiodiversity: as non-naturally occurring genotypes. Wild biodiversity: as Naturally occurring living species, not subject to human-mediated selection. Crop wild relatives: as wild relatives of domesticated species; and conservation efforts needed: as wild relative plants who need conservation efforts to avoid their extinction.

MATERIALS AND METHODS

The research was conducted using a bibliometric and data mining-based approach, which included the selection of the database as well as the identification of search terms and filters. The titles and abstracts of the articles were reviewed to identify and exclude those that were not relevant. Subsequently, the selected dataset was analyzed.

Bibliographic base

A search was conducted on the following scientific information platforms: Web of Science database (https://www.webofknowledge.com) and Google Scholar (https://scholar.google.com) (Pranckutė, 2021). A systematic search for publications related to agrobiodiversity systems was carried out in the WoS database and Google Scholar over the last 49 years (1975-2024). The most general logical operators were used in this search (agrobiodiversity, agri-food security, genetic resources, biodiversity, and conservation) to extract all possible publications related to the topic. Subsequently, search filters were applied (scientific articles, review articles, systematic reviews, meta-analyses, and international conservation guidelines/protocols) to meet the corresponding inclusion criteria. The exclusion criteria were articles that exceeded the time limit, as well as opinion pieces, case reports, or essays.

RESULTS AND DISCUSSION

Relationship between agricultural biodiversity and food security

Agricultural biodiversity is a fundamental component of global food security, as it enables agricultural systems to be more productive, resilient, and capable of facing various threats arising from climate change, pests, and diseases (Engels *et al.*, 2021; Agnoletti & Santoro, 2022). Throughout history, farmers have selected and cultivated thousands of plant varieties and animal breeds, resulting in an enormous wealth of genetic diversity, which has helped ensure the availability of food in both quantity and quality (Jago *et al.*, 2024).

One of the main benefits of agricultural biodiversity is the possibility of diversifying crops, which not only enriches human diets but also contributes to the stability of food production (Ceccarelli & Grando, 2022; Jago *et al.*, 2024). Instead of relying solely on a few staple crops such as maize, wheat, or rice, which make up the bulk of global food production, genetic diversity in agriculture allows farmers to choose from a wider range of crops (Zimmerer, 2014; Zimmerer & De Haan, 2017). This is crucial for ensuring balanced diets that provide all the necessary nutrients for human health. For example, incorporating a greater variety of legumes, fruits, vegetables, and cereals into farming systems allows rural and urban populations to access a wider range of micronutrients, vitamins, and minerals, thereby preventing nutritional deficiencies, such as iron or vitamin A deficiencies, which are common in regions where diets rely on a few staple foods (Zimmerer *et al.*, 2021; Ceccarelli & Grando, 2022; Jago *et al.*, 2024). This has been demonstrated in rural areas of Kenya, where an increase in agricultural biodiversity has been associated with improved dietary diversity, which in turn reduces malnutrition and growth problems in children (Kahane *et al.*, 2013; Jones *et al.*, 2021). However, this relationship is not always direct, as food security is also influenced by socioeconomic factors such as household income levels, food distribution within the household, and access to food (Chappell & LaValle, 2011; M'Kaibi *et al.*, 2017). The above allows us to conclude that agricultural biodiversity is intrinsically linked to food security, providing a foundation for dietary diversity and improving access to nutritious foods. However, its impact on nutrition depends on various interrelated factors, such as household economic stability and cultural practices. To achieve comprehensive food security, it is crucial to promote policies that not only encourage agricultural biodiversity but also address the social and economic challenges affecting nutrition in rural communities.

Resilience to pests and diseases in agriculture

Resilience in agricultural systems is essential to ensuring food security in a global context increasingly affected by climate change, emerging pests, and diseases (Chappell & LaValle, 2011). The ability of crops to withstand and recover from these stressors is crucial for maintaining sustained yields and protecting the genetic resources that are fundamental to agriculture (Frison *et al.*, 2011; Murrell, 2017). Pests and diseases pose a significant threat to the stability of agricultural systems, and climate change has exacerbated these challenges by altering the geographic distribution of many pest and pathogen species, as well as their life cycles and virulence. This has created a need to develop new strategies that strengthen the adaptive capacity of crops, leveraging both technological advancements and traditional agronomic management practices (Lin, 2011; Shroff *et al.*, 2020; Chauhan *et al.*, 2023).

One of the main strategies to enhance crop resilience against pests and diseases is proper soil management (Dardonville *et al.*, 2022). The use of cover crops and the incorporation of organic amendments not only improve soil structure and increase its water retention capacity but also promote microbial biodiversity, which in turn strengthens the natural defenses of crops. In this way, the addition of organic matter increases biological activity in the soil, enhancing crop resistance to pathogen attacks and creating a less favorable environment for pest development (Nciizah *et al.*, 2021; Dardonville *et al.*, 2022). Another essential strategy is crop diversification, which can reduce pest and disease pressure (Huss *et al.*, 2022). By increasing biodiversity in agricultural systems, the life cycles of many pests are disrupted, and disease spread is reduced, contributing to the creation of more robust agricultural systems (Huang & Zhao, 2017; Yu *et al.*, 2022). Including different species in crop rotations has shown positive effects not only on soil health improvement but also on the capacity of agricultural systems to withstand external disturbances (Wu & Wang, 2017; Wang *et al.*, 2021). In fact, diversification at the field and landscape levels has been associated with lower pest incidence and greater stability of agroecosystems in general. Conversely, when farmers cultivate large areas of monocultures (plantations dominated by a single crop variety), they become more vulnerable to disease spread (Yin *et al.*, 2010; Liu *et al.*, 2022). A pest adapted to a particular species can spread quickly and devastate entire crops, jeopardizing food production (Wang *et al.*, 2021; Liu *et al.*, 2022). In addition to the aforementioned positive effects, agricultural biodiversity promotes healthy agricultural ecosystems by enhancing soil fertility and conserving beneficial insect biodiversity, such as pollinators and natural pest predators (Sarwar *et al.*, 2008; N'Dayegamiye *et al.*, 2017).

Additionally, biotechnology has emerged as a powerful tool to improve crop resilience against pests and diseases. Through advanced techniques such as gene editing and genetic engineering, scientists have developed crop varieties resistant to specific pests and diseases, reducing the need for pesticides and other chemicals (Pathirana *et al.*, 2024). In particular, genetic engineering has enabled the creation of crops with intrinsic resistance to insects or viruses that would otherwise cause significant agricultural yield losses. Moreover, advances have been made in developing crops that are more resistant to extreme environmental conditions, such as drought or high temperatures, which is crucial in the context of climate change (Lindberg *et al.*, 2021; Henderson *et al.*, 2024; Pathirana *et al.*, 2024).

On the other hand, the effects of climate change are not limited solely to the increase in the severity of pests and diseases; they also alter the dynamics of agricultural ecosystems (Nciizah *et al.*, 2021). Higher temperatures and variations in precipitation patterns affect both plants and the organisms that depend on them. Some studies have shown, for example, that certain pest insects, such as aphids, can increase their populations in warmer climates, while the natural enemies of these insects are negatively impacted, reducing their ability to effectively control pests (Lobell *et al.*, 2008; Aukema *et al.*, 2017).

In conclusion, resilience against pests and diseases is fundamental to agri-food security. Strategies that combine adapted agricultural practices, such as climate-smart agriculture and agroforestry, along with the use of advanced biotechnology and sustainable resource management, offer the best opportunities to protect agricultural systems and ensure stability in food production. However, it is crucial to consider the ethical and environmental challenges posed by biotechnology, as well as the inequalities in access to these innovations, especially for small-scale farmers. In this regard, continued investment in research and public policies that promote both the conservation of genetic resources and the development of sustainable technologies will be key to addressing future challenges in an equitable and effective manner.

Impacts of genetic erosion on agriculture

Genetic erosion in agriculture is closely linked to the loss of genetic diversity in crops, which negatively impacts the productivity, resilience, and adaptability of agricultural systems (Sirami *et al.*, 2019; Khoury *et al.*, 2022). This process involves a reduction in variability among species, varieties, and within the crops themselves. Such loss affects both wild relatives of crops and traditional varieties, which have been managed by farmers for generations, limiting their ability to adapt (Harlan, 1975; Egli *et al.*, 2020). Currently, various factors such as habitat fragmentation, climate change, the introduction of non-native species, pollution, and overexploitation have intensified the rate of extinction (Hammer & Teklu, 2008; Pathirana & Carimi, 2022). This has triggered a phenomenon known as the "extinction vortex," where declining populations experience a reduction in genetic variability, diminishing their ability to adapt and survive (Díez-del-Molino *et al.*, 2018; Bosse & van Loon, 2022).

Genetic erosion is particularly concerning because genetic diversity is essential for crops to face environmental challenges such as climate change, pests, and diseases (Bosse & van Loon, 2022; Khoury *et al.*, 2022). The loss of traditional varieties, which are selected by local farmers to adapt to specific conditions, increases agriculture's vulnerability to external disruptions. These landraces, having been cultivated in genetically diverse mosaics, offer protection against catastrophic losses in the event of crop failures due to extreme conditions or diseases (Tsegaye & Berg, 2007; Babay *et al.*, 2020). However, the replacement of these varieties with modern crops, which are generally homogeneous and designed for high yields under controlled conditions, has increased dependence on external inputs such as fertilizers and pesticides (Casañas *et al.*, 2017; Birhanu Abegaz & Hailu Tessema, 2021). Furthermore, genetic erosion has significant implications for global food security. The reduction in crop diversity limits farmers' options, which can result in decreased production, particularly under environmental stress conditions such as droughts or rising temperatures (Fu & Dong, 2015; Hailu, 2017; Legesse, 2020). This point is especially relevant in the context of climate change, where the ability of crops to adapt to new conditions is crucial for ensuring sustainable agricultural production (Dempewolf *et al.*, 2014; Bosse & van Loon, 2022). Another significant impact of genetic erosion is the loss of local adaptation. Traditional varieties have evolved over centuries to adapt to specific environments, making them a vital part of agriculture in regions with complex or changing environmental conditions (Casañas *et al.*, 2017). Replacing these varieties with modern crops can lead to the loss of this valuable adaptive capacity, leaving agricultural systems more exposed to the adverse effects of environmental changes or the emergence of new pests and diseases (Zeven, 1999).

At a cultural level, genetic erosion also has profound consequences. The management and conservation of agricultural diversity are intrinsically linked to traditional knowledge, which forms part of the cultural heritage of many rural communities (Rajeswara, 2016). When traditional varieties disappear, this knowledge is lost along with them, leading to both genetic and cultural erosion (Rogers, 2004). This loss directly impacts the self-sufficiency of farming communities, hindering their ability to effectively manage their agricultural resources (Van de Wouw *et al.*, 2010).

To assess genetic erosion, several methodologies have been proposed, such as genomic heterozygosity analysis and the detection of runs of homozygosity (ROH), which can indicate recent inbreeding (Narasimhan *et al.*, 2016). ROHs reveal regions of the genome where recessive, deleterious mutations may be expressed in a homozygous state, negatively affecting health and reproduction (Bosse *et al.*, 2018; Stoffel *et al.*, 2021). The accumulation of deleterious mutations in small populations, known as genetic load, can also increase rapidly, contributing to population decline and, eventually, extinction (Doekes *et al.*, 2021; Stoffel *et al.*, 2021). One of the main challenges in genetic conservation is the lack of precise tools to quantify genetic erosion. Although whole-genome sequencing has enabled advances in identifying the loss of genetic diversity, there is still no consensus within the scientific community on the optimal methods for accurately measuring it. The difficulty also lies in translating these genomic advances into practical applications for conservation (Silva *et al.*, 2021; Bosse & van Loon, 2022).

In response to these challenges, various conservation strategies have been implemented, such as *ex situ* conservation in gene banks and in situ conservation on farms, allowing varieties to continue evolving in their natural environments (Pathirana *et al.*, 2022).

Additionally, genetic rescue initiatives have been carried out, where genetic variability from other populations is introduced to improve genetic fitness, as seen in cases like the Florida panther and the American bison (Hedrick, 2009). However, these strategies are not without risks, as there is also the possibility of introducing harmful mutations that could increase genetic load in the long term (Salgotra & Chauhan, 2023). Despite international efforts, the scale and implications of genetic diversity loss are still not fully understood, making it difficult to plan more effective conservation strategies (Brush, 1999).

In conclusion, genetic erosion is a critical threat to species survival, especially in the context of accelerated environmental change. Despite advances in genomic technology, it remains urgent to develop and standardize methods that effectively quantify genetic erosion. This effort would facilitate the identification and prioritization of the most vulnerable populations and enable the implementation of appropriate genetic interventions to mitigate the effects of inbreeding and the loss of genetic diversity.

Strategies for the conservation of agricultural biodiversity

The conservation of agricultural biodiversity is a critical challenge that has gained relevance in recent decades due to its importance for the sustainability of global food systems and the ability of crops to adapt to changing environmental conditions (Pe'er *et al.*, 2020; Williams *et al.*, 2021). With the advent of genetic improvement programs in the 20th century, high-yielding varieties resistant to biotic and abiotic factors were promoted, leading to a drastic reduction in genetic diversity in agricultural fields. More than 75% of genetic diversity in plant genetic resources (PGRs) and 90% of crop varieties have disappeared, endangering the sustainability of the global agricultural system (Thrupp, 2000; FAO, 2018; Bélanger & Pilling, 2019). As a result, various international institutions and multilateral agreements have implemented strategies to preserve agricultural genetic resources and promote their sustainable use, with the aim of protecting biodiversity, ensuring food security, and strengthening resilience against threats such as climate change and environmental degradation (Priyanka *et al.*, 2021; Pathirana & Carimi, 2022). In response to this crisis, various conservation strategies have been developed. The first is in situ conservation, which involves maintaining genetic resources in their natural environments or on farms where they continue to evolve (Salgotra & Gupta, 2015; Salgotra & Chauhan, 2023), allowing plant varieties to keep adapting to changing environmental conditions, which is vital in the context of climate change (Ogwu *et al.*, 2014). Additionally, *in situ* conservation promotes the use of landraces and other local varieties by farmers, thereby helping to maintain genetic diversity in the fields (Hammer & Teklu, 2008).

The second approach is *ex situ* conservation, which allows genetic resources to be stored outside their natural environment through seed banks (Pathirana & Carimi, 2022). This has been made possible through the participation of various institutions, such as the Food and Agriculture Organization of the United Nations (FAO), which has played a central role since the 1960s, promoting initiatives like the Global Plan of Action for the Conservation and Sustainable Use of Plant Genetic Resources and collaborating in the adoption of international frameworks such as the Convention on Biological Diversity (CBD) and the International Treaty on Plant Genetic Resources for Food and Agriculture

(ITPGRFA), which came into force in 2004 and has been a key instrument for coordinating global efforts in the conservation and sustainable use of these resources (Priyanka *et al.*, 2021; Pathirana & Carimi, 2022; Salgotra & Chauhan, 2023). This treaty not only seeks to conserve genetic diversity but also ensures that the benefits derived from its use are shared fairly and equitably among all parties involved. Additionally, the Nagoya Protocol, which came into effect in 2014, sets guidelines for access to genetic resources and the equitable distribution of benefits obtained from their use (Buck & Hamilton, 2011). This protocol creates incentives for the conservation and sustainable use of biodiversity, linking the conservation of genetic resources with economic development and human well-being (Smith *et al.*, 2017). Alongside these agreements, the Cartagena Protocol on Biosafety addresses the importance of ensuring the safe handling of genetically modified organisms (GMOs) that may affect biodiversity, contributing to safety in biotechnology agriculture. This is crucial to promoting crop improvement that can adapt to environmental challenges and meet the food needs of a growing population (FAO, 2019; FAO, 2020). The safeguarding and storage of these genetic resources have been achieved through institutions such as the Svalbard Global Seed Vault and other programs supported by the Global Crop Diversity Trust (Global Crop Trust). This approach provides a secure way to preserve the long-term viability of crops while protecting threatened species (Priyanka *et al.*, 2021). Likewise, organizations like Botanic Gardens Conservation International (BGCI) have played a crucial role in the conservation of live plants through botanical gardens and in-field gene banks, which are particularly useful for protecting species that cannot be stored as seeds or perennial crops (BGCI, 2020) (Acuña *et al.*, 2019; Priyanka *et al.*, 2021; Salgotra & Chauhan, 2023). In Mexico, germplasm banks such as the International Maize and Wheat Improvement Center (CIMMYT) and the National Center for Genetic Resources (CNRG-INIFAP) stand out, with a primary mission of conserving agricultural biodiversity within the context of food security (Ortiz *et al.*, 2008; Vélez-Torres *et al.*, 2023). Similarly, many other conservation centers around the world (Table 1) are dedicated to the conservation of specific genetic resources. These institutions focus on the collection, storage, and preservation of agro-food genetic resources from thousands of crop varieties, ensuring their availability for future generations and their use in plant research and improvement.

However, despite international efforts and technological advances, the conservation of agricultural biodiversity faces significant challenges related to the integration of various stakeholders, particularly farmers and scientists. While both groups recognize the importance of biodiversity, their perceptions of ecosystem services and conservation measures differ considerably; farmers tend to focus on tangible and immediate benefits, such as pest control, whereas scientists emphasize the importance of less visible ecosystem services, such as air quality, water quality, and genetic diversity (Concepción *et al.*, 2020; Maas *et al.*, 2021; Williams *et al.*, 2021). This underscores the importance of improving communication channels between scientists, farmers, and policymakers, with the aim of overcoming this disconnect through the creation of dialogue platforms and educational programs that provide farmers with practical tools for the sustainable management of their lands (Concepción *et al.*, 2020; Maas *et al.*, 2021).

Table 1. Research institutes focused on the conservation and maintenance of genetic resources (Salgotra & Chauhan, 2023; Pathirana & Carimi, 2024).

Institute	Crop	Country
International Rice Research Institute (IRRI)	Rice	Philippines
Centre International de Mejoramiento de Maíz y Trigo (CIMMYT)	Maize and wheat (triticale, barley, sorghum)	Mexico
Center International de Agricultura Tropical (CIAT)	Cassava and beans (also maize and rice), in collaboration with CIMMYT and IRRI	Colombia
International Institute of Tropical Agriculture (IITA)	Grain legumes, roots and tubers, farming systems, cassava, banana, yam	Nigeria
Centre International de la Papa (CIP)	Potato, Andean root, and tubers	Peru
International Crops Research Institute for Semi-Arid Tropics (ICRISAT)	Sorghum, groundnut, pearl millet, Bengal gram, red gram	India
West African Rice Development Association (WARDA)	Regional cooperative rice research in collaboration with IITA and IRRI	Liberia
International Plant Genetic Research Institute (IPGRI)	Genetic conservation	Italy
National Bureau of Plant Genetic Resources	Fruits, tubers, medicinal and aromatic crops, spices, bulbous crops	India
The Asian Vegetable Research and Development Center (AVRDC)	Tomato, onion, peppers, Chinese cabbage	Taiwan
International Center for Tropical Agriculture (CIAT)	Cassava	Colombia
The New Zealand Institute for Plant and Food Research Limited	Kiwi fruit (*Actinidia* spp.)	New Zealand
National Center for Genetic Resources (CNRG)	Plant and animal genetic resources	Mexico

In conclusion, the conservation of agricultural biodiversity cannot rely solely on economic incentives or technological advancements; it requires effective collaboration among the various stakeholders involved. The FAO, CGIAR (Consortium of International Agricultural Research Centres), and other international institutions have established a solid foundation through global frameworks and ex situ and in situ strategies, but it is necessary to better integrate the perceptions and needs of farmers and improve communication between scientists and producers (Noriega *et al.*, 2019). Only through an inclusive and collaborative approach can the adoption of practices that promote agricultural sustainability and the conservation of genetic resources, essential for facing future agricultural challenges, be ensured.

CONCLUSION

Agricultural biodiversity is essential for food security in a world facing unprecedented climatic and environmental challenges. The loss of this biodiversity jeopardizes the ability to produce food sustainably and adapt to a changing environment. Preserving agrobiodiversity not only ensures greater stability in food production but also strengthens rural economies, protects ecosystems, and promotes social equity. For this reason, solutions for its conservation must be comprehensive, involving farmers, governments, national and international institutions, and society as a whole to ensure food security for future generations and build a more resilient and sustainable food system.

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