Biotechnology of Neglected and Underutilized Legume Crops

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Sustainable Progress and Development

By

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This book first published 2026

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-0364-6462-2
ISBN (Ebook): 978-1-0364-6463-9

CONTENTS

CHAPTER 1

IMPORTANCE OF UNDERUTILIZED LEGUME CROPS

Abstract

Climate change has become a global concern, significantly impacting food and nutritional security worldwide, exacerbated by the increasing heatwaves and droughts. Moreover, various factors contribute to the challenges in food and nutritional security, including insufficient awareness of protein-rich crop cultivation strategies, excessive dependence on high-calorie staple crops, economic constraints, and the rapid growth of the global population. These factors collectively exert immense pressure on limited food resources, making it challenging to effectively meet the global food needs of the ever-growing population. Recent studies have underscored the importance of underutilized legume crops as a potential solution to ensure global food security while enhancing growth and productivity through improved soil quality via nitrogen fixation. Despite being less recognized than their mainstream counterparts, such as peas, cowpeas, and common beans, these underutilized legumes possess a rich source of proteins and fibres. Additionally, they serve as important reservoirs of bioactive compounds with therapeutic applications. Notably, biopeptides derived from these underutilized legumes have demonstrated promising effects on improving metabolism and treating various chronic diseases. This chapter aims to provide comprehensive understanding of the sustainable utilization of underutilized legumes to ensure food and nutritional security.

Keywords: Genetic diversity, Nutritional value, Therapeutic, Climate change

Introduction

Food and nutritional insecurity have become critical issues in the era of global climate change, leading to severe hunger and significant health problems (Bhat and Karim, 2009). Moreover, these insecurities also hinder the socio-economic development of countries facing such challenges. Factors such as the inevitable population increase, anthropogenic activities, declining water availability, and shrinking arable land have irreversibly impacted agricultural productivity (Cheng et al. 2019). Rapid industrialization, urbanization, and anthropogenic activities have contributed to intensive global warming, resulting in the decline of arable land due to the melting of polar ice (Arora et al. 2018). While the Green Revolution in the 1960s brought about extensive irrigation and the use of chemical fertilizers and pesticides, it also posed a severe threat to soil quality and fertility. As a result, agricultural scientists have started exploring alternative means to address these concerns, with legumes gaining attention due to their nutritional and soil improvement properties (Singh 2000).

In contrast to mainstream legumes, underutilized legumes have emerged as promising new sources of vegetable proteins with enhanced nitrogen-fixing ability (Bhat and Karim, 2009). They have also garnered increased visibility due to their better endurance under abiotic stress conditions, particularly drought stress. Recent research has highlighted their potential in combating hunger and malnutrition, thanks to their higher resilience and hardiness in the face of climate extremes (Cheng et al. 2019). Furthermore, a substantial body of literature suggests that underutilized legumes can thrive in agroecological conditions when cultivated using good agricultural practices. Underutilized legume crops exhibit significant genetic diversity within their wild species in contrast to their cultivated counterparts (Smykal et al. 2015). These leguminous species of limited utilization are predominantly farmed across Asia, Africa, and North America, where they serve as prominent reservoirs of proteins, vitamins, dietary fibre, minerals, and diverse bioactive compounds (Popoola et al. 2019). Among these species, lablab bean, African yam bean, Bambara groundnut, lima bean, and winged bean are noteworthy members of the underutilized legume category, displaying considerable potential to foster sustainable agricultural practices and ameliorate global food and nutritional security concerns (Rai et al. 2021). Recent years have witnessed an upsurge in research endeavours devoted to underutilized legumes, characterizing them as functional foods with notable implications in managing various chronic ailments, including breast cancer, thereby imparting favourable impacts on human health (Prasad and Singh 2015).

A series of recent analyses focusing on the cultivation and utilization of underutilized legume crops has sparked heightened interest within the plant science community, underscoring their considerable significance and promising prospects in agriculture and the pharmaceutical industry. This surge in attention underscores the avenues for augmenting food productivity and soil vitality, thereby presenting a sustainable paradigm to effectively counteract the challenges posed by food insecurity amidst the dynamic backdrop of global climate shifts. Consequently, the ensuing discourse will accentuate efficacious methodologies for cultivating underutilized legumes, concurrently delving into their prospective applications within agricultural and pharmaceutical domains. By illuminating the intrinsic value of these crops and elucidating their multifaceted merits, will allow their exploitation into global agricultural initiatives aimed at amplifying food security and nurturing more healthful societies.

Historical overview of legume crop diversity

The intricate journey of legume crop diversity through the annals of history is a captivating narrative that unveils the remarkable interplay between human ingenuity, plant adaptation, and the evolution of agricultural practices (Paliwal 2021). Leguminous crops, belonging to the Leguminosae family, have etched their presence onto the landscape of human civilization, leaving an enduring mark on food systems, nutritional landscapes, and the very fabric of agricultural biodiversity (Ebert 2014). The roots of legume crops can be traced back to the genesis of agriculture itself, where leguminous plants commenced their evolutionary journey as wild species (Padulosi et al. 2002). These precursors to cultivated legumes exhibited an innate capacity to engage in a symbiotic dance with nitrogen-fixing bacteria residing within their root nodules (Chandra et al. 2020). This transformative relationship endowed legumes with the remarkable ability to harness atmospheric nitrogen, effectively enriching the soil in which they grew (Palai et al. 2019).

As humanity transitioned from nomadic ways to settled agricultural communities, the profound benefits of leguminous plants became increasingly evident (Mohanty et al. 2020). Early cultivators recognized the capacity of legumes to rejuvenate soil fertility, enhancing agricultural productivity in a sustainable manner (Mabhaudhi et al. 2017). The process of domestication involved an intricate balance between human selection and natural adaptation (Popoola et al. 2019). Cultivators, equipped with an incipient understanding of plant genetics, chose legume individuals

displaying desirable traits such as larger seeds, enhanced yields, improved taste, nurturing them through generations and transforming them into cultivated legume varieties (Minde et al. 2021). Legumes are invaluable agricultural companions by forging symbiotic partnerships with *Rhizobium* bacteria (Sprent et al. 2010). These microscopic allies, nestled within the roots of leguminous plants, facilitated the conversion of atmospheric nitrogen into bioavailable forms that nourished the plants themselves (Rai et al. 2021). This symbiotic relationship elevated legumes' nutritional content and gave them the power to enhance soil fertility. This unique attribute enabled early agricultural communities to engage in more sustainable and productive cropping systems, where legumes play pivotal role of natural nutrient replenishers in crop rotations (Adegboyega, 2019).

The domestication of legume crops transcended themselves as a nutritional reservoir permeating cultural and culinary domains (Considine et al. 2017). Across diverse civilizations, legumes became revered staples, particularly for their nutritional value, storability, and versatility in the kitchen. From the creamy indulgence of lentil soups to the hearty richness of chickpea stews, legumes became the keystones of countless traditional dishes, symbolic of cultural heritage and gastronomic activity (Aditya et al. 2019). In the wake of the Green Revolution and the ascendancy of high-yielding cereal crops, the importance of legumes experienced a momentary decline (Palai et al. 2019). However, a contemporary resurgence of interest in legume diversity is reshaping the agricultural landscape. The legumes' unparalleled ability to fix nitrogen and enrich soils, coupled with their nutritional prowess, is significantly boosting the efforts to reintegrate them into cropping systems (Joshi et al. 2008). The genetic diversity concealed within underutilized legumes contain genes imparting resilience against pests, diseases, and shifting climatic patterns, cultivating a sustainable path forward in agriculture.

Nutritional value and health benefits of underutilized legumes

Ensuring global food security presents a complex challenge in the contemporary era. Prolonged reliance on predominant staple crops such as wheat, rice, and maize has resulted in pronounced repercussions on a nutritional, agronomic, and economic nature (Bhartiya et al. 2015). Simultaneously, the increasing incidences of malnutrition has provoked a dual burden encompassing undernutrition, vitamin/mineral deficiencies, and underweight individuals, as well as overnutrition, resulting in

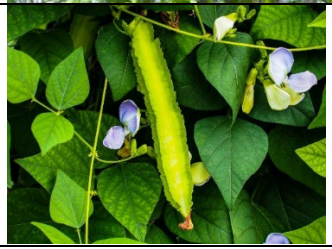
conditions such as diabetes, cancer, and cardiovascular diseases (Jena et al. 2018). According to data sourced from the World Health Organization (WHO), approximately 462 million individuals grapple with malnutrition globally, comprising 194 million children afflicted by underweight conditions and 2.5 billion adults contending with overweight issues (Popoola et al. 2019). Furthermore, research investigations have underscored the significant impact of severe nutritional deficiencies on healthcare costs, recuperative outcomes, and mortality rates, positing that substantial improvements could be achieved through the mitigation of malnutrition (Nayak et al. 2022). Contemporary society has witnessed a considerable dependency on artificial or animal-derived protein supplements, a trend fraught with inherent health risks and substantial economic burdens (Tan et al. 2020). Consequently, the paradigm of plant-based proteins is emerging as a viable alternative to animal-based counterparts, poised to meet the nutritional and pharmaceutical demands of a burgeoning global population (Murthy and Paek 2020).

Underutilized leguminous species, characterized by their economic viability and protein-rich composition, have historically remained underappreciated but hold significant potential for fortifying food, nutritional, and health security (Jena et al. 2018). Noteworthy among these underutilized legumes are *Lablab purpureus* L. (Indian bean*), Vigna subterranea* (Bambara groundnut), *Canavalia ensiformis* (Jack bean), *Phaseolus lunatus* (Lima bean), and *Phaseolus edulis* (sword bean). These legumes represent valuable reservoirs of protein, dietary fibre, essential minerals, and dietary lipids (Rai et al. 2021a). Additionally, *Cassia hirsute* L. and *Mucuna pruriens* emerge as high-protein, underutilized legumes, exhibiting substantial concentrations of minerals, lipids, dietary fibre, and crude protein within various parts, including pods, seeds, tuberous roots, and edible leaves (Minde et al. 2021). Extensive literature substantiates that many underutilized legumes, such as species belonging to the *Bauhinia* and *Canavalia gladiata* genera, surpass soybean in terms of protein content (Ebert, 2014). Furthermore, these underutilized legumes consistently present a protein range of 45-55 g/kg, lipids in the range of 55-75 g/kg, and fibre content between 25-35 g/kg (Pasricha et al. 2014). Among all, lima bean has intrigued researchers around the globe owing to its high protein composition (20-295%), lipid content (6-7%) and carbohydrate content (50-60%) compared to other mainstream legumes (Bhat and Karim, 2009). Numerous research findings highlight the enriched profiles of amino acids and fatty acids within certain underutilized legumes, such as *Vigna aconitifolia*, *V. vexillata*, and *Bauhinia malabarica*, with notable

concentrations of glutamic acid, oleic acid, and linoleic acid (Popoola et al. 2023).

A wealth of scientific investigations has underscored the substantial presence of bioactive and therapeutic compounds within underutilized leguminous species (Table 1.1), establishing their pivotal role in mitigating the effect of chronic diseases (Jena et al. 2018). Both conventional and underutilized legumes act as rich reservoirs of flavonoids, alkaloids, carotenoids, terpenoids, omega-3-fatty acids, and anthocyanins (Kaundal et al. 2019). These secondary metabolites have garnered recognition for their multifaceted functionality as antioxidants, antimicrobial agents, anti-inflammatory agents, anti-cancer agents, and anti-tumour agents, and their contribution to shielding plants against a wide array of biotic and abiotic stresses (Ikhajiagbe et al. 2022). Recent research has unveiled the presence of bioactive compounds in diverse underutilized leguminous crops, including but not limited to lima bean, winged bean, yam bean, and Bambara groundnut (Babalola et al. 2017). Remarkably, these underutilized legumes exhibit the potential to serve as nutraceuticals, offering an array of health benefits such as enhanced digestion, attenuation of various chronic diseases, including heart disease and diabetes, and support for weight management (Sharma and Thakur 2022). Moreover, recent investigations have revealed the existence of dietary fibres, polyphenols, and other antioxidative compounds within both the seeds and pods of these legumes, which are instrumental in scavenging reactive oxygen species (Murthy and Paek 2020). Effectively harnessing these compounds by applying appropriate techniques holds the promise of averting various degenerative diseases in human and animal populations.

Table 1.1: Taxonomy of underutilized legume crops and their nutritional and pharmaceutical attributes

Legume Crop	Nutritional Properties	Pharmaceutical Properties	Plant morphology
Bambara Groundnut	High protein content, rich in fiber, vitamins, and minerals.	Antioxidant compounds, potential anti-inflammatory agents.	
Mucuna Pruriens	High protein, fiber, and mineral content. Contains L-DOPA, a precursor to dopamine.	Used in traditional medicine for its neurological benefits.	
Winged Bean	Rich in protein, vitamins (A and C), and minerals (calcium, iron).	Antibacterial and anti-inflammatory properties.	

Velvet Bean (Mucuna)	Abundant protein, vitamins (B1, B2, and B3), and minerals. L-DOPA content.	Used in Parkinson's disease management due to L-DOPA.	
Chickling Vetch	Good protein source, high in dietary fiber, and vitamins (A and C).	Potential antioxidant and antimicrobial activities.	
Lablab Bean	Protein-rich, high in dietary fiber, vitamins (A and C), and minerals.	Potential anti-inflammatory and anti-diabetic properties.	

Jack Bean	High protein content, rich in dietary fiber, vitamins (A and C), and minerals.	Used traditionally for its antimicrobial properties.	
Rice Bean	Good protein source, high in dietary fiber, vitamins (B1 and B2), and minerals.	Contains antioxidants with potential health benefits.	
Pigeon Pea	Protein-rich, good source of dietary fiber, vitamins (A and C), and minerals.	Traditional use in Ayurvedic medicine for various ailments.	

Guar	High protein content, rich in dietary fiber, vitamins (A and C), and minerals.	Potential applications in pharmaceutical formulations.		

Agroecological and environmental contributions

The utilization of underutilized legume crops holds significant promise in addressing various environmental challenges and enhancing sustainable agricultural practices (Tan et al. 2020). Several studies have performed comprehensive exploration of the adaptability and resilience of underutilized legumes in different environmental conditions (Singh et al. 2016). Additionally, they have also unravelled their vital role in facilitating nitrogen fixation, enhancing soil fertility, promoting water use efficiency, and contributing to climate change mitigation (Popoola et al. 2019). Underutilized legume crops exhibit remarkable adaptability and resilience across diverse environmental conditions (Table 1.2). Unlike some conventional crops that require specific soil types or climate conditions, underutilized legumes often thrive in marginal lands and adverse climates (Feldman et al. 2019). This adaptability makes them valuable resources for expanding agriculture into less hospitable regions, thereby reducing pressure on prime agricultural lands and preserving natural ecosystems (Feldman et al. 2019). Underutilized legumes have been cultivated successfully in arid and semi-arid regions where water scarcity is a prevalent issue. Species like Bambara groundnut, Indian bean, cowpea, and chickpea have demonstrated their ability to endure prolonged drought periods (Singh et al. 2016). This resilience helps ensure food security in regions vulnerable to erratic rainfall and water scarcity.

The underutilized legumes have been shown to exhibit all the three drought tolerance traits such as avoidance, escape and tolerance, making them "super plants" that can withstand a wide range of environmental perturbations without compromising yield (Mayes et al. 2019). For example, increasing literature on Bamabra groundnut has shown its potential to tolerate a wide range of temperature fluctuations, i.e., capable of growing in the arid environment of Botswana to the more humid climate in Indonesia (Tan et al. 2020). Further studies have indicated that it is the only underutilized legume that can sustain the progressive climate change in South Africa without affecting its growth and productivity (Mabhaudhi et al. 2018). Their study also demonstrated that yield of Bamabra groundnut will increase by 35% under climate change, and the area for Bamabra groundnut cultivation will also rise in South Africa (Mabhaudhi et al. 2018; Mayes et al. 2019). Concomitantly in India, underutilized legumes are a pivotal source of plant-based proteins and contribute 62% towards food and health security of ethnic communities (Mabhaudhi et al. 2018). In the Indian subcontinent, these underutilized legumes are cultivated across different agroecological regions ranging from humid/western Himalayan region,

Bengal Assam basin, humid/eastern Himalayan region, Arid western plain, semi-arid lava plateau and central highlands (Tan et al. 2020). Approx. Seven hundred nineteen economically important legumes have been reported, out of which four hundred species belonging to 35 genera are commonly cultivated considering their nutritional and pharmaceutical importance (Varaprasad et al. 2011).

Nitrogen is a critical element for plant growth, and legumes are known for their unique ability to fix atmospheric nitrogen through a symbiotic relationship with nitrogen-fixing bacteria, commonly known as rhizobia (Ayilara et al. 2022). This process enhances soil fertility by converting atmospheric nitrogen into a form that plants can readily absorb. The importance of nitrogen fixation by underutilized legumes cannot be overstated, especially in regions with limited access to synthetic fertilizers (Babalola et al. 2017). Legume crops fulfil their nitrogen requirements and leave a surplus of fixed nitrogen in the soil. This surplus can benefit subsequent crops, reducing the need for synthetic fertilizers and minimizing the environmental impact associated with their production and use (Mayes et al. 2019). Thus, underutilized legumes such as cowpea, Indian bean, Lima bean and cluster beans play a pivotal role in sustainable crop rotation systems that maintain soil health and productivity. Beyond nitrogen fixation, underutilized legume crops contribute to soil fertility in various ways. Their deep root systems help improve soil structure, enhancing water infiltration and reducing erosion. Legumes also release organic compounds into the soil, increasing microbial activity and nutrient cycling. These processes promote overall soil health and reduce the need for external inputs like chemical fertilizers and pesticides (Tan et al. 2020).

Furthermore, underutilized legumes can be incorporated into agroecological practices such as intercropping and cover cropping (Cheng et al. 2019). When grown alongside other crops, they act as natural mulch, suppressing weed growth and reducing the need for herbicides. Additionally, their ability to fix nitrogen benefits neighbouring crops, resulting in higher yields and reduced nutrient runoff into water bodies (Brockwell et al. 2005). Underutilized legumes can also be integrated into conservation agriculture practices, which emphasize minimal soil disturbance and permanent soil cover. By reducing the need for excessive irrigation and conserving soil moisture, they contribute to sustainable water management. In regions prone to drought, the cultivation of drought-resistant legume varieties can further enhance water use efficiency (Popoola et al. 2019).

Table 1.2: Underutilized legume crops with corresponding cultivation strategies and agronomic approaches for enhanced growth and yield

Legume crop	Cultivation techniques	Agronomical practices
Bambara Groundnut	Well-drained sandy loam soil; direct seeding or transplanting; proper spacing.	Rhizobium inoculation for nitrogen fixation; regular weeding.
Mucuna Pruriens	Warm climate; direct seeding; trellising for support.	Organic matter incorporation; phosphorus application.
Winged Bean	Loose, well-drained soil; direct seeding; trellising for vertical growth.	Proper water management; foliar nutrient application.
Velvet Bean (Mucuna)	Tropical climate; direct seeding or transplanting; trellising or staking.	Rhizobium inoculation for nitrogen fixation; pest management.
Chickling Vetch	Sandy loam soil; direct seeding; proper row spacing.	Phosphorus and potassium supplementation; pest control.
Lablab Bean	Well-drained soil; direct seeding or transplanting; support for vine growth.	Adequate irrigation; intercropping with compatible crops.
Jack Bean	Sandy loam soil; direct seeding; ample spacing between plants.	Organic mulching; balanced nutrient application.
Rice Bean	Well-drained loamy soil; direct seeding; row spacing for air circulation.	Proper crop rotation; disease and pest monitoring.
Pigeon Pea	Sandy loam soil; direct seeding or transplanting; adequate spacing.	Phosphorus and potassium fertilization; pruning for bushy growth.
Guar	Sandy soil with good drainage; direct seeding; spacing for plant development.	Soil moisture conservation; pest and weed management.

Economic and socio-cultural aspects

Underutilized legume crops have the potential to serve as a powerful tool for income generation and poverty alleviation, particularly in rural and marginalized communities (Padulosi et al. 2002). Their resilience and adaptability to various environmental conditions mean that they can be cultivated in regions where other crops struggle to thrive (Ojuederie et al. 2021). This makes underutilized legumes a reliable source of income for

smallholder farmers, who often lack access to superior agricultural resources and thrive under climate extremes. The legumes, such as lima beans, Indian beans and Bambara groundnuts, require minimal inputs and can be grown with limited access to synthetic fertilizers and pesticides (Zhou 1999). This reduces production costs and makes them accessible to resource-constrained farmers. The sale of underutilized legume crops in local and regional markets can provide a steady source of income, enabling households to meet their basic needs and invest in education and healthcare (Mondo et al. 2021). Furthermore, underutilized legumes play pivotal role in crop diversification, reducing dependence on a single crop and increasing resilience to market fluctuations. This diversification can shield farmers from the adverse impacts of crop failure and price volatility, further contributing to poverty reduction (Kouonon et al. 2020).

Underutilized legume crops, spanning a diverse range of species, hold profound cultural significance in numerous communities worldwide. These legumes are more than just agricultural commodities; they are symbolic of cultural identity, heritage, and traditions passed down through generations (Jain and Gupta, 2013). For example, Chickpeas are a staple in Middle Eastern cuisine, playing a central role in dishes like hummus and falafel. In contrast, in India, they are used in various dishes like chana masala and are featured prominently during festivals and celebrations, underscoring their cultural significance (Jain and Gupta, 2013). Likewise, Cowpeas are a dietary staple in West Africa, forming the basis of dishes like "achara" (fried bean cakes) and "waakye" (a rice and cowpea dish). On the other hand, in the Southern United States, cowpeas, often referred to as "field peas" or "black-eyed peas," are a vital element of soul food cuisine (Mayes et al. 2019). Bambara groundnuts have deep cultural roots in Sub-Saharan Africa, where they are used in various culinary preparations. They feature prominently in rituals, ceremonies, and traditional feasts, symbolizing the connection between food and culture (Mondo et al. 2021).

While underutilized legumes have been historically undervalued in commercial markets, there is a growing awareness of their nutritional value and environmental benefits. This presents exciting opportunities for marketing and commercialization in both traditional and modern contexts. Traditional markets: Underutilized legumes have been staples of local diets and needs for centuries in many regions. Strengthening the value chains for these crops can enhance their economic importance (Jain and Gupta, 2013). Initiatives that support smallholder farmers in improving post-harvest handling, storage, and marketing can help tap into existing traditional markets and increase the income generated from these crops. Modern

markets: With the increasing demand for nutritious and sustainable foods, underutilized legumes are gaining attention in current food markets (Negi and Maikhuri, 2013). They are recognized for their protein-rich composition, drought resistance, and low environmental footprint. Food companies and entrepreneurs are exploring the incorporation of these legumes into various food products, from snacks to plant-based meat alternatives (Negi and Maikhuri, 2013). International organizations and governments are also promoting underutilized legumes as part of their sustainable development agendas. These initiatives include research and development projects, capacity-building programs, and policy support that facilitate the integration of underutilized legumes into mainstream agriculture and food systems.

Underutilized legumes in sustainable agriculture

Underutilized legumes have been an integral part of traditional farming systems worldwide, offering numerous advantages for sustainable agriculture (Rathi et al. 2021). Two effective conventional practices in which underutilized legumes excel are intercropping and crop rotation. Underutilized legumes are well-suited for intercropping, a technique where different crops are cultivated together in the same field (Mal, 2007). Their ability to fix atmospheric nitrogen enriches the soil with this vital nutrient, benefiting the legume and the companion crops. For instance, intercropping maize with cowpeas or pigeon peas provides a natural source of nitrogen, reducing the need for synthetic fertilizers (Ebert, 2014). Moreover, intercropping helps deter pests and diseases through plant diversity, reducing the reliance on chemical pesticides. This practice enhances soil fertility and increases overall crop yield per unit area, contributing to sustainable food production. Cowpeas are a classic example of an underutilized legume that excels in intercropping systems and in regions of sub-Saharan Africa, where farmers commonly intercrop maize or sorghum with cowpeas (Gulzar and Minnaar, 2017). The cowpea's ability to fix nitrogen enriches the soil, benefiting both crops and reduces the need for synthetic fertilizers to enhance overall crop yield. Another example includes pigeon peas, another underutilized legume known for their suitability in intercropping (Singh et al. 2022). Farmers intercrop pigeon peas in India with crops like pearl millet and cotton. The nitrogen-fixing capacity of pigeon peas enhances soil fertility and supports companion crops while also offering economic diversity (Singh et al. 2022).

Moreover, underutilized legumes are ideal for crop rotation systems, where different crops are grown sequentially on the same land. Legumes like chickpeas and lentils break the life cycles of pests and diseases specific to other crops, reducing their incidence (Ikhajiagbe et al. 2022). This practice minimizes the need for chemical interventions, promoting soil health and reducing environmental impacts (Bhartiya et al. 2015). Crop rotation with legumes improves soil structure and reduces erosion, as their root systems enhance soil stability. This contributes to the long-term sustainability of agricultural landscapes by maintaining soil fertility and reducing the risks of land degradation (Joshi et al. 2008). Chickpeas are an excellent example of underutilized legumes used in crop rotation systems and are rotated with cereals like wheat and barley (Palai et al. 2019). Their presence disrupts the life cycles of pests and diseases specific to grains, reducing the need for chemical interventions and promoting soil health (Mabhaudhi et al. 2017). Lentils are commonly integrated into crop rotation systems in Canada, where they are grown alongside wheat or canola. This practice enhances soil fertility, as lentils and legumes fix nitrogen. It also contributes to diversified crop options and sustainable pest management (Chivenge et al. 2015).

Underutilized legumes contribute to agrobiodiversity by diversifying crop options. In traditional farming systems, they are often grown alongside other crops, increasing overall crop diversity (Nayak et al. 2022). This diversity supports pollinators and beneficial insects, which are essential for crop pollination and pest control (Chivenge et al. 2015). By promoting a wide variety of crops, underutilized legumes help maintain a healthier and more resilient agricultural ecosystem (Nayak et al. 2022). Agroforestry combines the cultivation of trees with other crops or livestock. Underutilized legume trees, such as acacia and leucaena, have nitrogen-fixing abilities that enhance soil fertility and provide valuable forage for livestock (Mabhaudhi et al. 2017). These legume trees also promote carbon sequestration, mitigating climate change by capturing and storing atmospheric carbon dioxide in their biomass and root systems (Minde et al. 2021). Additionally, they contribute to the preservation of native vegetation by providing alternative sources of fuelwood and timber, reducing the pressure on natural forests (Minde et al. 2021).

Challenges and constraints in promoting underutilized legume crops

The Green Revolution, the Third Agricultural Revolution, has exerted a profound global impact on food and nutritional security. This transformation has been achieved through the amalgamation of traditional agricultural practices with technological advancements (Paliwal et al. 2021). Notably, it has engendered significant diversification within local crop varieties, enriching our food and nutritional repertoire. This diversification has been facilitated by food production enterprises, which have intensified their operations through the adoption of mechanized processes (Padulosi et al. 2002). Despite the monumental strides achieved by the Green Revolution and associated technological advancements, underutilized legume crops remain orphan and obscure for an extended period, despite their inherent attributes as a rich source of protein, which holds the potential to combat nutritional insecurity (Paliwal et al. 2021).

Furthermore, these underutilized legumes possess the capacity to enhance the growth and productivity of other economically consequential crops by augmenting nitrogen fixation processes and enhancing tolerance to biotic and abiotic stressors (Padulosi et al. 1999). The Food and Agricultural Organization (FAO) has comprehensively documented the persistent decline in soil fertility and the regenerative capacity of soils, rendering agricultural systems increasingly susceptible to infestations by insect and pest populations (Padulosi et al. 1999). As crops become progressively vulnerable to the manifestations of climate change, food production enterprises are confronted with escalating challenges in their efforts to provide consumers with healthful dietary options, thus anticipatively observing a diminishment in the availability of naturally derived plant-based nutritional offerings in the foreseeable future (Rai et al. 2021).

Due to their significant nutritional and pharmaceutical value, underutilized legumes are pivotal in propelling a nascent Green Revolution, offering promising avenues for addressing the formidable challenges of poverty and malnutrition in diverse developing nations (Rai et al. 2021a). Simultaneously, it is imperative to promptly discern and amass these underutilized legumes, as their existence becomes increasingly imperilled due to escalating anthropogenic activities and the dwindling availability of their seeds within gene banks (Mabhaudhi et al. 2017). Numerous underutilized legume species, replete with latent nutraceutical and pharmaceutical potential, have been ascertained across the global expanse, positively representing a transformative opportunity to impact rural

communities' livelihoods (Mabhaudhi et al. 2017a). However, the rise of underutilized legumes to competitive standing compared to mainstream legumes necessitates a concerted research drive and rural advisory services driven by acknowledging the pervasive barriers impeding their broader adoption. These barriers encompass:

1. A pronounced dearth of ex-situ and in-situ genetic diversity.
2. A scarcity of accessible seeds and other reproductive materials essential for their integration into breeding programs.
3. Adequate sharing of genetic resources between public sector units (PSUs) and farmers is crucial for sustaining crop diversity.
4. A deficiency in the availability of high-yielding cultivars and varieties tailored to the specific needs of underutilized legumes.
5. A shortage of optimal agricultural practices, often characterized by intensive labour inputs, intertwined with cultivation and harvesting.
6. The steep decline in arable land as a consequent of rapid industrialization and urbanization.

Furthermore, impediments to marketing and value chain dynamics exert a sustainable influence on the progression of products rooted in underutilized legumes, as well as strategies for market development and diversification (Popoola et al. 2019). Moreover, formulating investment strategies and formulating judicious decision-making policies concerning packaging and processing procedures encounter substantial complexities when applied to underutilized legumes. This complexity arises due to the lack of comprehensive information and resources tailored to these specific crops (Rathi et al. 2021). Numerous barriers contribute to the multifaceted challenges in this domain, such as:

Disrupted value chains: Value-chain disruption result in diminished price incentives associated with underutilized legumes.

Market knowledge deficiency: Inadequate market knowledge and a shortage of collaborative initiatives result in the establishment of inefficient market linkages.

Entrepreneurial skills deficit: A general lack of interest in fostering business support services due to lack of entrepreneurial skills in this sector.

Transportation, packaging, and processing constraints: Inadequacies in transportation, packaging, and processing techniques adversely affect the quality of underutilized legume products.

Labour-intensive processes: The cultivation, harvesting, and subsequent processing of these crops necessitate substantial labour inputs, with a disproportionate burden often borne by women.

Limited market reach: Insufficient market understanding for underutilized legumes is engendered by a lack of awareness about their cultivation and agronomic practices.

Regulatory framework shortcomings: An absence of robust regulatory policies governing their cultivation and utilization hinders the integration of underutilized legumes into the purview of the food and pharmaceutical industries.

Recent investigations have shed light on the prevailing adverse perceptions regarding the nutritional attributes of underutilized legumes, particularly among younger demographic cohorts, thereby impacting their efficacious utilization (Babalola et al. 2017). Frequently categorized as crops associated with economically disadvantaged segments of society or relegated to the realm of forage crops for animal husbandry, underutilized legumes encounter impediments to commercialization within more economically developed nations (Rathi et al. 2021). Nevertheless, countries such as India, Brazil, and Nigeria house substantial middle-class populations poised to embrace underutilized legumes as sources of healthful, pesticide-free food. These countries have seamlessly woven these legumes into their culinary traditions, effectively generating demand among lower-income households. However, persistent barriers persist, characterized by:

Cultural erosion: The erosion of cultural diversity has led to a knowledge deficit concerning traditional food preparation techniques for underutilized legumes.

Innovative recipes: The absence of creative, time-efficient culinary recipes that align with modern dietary practices.

Nutritional awareness: A scarcity of accessible nutritional information capable of mitigating potential health risks and ailments.

Agronomic knowledge gap: A limited understanding of sound agronomic practices conducive to efficient cultivation and the preservation of nutritional properties within underutilized legumes.

Conclusion

Underutilized legumes represent a vital component of sustainable agriculture, offering an array of advantages derived from their compatibility with traditional farming systems. These legumes play exceptional role in intercropping and crop rotation, significantly contributing to soil fertility and pest control. Intercropping with underutilized legumes, such as cowpeas and pigeon peas, can reduce reliance on synthetic fertilizers and chemical pesticides while increasing overall crop yield. Furthermore, crop rotation involving legumes like chickpeas and lentils disrupts the life cycles of pests and diseases, minimizing the need for chemical interventions and promoting soil health. Additionally, underutilized legumes foster agrobiodiversity by diversifying crop options, supporting pollinators, and enhancing pest control. However, the adoption of underutilized legumes faces several challenges. Addressing these barriers requires concerted research efforts, rural advisory services, and policies to promote the cultivation and utilization of underutilized legume crops. In a broader context, underutilized legumes hold promise in mitigating global challenges such as poverty, malnutrition, and environmental sustainability. Their nutritional and pharmaceutical significance can potentially drive a new wave of agricultural development akin to the Green Revolution. However, urgent action is needed to conserve these legumes and unlock their full potential to benefit rural communities and global food security.

References

Adegboyega, T.T., 2019. Genetic diversity and nitrogen fixation in underutilized tropical legumes (Doctoral dissertation, North-West University (South Africa)).

Aditya, J.P., Bhartiya, A., Chahota, R.K., Joshi, D., Chandra, N., Kant, L. and Pattanayak, A., 2019. Ancient orphan legume horse gram: a potential food and forage crop of future. Planta, 250, pp.891-909.

Arora, N.K., Fatima, T., Mishra, I., Verma, M., Mishra, J. and Mishra, V., 2018. Environmental sustainability: challenges and viable solutions. Environmental Sustainability, 1, pp.309-340.

Ayilara, M.S., Abberton, M., Oyatomi, O.A., Odeyemi, O. and Babalola, O.O., 2022. Potentials of underutilized legumes in food security. Frontiers in Soil Science, 2.

Babalola, O.O., Olanrewaju, O.S., Dias, T., Ajilogba, C.F., Kutu, F.R. and Cruz, C., 2017. Biological nitrogen fixation: the role of underutilized

leguminous plants. Microorganisms for Green Revolution: Volume 1: Microbes for Sustainable Crop Production, pp.431-443.

Babalola, O.O., Olanrewaju, O.S., Dias, T., Ajilogba, C.F., Kutu, F.R. and Cruz, C., 2017. Biological nitrogen fixation: the role of underutilized leguminous plants. Microorganisms for Green Revolution: Volume 1: Microbes for Sustainable Crop Production, pp.431-443.

Bhartiya, A., Aditya, J.P. and Kant, L., 2015. Nutritional and remedial potential of an underutilized food legume horsegram (*Macrotyloma uniflorum*): a review. JAPS: Journal of Animal & Plant Sciences, 25(4).

Bhat, R. and Karim, A.A., 2009. Exploring the nutritional potential of wild and underutilized legumes. Comprehensive Reviews in Food Science and Food Safety, 8(4), pp.305-331.

Brockwell, J., Searle, S.D., Jeavons, A.C. and Waayers, M., 2005. Nitrogen fixation in acacias: an untapped resource for sustainable plantations, farm forestry and land reclamation (No. 435-2016-33700).

Chandra, M.S., Naresh, R.K., Thenua, O.V.S., Singh, R. and Geethanjali, D., 2020. Improving resource conservation, productivity and profitability of neglected and underutilized crops in the breadbasket of India: A review. Breeding Science, 70(1), pp.19-31.

Cheng, A., Raai, M.N., Zain, N.A.M., Massawe, F., Singh, A. and Wan-Mohtar, W.A.A.Q.I., 2019. In search of alternative proteins: unlocking the potential of underutilized tropical legumes. Food Security, 11, pp.1205-1215.

Chivenge, P., Mabhaudhi, T., Modi, A.T. and Mafongoya, P., 2015. The potential role of neglected and underutilised crop species as future crops under water scarce conditions in Sub-Saharan Africa. International journal of environmental research and public health, 12(6), pp.5685-5711.

Considine, M.J., Siddique, K.H. and Foyer, C.H., 2017. Nature's pulse power: legumes, food security and climate change. Journal of Experimental Botany, 68(8), pp.1815-1818.

Ebert, A.W., 2014. Potential of underutilized traditional vegetables and legume crops to contribute to food and nutritional security, income and more sustainable production systems. Sustainability, 6(1), pp.319-335.

Feldman, A., Ho, W.K., Massawe, F. and Mayes, S., 2019. Bambara groundnut is a climate-resilient crop: how could a drought-tolerant and nutritious legume improve community resilience in the face of climate change? Sustainable Solutions for Food Security: Combating Climate Change by Adaptation, pp.151-167.

Gulzar, M. and Minnaar, A., 2017. Underutilized protein resources from African legumes. In Sustainable protein sources (pp. 197-208). Academic Press.

Ikhajiagbe, B., Ogwu, M.C., Ogochukwu, O.F., Odozi, E.B., Adekunle, I.J. and Omage, Z.E., 2022. The place of neglected and underutilized legumes in human nutrition and protein security in Nigeria. Critical Reviews in Food Science and Nutrition, 62(14), pp.3930-3938.

Jain, S.M. and Gupta, S.D., 2013. Biotechnology of neglected and underutilized crops (p. 459). Berlin, Germany: Springer.

Jena, A.K., Deuri, R., Sharma, P. and Singh, S.P., 2018. Underutilized vegetable crops and their importance. Journal of Pharmacognosy and Phytochemistry, 7(5), pp.402-407.

Joshi, K.D., Bhanduri, B., Gautam, R., Bajracharya, J. and Hollington, P.B., 2008. Rice bean: a multi-purpose underutilized legume. Smart, J. Haq, N. New crops and uses: their role in a rapidly changing world. CUC, UK, pp.234-248.

Kaundal, S.P., Sharma, A., Kumar, R., Kumar, V. and Kumar, R., 2019. Exploration of medicinal importance of an underutilized legume crop, *Macrotyloma uniflorum* (Lam.) Verdc.(Horse gram): a review. Int. J. Pharm. Sci. Res, 10(7), pp.3178-86.

Kouonon, L.C., Koffi, K.G., Adjoumani, K. and Goba, K.A.E., 2020. Morphological Variability of Neglected and Underutilized Legumes (NULs) Collection from Côte d'Ivoire. American Journal of Plant Sciences, 11(02), p.226.

Mabhaudhi, T., Chibarabada, T.P., Chimonyo, V.G.P., Murugani, V.G., Pereira, L.M., Sobratee, N., Govender, L., Slotow, R. and Modi, A.T., 2018. Mainstreaming underutilized indigenous and traditional crops into food systems: A South African perspective. Sustainability, 11(1), p.172.

Mabhaudhi, T., Chimonyo, V.G., Chibarabada, T.P. and Modi, A.T., 2017. Developing a roadmap for improving neglected and underutilized crops: A case study of South Africa. Frontiers in Plant Science, 8, p.2143.

Mal, B., 2007. Neglected and underutilized crop genetic resources for sustainable agriculture. Indian Journal of Plant Genetic Resources, 20(01), pp.1-14.

Mayes, S., Ho, W.K., Chai, H.H., Gao, X., Kundy, A.C., Mateva, K.I., Zahrulakmal, M., Hahiree, M.K.I.M., Kendabie, P., Licea, L.C. and Massawe, F., 2019. Bambara groundnut: an exemplar underutilised legume for resilience under climate change. Planta, 250, pp.803-820.

Minde, J.J., Venkataramana, P.B. and Matemu, A.O., 2021. Dolichos Lablab-an underutilized crop with future potentials for food and

nutrition security: a review. Critical Reviews in Food Science and Nutrition, 61(13), pp.2249-2261.

Mohanty, C.S., Singh, V. and Chapman, M.A., 2020. Winged bean: An underutilized tropical legume on the path of improvement, to help mitigate food and nutrition security. Scientia Horticulturae, 260, p.108789.

Mondo, J.M., Chuma, G.B., Kwalya, P.B., Balagizi, S.A., Ndjadi, S.S., Mugumaarhahama, Y., Balezi, A.Z., Karume, K., Mushagalusa, G.N. and Civava, R.M., 2021. Neglected and underutilized crop species in Kabare and Walungu territories, Eastern DR Congo: Identification, uses and socio-economic importance. Journal of Agriculture and Food Research, 6, p.100234.

Murthy, H.N. and Paek, K.Y., 2020. Health benefits of underutilized vegetables and legumes. Bioactive Compounds in Underutilized Vegetables and Legumes, pp.1-37.

Nayak, S.P., Lone, R.A., Fakhrah, S., Chauhan, A., Sarvendra, K. and Mohanty, C.S., 2022. Mainstreaming underutilized legumes for providing nutritional security. In Future Foods (pp. 151-163). Academic Press.

Negi, V.S. and Maikhuri, R.K., 2013. Socio-ecological and religious perspective of agrobiodiversity conservation: issues, concern and priority for sustainable agriculture, Central Himalaya. Journal of agricultural and environmental ethics, 26, pp.491-512.

Ojuederie, O.B., Popoola, J.O., Aremu, C. and Babalola, O.O., 2021. Harnessing the hidden treasures in African yam bean (*Sphenostylis stenocarpa)*, an underutilized grain legume with food security potentials. Food Security and Safety: African Perspectives, pp.1-20.

Padulosi, S., Eyzaquirre, P. and Hodgkin, T., 1999. Challenges and strategies in promoting conservation and use of neglected and underutilized crop species. Perspectives on new crops and new uses, pp.140-145.

Padulosi, S., Hodgkin, T., Williams, J.T. and Haq, N., 2002. Underutilized crops: trends, challenges and opportunities in the 21st century. In Managing plant genetic diversity. Proceedings of an international conference, Kuala Lumpur, Malaysia, 12-16 June 2000 (pp. 323-338). Wallingford UK: CABI Publishing.

Palai, J.B., Jena, J. and Maitra, S., 2019. Prospects of underutilized food legumes in sustaining pulse needs in India–A review. Crop Research, 54(3and4), pp.82-88.

Paliwal, R., Adegboyega, T.T., Abberton, M., Faloye, B. and Oyatomi, O., 2021. Potential of genomics for the improvement of underutilized legumes in sub-Saharan Africa. Legume Science, 3(3), p.e69.

Pasricha, V., Satpathy, G. and Gupta, R.K., 2014. Phytochemical & Antioxidant activity of underutilized legume Vicia faba seeds and formulation of its fortified biscuits. Journal of Pharmacognosy and phytochemistry, 3(2), pp.75-80.

Popoola, J., Ojuederie, O., Omonhinmin, C. and Adegbite, A., 2019. Neglected and underutilized legume crops: Improvement and future prospects. In Recent advances in grain crops research. IntechOpen.

Popoola, J.O., Ojuederie, O.B., Aworunse, O.S., Adelekan, A., Oyelakin, A.S., Oyesola, O.L., Akinduti, P.A., Dahunsi, S.O., Adegboyega, T.T., Oranusi, S.U. and Ayilara, M.S., 2023. Nutritional, functional, and bioactive properties of african underutilized legumes. Frontiers in Plant Science, 14, p.1105364.

Prasad, S.K. and Singh, M.K., 2015. Horse gram-an underutilized nutraceutical pulse crop: a review. Journal of food science and technology, 52, pp.2489-2499.

Rai, K.K., Pandey, N., Meena, R.P. and Rai, S.P., 2021. Biotechnological strategies for enhancing heavy metal tolerance in neglected and underutilized legume crops: A comprehensive review. Ecotoxicology and Environmental Safety, 208, p.111750.

Rai, K.K., Rai, N. and Pandey-Rai, S., 2021a. Unlocking pharmacological and therapeutic potential of hyacinth bean (*Lablab purpureus* L.): Role of OMICS based biology, biotic and abiotic elicitors. In Legumes Research-Volume 2. IntechOpen.

Rathi, D., Chakraborty, S. and Chakraborty, N., 2021. Grasspea, a critical recruit among neglected and underutilized legumes, for tapping genomic resources. Current Plant Biology, 26, p.100200.

Sharma, V. and Thakur, M., 2022. Horsegram [*Macrotyloma uniflorum*]: an underutilized pulse crop as a sustainable plant-based protein.

Singh, N.P., Praharaj, C.S. and Sandhu, J.S., 2016. Utilizing untapped potential of rice fallow of East and North-east India through pulse production. Indian Journal of Genetics and Plant Breeding, 76(04), pp.388-398.

Singh, R.B., 2000. Environmental consequences of agricultural development: a case study from the Green Revolution state of Haryana, India. Agriculture, ecosystems & environment, 82(1-3), pp.97-103.

Singh, R.K., Sreenivasulu, N. and Prasad, M., 2022. Potential of underutilized crops to introduce the nutritional diversity and achieve zero hunger. Functional & Integrative Genomics, 22(6), pp.1459-1465.

Smykal, P., Coyne, C.J., Ambrose, M.J., Maxted, N., Schaefer, H., Blair, M.W., Berger, J., Greene, S.L., Nelson, M.N., Besharat, N. and Vymyslický, T., 2015. Legume crops phylogeny and genetic diversity