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Multifunctionality in neglected and underutilized crop species

Multifuncionalidad en especies de cultivo olvidadas e infrautilizadas

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Abstract

Neglected and underutilized crop species (NUS) are not widely grown or marketed. Certain crop types (amaranth, buckwheat, and quinoa) have advantages over commercial crops (rice, maize, and wheat). They can grow in harsh environments because of their greater resistance to abiotic and biotic stresses. Harnessing the NUS can solve global problems such as climate change, loss of agrobiodiversity, food insecurity, poverty, and unemployment in rural regions. Hence, this review investigates the various social, environmental, and economic functions associated with NUS cultivation to encourage and support future research on these crops.

Keywords: *Abandoned crops; Dietary diversity; Future smart food; Minor crops; Orphan crops*

Resumen

Las especies agrícolas desatendidas e infrautilizadas (NUS) no se cultivan ni comercializan ampliamente. Ciertos tipos de cultivos (amaranto, trigo sarraceno y quinua) tienen ventajas sobre los cultivos comerciales (arroz, maíz y trigo). Pueden crecer en ambientes hostiles debido a su resistencia al estrés abiótico y biótico. Aprovechar la NUS puede resolver problemas globales como el cambio climático, la pérdida de agrobiodiversidad, la inseguridad alimentaria, la pobreza y el desempleo en las regiones rurales. Por lo tanto, esta revisión investiga las diversas funciones sociales, ambientales y económicas asociadas con el cultivo de NUS para fomentar y apoyar futuras investigaciones sobre estos cultivos.

Palabras clave: *Cultivos abandonados; Diversidad dietética; Alimentos inteligentes del futuro; Cultivos menores; Cultivos huérfanos*

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1. Introduction

There are over 250 000 known edible plant species worldwide, but fewer than 20 "major" crop species meet most dietary needs, and only three crops - rice, wheat, and maize - provide more than 40 percent of the calories consumed (Cheng, 2018; Knez et al., 2023). The decline in crop diversity can be traced back to the 1960s, when the Green Revolution emerged as a transformative force in agriculture. This period witnessed the introduction of high-yielding varieties, chemical fertilizers, pesticides, and agricultural mechanization, which resulted in remarkable success in grain production. However, agricultural transformation has negative consequences in terms of the environment, social dynamics, and economy. For example, the loss of beneficial genes, hidden hunger, social inequality, and vulnerability of smallholder farmers have been identified as significant side effects (Horlings & Marsden, 2011; Li et al., 2020; Kumar et al., 2023).

Research on neglected and underutilized crop species (NUS) has gained significance due to their ability to thrive on marginal lands with limited resources and in adverse environmental conditions. These crops exhibit natural resilience to various abiotic stresses, including low temperatures, salinity, drought, and heat. Thus, NUS can help overcome the global challenges of food insecurity, poverty, and climate change by aligning with Sustainable Development Goals (SDGs) 1, 2, 3, 5, 8, 12, and 15 (Li et al., 2020).

Currently, a paradigm shift is needed, in which agriculture stops seeking chrematistic concerns and starts pursuing positive externalities. Therefore, it is necessary to promote research on multifunctional crops that can contribute to a "triple bottom line" of sustainable rural development with economic, social, and environmental components. In addition, Adhikari et al. (2019), NUS have been found to possess high nutritional value (social sustainability), contribute to agrobiodiversity and farming system resilience (environmental sustainability), and have a high potential to be sources of income generation (economic sustainability). It has been mentioned that NUS are multipurpose crops, but NUS cultivation has not been explicitly addressed as part of multifunctional agriculture. Therefore, the aim of this review is to identify the multiple functions that are provided by the cultivation of NUS.

2. Social sphere

One of the main social functions found in NUS is to contribute to dietary diversity, as that currently most people around the world consume a diet based on only a few crops, together with the increased consumption of processed, imported, and fast food, which has led to an alarming widespread malnutrition called "hidden hunger" which translates as having sufficient calories, but inadequate vitamins and minerals. It is a deadly factor affecting both developed and developing countries and accelerating the global rise in non-communicable diseases. Studies have shown that neglected and underutilized species have the potential to reverse the trend of hidden hunger. This is because various NUS have nutritional values needed to ameliorate micronutrient deficiencies, and a diversified diet can only be achieved with genetic diversity (Li et al., 2020; Kapoor et al., 2022). According to Massawe et al. (2016), crop diversification is not just a strategy for tackling malnutrition and overnutrition, but it also serves to combat hunger. As a result, diversifying crops is not a choice, but rather a necessity for ensuring food security.

Studies suggest that underutilized pseudocereals have the potential to serve as a tangible option that can be part of the basic food basket and help supplement the nutritional content of major crops (Alemayehu et al., 2015; Rao & Poonia, 2023). Pseudocereals are seeds or fruits of species other than grasses that can be consumed in a manner similar to cereals. The most used varieties are amaranth (*Amaranthus* spp.), quinoa (*Chenopodium quinoa*), buckwheat varieties such as common (*Fagopyrum esculentum*) and tartary (*Fagopyrum tataricum*), chia (*Salvia hispanica L.*), albumen (*Chenopodium album*), and acacia (*Acacia* spp.) seeds (Rao & Poonia, 2023).

Quinoa has twice the protein, five times the fiber, four times the iron, and 23 times the folate content of rice (*Oryza sativa*) (Li et al., 2020).

Amaranth has high nutritional value because it is rich in lysine, calcium, and fiber. Similar to spinach, some amaranth species have leaves that serve as traditional nutrient-rich vegetables. Buckwheat has more protein than corn, rice, or other wheat varieties. Pseudocereals are a good source of essential amino acids, essential fatty acids, phenolic compounds, vitamins, flavonoids, and minerals and have been found to have antidiabetic, anticancer, cardioprotective, anti-inflammatory, hypocholesterolemic, anti-obesity, and antioxidant properties (Rao & Poonia, 2023; Sarker et al., 2022).

Another type of underutilized crops are legumes such as bambara groundnut (*Vigna subterranean*), black-eyed pea (*Vigna unguiculata)* and marama bean (*Tylosema esculentum*), which are excellent sources of protein and essential amino acids, ranging from 22 g to 35 g of protein per 100 g. Lima beans (*Phaseolus lunatus* L.*)* have twice as much extra protein as cereals and are rich in essential amino acids such as lysine, phenylalanine, leucine, valine, threonine, isoleucine, and histidine, important biological components necessary in the human body for biosynthesis, neurotransmission, and other metabolic activities, as well as being an excellent source of minerals, fiber, and B-complex vitamins (folate, B6, and niacin). Legumes are the main source of proteins in many developing countries (Conti et al., 2019; Adebo, 2023).

Local, seasonal fruits and vegetables have been shown to maintain population health and nutrition security over imported, off-season crops and highly processed produce (Nandal & Bhardwaj, 2014). Thus, while NUS support dietary diversity, they also provide food security. Because NUS are locally available and adaptable, they are accessible and affordable to the local population, thus contributing to food security. They provide a safety net when weather worsens or external inputs become undesirable because they damage the environment, become unavailable during disasters and emergencies, or become unaffordable owing to high prices (Mabhaudhi et al., 2016; Li et al., 2020).

3. Environmental sphere

In the wake of the Green Revolution, farmers have gradually abandoned and relegated traditional crops to cash crops. This decline in crops in agricultural systems has led to a loss of diversity, including genetic diversity, with serious implications for the environment and essential ecosystem services such as pollination, water retention, nutrient cycling, and decomposition. In addition, they undermine the resilience of agricultural systems to pests, pathogens, and biotic stress, posing significant threats to global food security (Adhikari et al., 2019; Borelli et al., 2020).

Climate change and loss of agrobiodiversity are the primary factors affecting the sustainability of socioecosystems. Several authors consider NUS to be key to enhancing agrobiodiversity and resilience of agricultural systems, as they are a source of genetic material for agriculture to cope with abiotic and biotic stresses (Mabhaudhi et al., 2017; Knez et al., 2023). The fact that NUS are the product of many generations of indigenous agriculture supports the idea that they are more resilient and better adapted to a wide variety of agroecosystems and may offer better prospects in marginal agricultural environments. Germplasm collection and conservation of NUS, which are more resilient to particular climates and environments, are key elements that can be used for viable and competitive breeding with the help of genomics (Mabhaudhi et al., 2016; Cheng, 2018).

For Kumar et al. (2023) NUS are a genetic treasure trove for hunting genes for tolerance to different stresses as some are tolerant to drought and heat stress, resistant to pests and diseases, and adapted to semi-arid and arid environments. Some underutilized cereals are relatively more drought-resistant than most major cereals, one of the most famous examples being amaranth, which is often hailed as a drought beater. Teff (*Eragrostis tef*) and proso millet (*Panicum miliaceum*) are drought-tolerant plants that survive in diverse agroecological zones. Canahua (*Chenopodium pallidicaule*), an underutilized Andean grain, is remarkably frost tolerant (Cheng, 2018; Li et al., 2020).

Recent advances in genomic resources allow the exploration of the untapped potential of NUS to identify new gene sources and mechanisms for developing crops that are resilient to abiotic and biotic stresses while maintaining yield. The adaptation of crop varieties tolerant to different stresses is key to ensuring global food security in the era of climate change (Kumar et al., 2023). In addition, they provide a range of provisioning and regulating ecosystem services, such as the provision of food or biomass for energy, bioremediation through the root system, erosion and pest control, mitigation of greenhouse gas emissions, carbon storage, pollination, habitat provisioning, soil fertility, and biodiversity stability.

4. Economic sphere

The production of NUS is not only a pillar of global food security, but also a key component of the rural economy, as NUS can be grown in marginal agricultural environments where other commercial crops cannot be grown, and often represent the only possible economic activities. In addition to requiring low input investment, some NUS, such as buckwheat and millet, were found to use inputs more efficiently than rice and maize, respectively (Adhikari et al., 2019). NUS can create economic opportunities for rural smallholder farmers with niche markets as they are able to supply new food products and commodities. They create new opportunities for income generation for communities that could not take part in mainstream crop value chains (Modi & Mabhaudhi, 2016).

Globally, the gluten-free retail market has seen a significant increase from $ 1.7 billion in 2011 to over $ 21.61 billion in 2019. This increase can be attributed to several factors, including increased consumer awareness of allergies and intolerance, or as part of a lifestyle due to cultural, environmental, civic, historical, ethnic, and health concerns, indicating a break in food monotony currently based on wheat, corn, rice, potato, and soybean products. This food trend is creating a great opportunity for some underutilized cereals that, besides to their ecological resilience, have the added advantage of being naturally gluten-free. Some of these cereals include amaranth, buckwheat, quinoa, teff, and millet (Cheng, 2018; Fornari et al., 2021; Melo et al., 2023).

Energy crops for biofuel production represent significant potential for meeting future global energy needs. One approach to meet the growing demand for vegetable oils is to introduce underutilized oilseed crops that are better suited for growing on less fertile land. These include ironweed (*Vernonia galamensis*), crambe (*Crambe abyssinica*), desert mustard (*Lesquerella fendleri*), niger (*Guizotia abyssinica*), camelina (*Camelina sativa*), Ethiopian mustard (*Brassica carinata*), sesame (*Sesamum indicum*), and jatropha (*Jatropha curcas*), which is one of the least expensive biodiesel feedstocks and is environmentally friendly (Mofijur et al., 2012; Tiwari & Kumar, 2013). Another crop with a high potential for bioethanol and bio-oil production is rockrose (*Cistus ladanifer*) (Raimundo et al., 2018). Grasses such as giant reed (*Arundo donax* L.) and halfa grass (*Desmostachya bipinnata*), among other neglected tall perennial grass species, and are presented as a viable option for biomass production on marginal lands. These grasses provide an opportunity to expand biomass production, which has been limited in the absence of suitable grasses (Singh et al., 2018).

Another area of economic interest for NUS are applications for the nutraceutical, pharmaceutical and cosmetic industries. A study revealed that, on the African continent, more than 5000 species have been identified and classified for their medicinal properties, such as donkey berry (*Grewia flavescens*), Ethiopian eggplant (*Solanum aethiopicum L.)*, and taro (*Colocasia esculenta*), which is a traditional crop with enormous nutritional and pharmaceutical potential (Mudau et al., 2022). Padulosi et al. (2013) documented the wide range of uses of NUS in sub-Saharan Africa, Latin America, Europe, and Western Asia, noting that they are used in food, beverages, spices and condiments, stimulants (*Erythroxylum coca*), textiles, construction, and pharmaceuticals, making each use a market opportunity. In this regard, Brazil is an example of a country that recognizes the potential of NUS, as it has made substantial efforts to increase knowledge about genetic resources and to adopt policies that provide access to and share the benefits derived from their use.

5. Multifunctionality and NUS

Currently, the species that are most cultivated and commercialized are not those that are most sustainable, but those that provide greater yields and profitability. Conversely, promoting the cultivation and use of NUS can unlock their potential to address multiple challenges simultaneously (Toensmeier et al., 2020; Ali & Bhattacharjee, 2023).

Table 1 describes some species that have been shown to have social, ecological, and economic functions, making their cultivation part of multifunctional agriculture:

6. NUS and SDGs

Several studies have highlighted the importance of neglected and underutilized crop species in achieving Sustainable Development Goals (SDGs), as these crops have a better water and carbon footprint than staple crops and provides food security to rural populations living in poverty (Ali & Bhattacharjee, 2023; Hossain & Hasan, 2018; Ismail et al., 2023; Mal, 2022).

In the social sphere, they relate directly to SDG1 (end poverty in all its forms everywhere), SDG2 (end hunger, achieve food security and improved nutrition, and promote sustainable agriculture), SDG3 (good health and well-being), SDG4 (inclusive and equitable education), and SDG5 (gender equality) (Mabhaudhi et al., 2017; Knez et al., 2023). In particular, goal 2.5 places traditional ethnobotanical knowledge as the basis for conserving and managing the biodiversity of local food production systems (Borelli et al., 2020). The implementation of Goal 4.7, which promotes the inclusion of indigenous peoples in spaces for social development through access to quality education, as well as fair and equitable

Table 1: Multifunctional NUS

Type crop	Specie	Perspectives	References
Cereals and Pseudocereals	*Amaranthus caudatus*	Contains bioactive compounds with therapeutic potential in diseases such as diabetes, cancer, and cardiovascular complications.	Netshimbupfe et al., 2023; Peña et al., 2023; Orona-Tamayo & Paredes-López, 2024.
	Chenopodium quinoa	It has the ability to produce high protein content under extreme ecological conditions (cold, drought and salinity).	Iqbal,2015; Calizaya et al., 2023; Schmidt et al., 2023.
	Salvia hispanica	It is characterized by its nutritional and functional properties, in particular by its high content of omega-3.	Mitrović et al., 2021; Ozón et al., 2023; Mondor, 2024.
Vegetables	*Vigna angularis*	It is characterized by its potential for the functional development of cereals. It is also a good source of protein, starch, essential fatty acids, and various pharmacological effects.	Li et al., 2022; Adebo, 2023; Singh et al., 2023b.
	Moringa oleifera	This species thrives in various climates and can be used as a crop enhancer. It is rich in phytochemicals and bioactive compounds and serves as a superfood.	Afrianto & Metananda, 2023; Maryam & Manzoor, 2023.
	Lablab purpureus	Has the potential to transform marginal lands, such as abandoned and unproductive mining areas, into productive food lands	Naeem et al., 2020; Aguilar-Garrido et al., 2023; Shubha et al., 2024.
Root and tubers	*Colocasia esculenta*	It has a wide geographical distribution and is a future food crop with enormous nutritional and pharmaceutical potential.	Kapoor et al., 2022; Mitharwal et al., 2022; Singh et al., 2023.
	Ipomoea batatas	It has nutritional relevance such as a high content of carbohydrates, proteins, minerals, and vitamins, so it can be considered as a substitute for staple food crops.	Cartabiano-Leite et al., 2020; Liu et al., 2024; Otálora et al., 2024.
	Manihot esculenta	It is highly valued for its value as a food crop, economic sphere, and social and cultural contribution. In addition, the species is adaptable to different biomes.	Mohidin et al., 2023; Da Mata et al., 2024; Scaria et al., 2024.
	Pachyrhizus erosus (L.)	It has a high nutritional content and biomolecules with antioxidant, immune modulating, anticancer, antidiabetic, and anti-aging effects, among others.	Ramos-de-la-Peña et al., 2013; Jaiswal et al., 2021; Fadjeri et al., 2023.
Fruits and Nuts	*Phoenix dactylifera*	It is vital in arid regions, contributes significantly to agricultural economies and community livelihoods, and contains a wide range of macro- and micronutrients.	Echegaray et al., 2020; Barakat & Alfheeaid, 2023; Al-Karmadi & Okoh, 2024.
	Artocarpus heterophyllus	Its bioactive compounds stand out, such as flavonoids with antioxidant, anti-inflammatory, anticancer and antibacterial properties.	Devanathan & Stalin, 2020; Srivastava & Singh, 2020; Khan et al., 2021.

participation in the benefits derived from the use of genetic resources and associated traditional knowledge (Buenavista et al., 2019; Unterhalter, 2019).

In the environmental domain, because of the diversity of ecosystem services presented by some NUS, Platis et al. (2023) relate them directly to SDG6 (clean water and sanitation), SDG7 (affordable and clean energy), SDG12 (responsible consumption and production), SDG13 (climate action), SDG15 (life on earth), especially with targets 6.6., 7.3, 12.2, 13.2, 15.1, 15.3 and 15.9.

Achieving sustainable development requires sustainable food production, which is explicitly mentioned in target 2.4: "Achieve sustainable food production systems and develop resilient agricultural practices that support productivity and production, contribute to the maintenance of ecosystems, enhance adaptation to climate change, extreme weather events, droughts, floods and other disasters, and improve land and soil quality. This goal is intrinsically linked to the NUS, which helps develop resilient agricultural practices and maintain and improve ecosystems (Jaramillo et al., 2019; Jones et al., 2021).

In the economic sphere, the NUS is linked to SDG 2, target 2.3 "Achieve a doubling of agricultural productivity and incomes of smallholder food producers, including through secure and equitable access to land, other resources and productive inputs, knowledge, financial services, markets and opportunities for value addition and off-farm employment" as well as SDG 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all (Padulosi et al., 2013; Mabhaudhi et al., 2016).

In summary, the cultivation of various NUS has multiple social, environmental, and economic functions that are key to achieving SDG2 (Figure 1). Here, NUS will be the means to help smallholders double their incomes through other productive resources and inputs (Target 2.3), as well as create markets and value-added opportunities through the development of resilient agricultural practices that support productivity and production with the use of genetic resources and associated traditional knowledge (Targets 2.4 and 2.5).

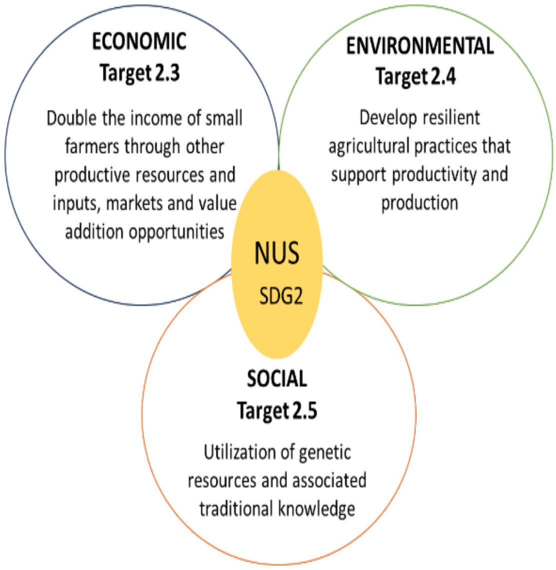

Figure 1:The importance of NUS in the SDG 2

7. The challenges of the NUS

The existing knowledge of NUS is still scarce compared to that of major crops. For example, the studies on rice (title and keywords) found in Scopus are about 169 394 documents, whereas on amaranth, which is the most studied among the NUS, 7487 documents were found, followed by buckwheat with 4,780 documents. According to Adebo (2023), the exploitation and use of crops depends largely on existing knowledge, so there is still a large knowledge gap between the NUS and the major crops. Another point to consider is that the existing literature on NUS is divided into eight main concepts: i) neglected and underutilized species (NUS), ii) underutilized crops, iii) indigenous crops, iv) traditional crops, v) abandoned crops, vi) orphan crops, vii) minor crops, viii) smart foods, and ix) superfoods. This is in line with Mabhaudhi et al. (2017) that the use of many terms to refer to NUS has been attributed to the scattered nature of NUS research findings because of the lack of a consensual definition. Nevertheless, there is an emerging trend towards the use of neglected and underutilized species (NUS).

On the other hand, because of their lack of economic importance, NUS are in some cases treated as weeds by extension workers and researchers. Farmers who maintain these species are criticized for not keeping weed populations under control. However, the conservation work done by farmers is essential to preserve these species, as both ex situ and in situ conservation of the genetic diversity of underutilized species is extremely limited (Neupane & Poudel, 2021).

8. Research perspectives

The economic aspect has been the least studied. Therefore, more market studies are needed to evaluate the value chain of crops to identify and recommend potential areas for further development. In this sense, it was found that NUS have a high economic potential because they can find their way into the food, pharmaceutical, nutraceutical, energy, textile, ornamental industries, among others, since it has been documented that NUS have different functions and properties and there are still more to be discovered. Future studies should look for new and untapped market segments that could position farmers in low-competition areas with a blue ocean-type strategy if they focus on the innovation, creativity, and uniqueness offered by the NUS.

Empirical studies on NUS should be holistic and integrate the multiple functions of these crops. Currently, NUS are not part of the conceptual body of multifunctional agriculture (Esquivel-Marín et al., 2023). However, they play an important role in multifunctional agriculture and are key to operationalizing sustainable development in rural areas (Renting et al., 2009; Singh et al., 2019).

9. Conclusions and Recommendations

The main social functions include providing dietary diversity, food security, and preservation of traditional practices, cultural diversity, and ancestral knowledge. The main environmental functions are the provision of agrobiodiversity, resilience of agricultural systems, and provision and regulation of ecosystem services. Economically, the NUS functions as the main source of income for farmers in the most marginal areas.

It can be concluded that the cultivation of some NUS can be part of multifunctional agriculture, so it is recommended that governments adopt policies that help to internalize the multiple positive externalities that the cultivation of NUS provides, thereby encouraging the production of these crops. Particularly in some areas of Latin America, Asia, and Africa, where the Green Revolution has deposited the negative externalities of intensive agriculture, the cultivation of NUS is not a preference but a necessity and is key to achieving sustainable development that involves the people who live in the most socially vulnerable areas with marginal soils.

Finally, bilateral and multilateral north–south associations are recommended to help preserve and conserve these species, which will be the key to solving the problems posed by global warming.

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Author's contributions

E-M conceived the idea and prepared the initial outline of the manuscript. J-A supervised the writing and structuring of the manuscript.

Declaration of competing interest

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