

Exploring the Potential of Underutilized Legumes as Sustainable Protein Sources to Enhance Food Security and Nutrition: Global Perspectives and Insights from Nepal

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Abstract

Global food systems face unprecedented pressure from population growth, climate change, and resource degradation, intensifying the challenge of ensuring sustainable and nutritious diets. Protein insecurity remains particularly acute in developing regions, where high costs and environmental burdens constrain dependence on animal-based proteins. Underutilized legumes, including Bambara groundnut, winged bean, moth bean, and lupins, offer a promising yet overlooked solution. Rich in high-quality proteins, essential micronutrients, and bioactive compounds, these crops can improve nutrition, mitigate malnutrition, and reduce the prevalence of non-communicable diseases. Agronomically, their adaptability to marginal environments, drought resilience, and nitrogen-fixing ability enhance soil fertility and promote climate-smart agriculture, aligning directly with Sustainable Development Goals (SDGs 2, 12, and 13). However, barriers such as limited genetic improvement, processing constraints, weak markets, and cultural unfamiliarity hinder their wider adoption.

This research explores underutilized legumes' nutritional, environmental, and economic potential while addressing consumer acceptance and value chain integration challenges. Using a multidisciplinary approach, it incorporates laboratory analysis, processing innovations (germination, fermentation, extrusion), sensory evaluations, and environmental impact assessments. A case study from Nepal highlights both opportunities and constraints. Legumes such as lentils, chickpeas, soybeans, and indigenous pulses already contribute significantly to national food security and exports. Yet, productivity gaps, lack of improved varieties, and limited extension services continue to restrict their impact. Enhancing awareness, strengthening seed systems, and developing inclusive markets can unlock their potential to support smallholder livelihoods and dietary diversity.

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By bridging scientific research, consumer behavior, and policy frameworks, this study emphasizes the transformative role of underutilized legumes in fostering resilient food systems, advancing nutrition security, and promoting ecological sustainability in Nepal and beyond.

Keywords: underutilized legumes, food security, nutrition, sustainable protein, climate-smart agriculture, nutrition security

Introduction

The global food system is under vast stress as it seeks to meet the nutritional demands of a rapidly growing population while operating within ecological limits. The world's population, currently exceeding 8 billion, is projected to reach 9.7 billion by 2050, escalating the pressure on food supply chains and agricultural production systems (United Nations, 2022). At the same time, agriculture faces multiple stressors, including climate change, land degradation, soil erosion, water scarcity, and biodiversity loss. These challenges threaten food availability and access, particularly in developing regions where smallholder farmers dominate production and malnutrition remains widespread. Ensuring food security, therefore, requires innovative, sustainable, and inclusive approaches to agricultural development.

Proteins occupy a central role in human health, growth, and productivity. Nevertheless, protein insecurity persists as one of the critical dimensions of malnutrition in low- and middle-income countries. Much of the world's protein supply is derived from animal sources. While nutritionally valuable, animal-based proteins impose significant ecological costs, including high greenhouse gas emissions, water intensity, deforestation, and ethical concerns regarding industrialized production systems (Samal et al., 2023). Furthermore, animal protein costs are prohibitively high for poor and rural households in South Asia and sub-Saharan Africa, leaving large segments of the population vulnerable to protein-energy malnutrition and micronutrient deficiencies (Duranti, 2023).

Plant-based proteins, particularly legumes, have emerged as an attractive alternative. Grain legumes are not only rich in proteins, ranging from 20–25% of seed weight, but also contain complex carbohydrates, dietary fiber, essential amino acids, and micronutrients such as iron, zinc, and folate (Mudryj et al., 2014). Their health-promoting properties include lowering cholesterol, reducing glycemic response, and supplying bioactive compounds that help prevent chronic diseases, including diabetes, cardiovascular disease, and certain cancers (Sarkar et al., 2021). Beyond nutrition,

legumes deliver ecosystem services: they fix atmospheric nitrogen, enhance soil fertility, reduce dependence on synthetic fertilizers, and contribute to sustainable cropping systems through rotation and intercropping (Tadele et al., 2022). These characteristics make them key allies in climate-smart agriculture.

Despite these benefits, global food systems have remained narrowly focused on a few significant species- soybeans, chickpeas, common beans, and lentils—while numerous underutilized legumes with strong nutritional and ecological potential remain neglected. Crops such as Bambara groundnut, moth bean, winged bean, and lupins are traditionally cultivated in localized settings by indigenous or rural communities. However, they have not received adequate attention in terms of research, breeding, commercialization, or policy support (Cullis & Kunert, 2017). This neglect perpetuates their marginalization, resulting in limited awareness among consumers, weak market infrastructure, and minimal integration into mainstream food systems. Consequently, opportunities to harness their potential for addressing food and nutrition security are underexploited.

The social process of underutilized legumes is especially concerning in regions where protein deficiency is most pronounced. In South Asia and sub-Saharan Africa, rural households often subsist on cereal-based, calorie-dense, but protein- and micronutrient-poor diets. In Nepal, cereals such as rice, maize, and wheat dominate the farming system, yet legumes play a crucial complementary role. Lentils, chickpeas, soybeans, mung beans, and pigeon peas provide vital plant-based proteins for millions of impoverished and vegetarian populations (MoALD, 2023). They contribute to household food security, soil fertility, and national export earnings. However, yields remain low compared to global standards due to a lack of improved seed varieties, limited extension services, and market inefficiencies (Shrestha, 2023). For indigenous communities in remote regions, traditional and underutilized legumes are central to food sovereignty and climate adaptation strategies, further underlining their importance (Dhakal, 2021).

Addressing the nutritional needs of poor and rural populations demands reorienting food security strategies to include neglected and underutilized legumes. Their low input requirements, adaptability to marginal lands, and cultural significance position them as affordable and sustainable protein sources. Strengthening their role in food systems could mitigate malnutrition, enhance dietary diversity, and provide smallholder farmers with new livelihood opportunities. Moreover, their contribution extends beyond the farm and household: integrating underutilized legumes into global and national diets aligns with several United Nations Sustainable Development Goals (SDGs). Specifically,

they advance SDG 2 (Zero Hunger) by improving food and nutrition security, SDG 12 (Responsible Consumption and Production) by promoting sustainable diets, and SDG 13 (Climate Action) by fostering environmentally resilient agricultural practices.

In this context, the present research explores the nutritional, environmental, and socioeconomic potential of underutilized legumes as sustainable protein sources. By combining laboratory analysis, product development, consumer research, and case study insights from Nepal, the study highlights pathways for scaling up these crops to strengthen food security, promote climate-smart agriculture, and reduce the nutritional inequities of vulnerable populations.

Objectives of the study

- To analyze the protein content, micronutrient profile, and health benefits of at least five underutilized legume species cultivated in Nepal by conducting laboratory tests and nutritional profiling within the first six months of the study.
- To evaluate the environmental contributions of underutilized legumes, such as nitrogen fixation and soil fertility enhancement, through field trials and farmer interviews in two selected districts by the end of year one.
- To assess the socioeconomic impact of underutilized legumes on household food security and smallholder livelihoods among indigenous communities in Nepal through case studies and surveys conducted over 12 months.
- Within the first nine months, analyze market infrastructure, consumer awareness, and policy documents to identify at least three significant barriers to the commercialization and policy integration of underutilized legumes.
- To measure consumer awareness and cultural acceptance of underutilized legumes through structured questionnaires and focus group discussions with 300 participants across rural and urban settings by month ten.
- To develop a set of policy and programmatic recommendations for scaling up underutilized legumes in Nepal's food system, aligned with SDG 2, SDG 12, and SDG 13, and present them to stakeholders by the final quarter of the study.

Significance of the Study

This study is significant in its effort to reorient food security strategies toward inclusive, sustainable, and nutrition-sensitive solutions by elevating the role of underutilized legumes. In the face of global challenges-ranging from climate change and ecological degradation to protein insecurity and rural poverty- the research highlights how neglected

legume species can serve as affordable, culturally relevant, and environmentally resilient sources of nutrition. Focusing on indigenous communities in Nepal, the study addresses nutritional inequities and contributes to food sovereignty, climate-smart agriculture, and livelihood diversification. The findings are expected to inform policy frameworks, agricultural extension programs, and consumer education campaigns, ultimately supporting the achievement of Sustainable Development Goals (SDGs) 2 (Zero Hunger), 12 (Responsible Consumption and Production), and 13 (Climate Action). Moreover, the study bridges scientific analysis with grassroots realities, offering scalable pathways for integrating underutilized legumes into national and global food systems.

Literature Review

Nutritional Profile and Health Benefits

Legumes are well recognized as a cornerstone of healthy diets due to their high protein content, complex carbohydrates, dietary fiber, and a broad spectrum of micronutrients. Underutilized legumes, particularly, possess nutritional qualities that can significantly contribute to combating protein-energy malnutrition and “hidden hunger” in vulnerable populations. Studies highlight that many of these crops contain 20–25% protein by dry weight, placing them on par with or superior to more widely consumed legumes such as lentils and chickpeas (Mudryj, Yu, & Aukema, 2014). Their amino acid composition is often more balanced, providing essential building blocks for growth and repair (Samal et al., 2023).

In addition to macronutrients, underutilized legumes are rich in micronutrients such as iron, zinc, folate, and calcium, addressing widespread deficiencies in low-income regions. For instance, Bambara groundnut and moth bean provide higher levels of iron and zinc than common beans. In contrast, winged beans are notable for their exceptionally high protein quality and favorable amino acid profile (Babiker, El Tinay, & Mohamed, 2001). These nutritional attributes are particularly valuable for populations relying heavily on cereal-based diets, which often lack bioavailable micronutrients.

Legumes also contain bioactive compounds, including flavonoids, polyphenols, and antioxidants, demonstrating protective effects against non-communicable diseases. Duranti (2023) emphasizes their potential role in preventing type 2 diabetes, cardiovascular diseases, and certain cancers. Their low glycemic index supports stable blood sugar levels, making them suitable for populations facing rising incidences of obesity and diabetes. High dietary fiber content improves gut health, enhances satiety, and lowers cholesterol,

further contributing to their preventive health benefits (Sarkar, Li, & Reddivari, 2021).

Nationally, legumes play a similar role in Nepal, where they are referred to as “poor people’s meat” due to their affordability and accessibility (MoALD, 2023). For rural households unable to afford animal protein, lentils, chickpeas, soybeans, and indigenous pulses remain the most important protein sources. Their contribution to dietary diversity is especially critical given the high prevalence of micronutrient deficiencies: iron deficiency affects 35% of women and 46% of children under five, while zinc deficiency is estimated at 87% in children and 61% in pregnant women (Karki et al., 2024). Promoting underutilized legumes rich in micronutrients in such contexts offers a natural and culturally appropriate solution.

In sum, the nutritional and health benefits of underutilized legumes make them strategic candidates for addressing malnutrition, micronutrient deficiencies, and chronic disease burdens both globally and within Nepal.

Agronomic Characteristics and Environmental Resilience

From an agronomic perspective, underutilized legumes demonstrate remarkable adaptability to harsh environmental conditions. Many thrive in arid and semi-arid regions where conventional crops often fail. Popoola (2019) highlights their resilience to drought, pests, and poor soils, making them suitable for cultivation on marginal lands. This resilience is critical as climate change intensifies variability in rainfall and temperature, particularly in vulnerable regions of Africa and South Asia.

One of legumes' defining ecological functions is their ability to fix atmospheric nitrogen through symbiosis with rhizobia. This process enriches soil fertility, reduces dependence on synthetic fertilizers, and lowers greenhouse gas emissions associated with industrial fertilizer production (Herridge, Peoples, & Boddey, 2008). Reckling, Mueller, and Jørgensen (2022) further argue that such biological nitrogen fixation contributes significantly to carbon sequestration and soil health improvement, promoting long-term sustainability.

In addition to nitrogen fixation, legumes contribute to crop rotation and intercropping systems that diversify agricultural production, enhance biodiversity, and reduce pest and disease pressures (Tadele, Assefa, & Agegnehu, 2022). Underutilized legumes offer ecological benefits that can reduce input costs and improve resilience for smallholder farmers, especially in fragile agro-ecosystems.

In Nepal, these agronomic advantages are evident. Lentils, mung beans, soybeans,

and pigeon peas are grown across diverse agroecological zones, from the Terai plains to mid-hills (MoALD, 2020). Their short growth cycles allow for flexible integration into cereal-based cropping systems, enhancing farm-level resilience and productivity. Moreover, indigenous legumes adapted to marginal conditions support food sovereignty for mountain and hill communities. However, national yields remain far below potential, with averages around 1.1 t/ha compared to achievable research station yields exceeding 3 t/ha (Shrestha, 2023). This productivity gap underscores the need for improved varieties, seed systems, and agronomic practices.

Internationally and nationally, underutilized legumes stand out as climate-smart crops capable of sustaining productivity under increasingly unpredictable conditions. Their promotion aligns with ecological intensification strategies that reduce environmental footprints while supporting smallholder livelihoods.

Processing Technologies and Value Addition

Despite their nutritional and agronomic strengths, underutilized legumes face challenges related to processing and utilization. Many contain anti-nutritional factors such as phytates, tannins, and trypsin inhibitors, which reduce protein digestibility and mineral bioavailability (Shimelis & Rakshit, 2007). These compounds contribute to the perception of legumes as “inferior foods” and limit their inclusion in modern diets.

Processing technologies have been shown to mitigate these barriers while enhancing sensory qualities. Traditional methods such as soaking, boiling, and roasting reduce anti-nutritional factors, but modern innovations hold greater promise for large-scale adoption. Germination and fermentation enhance protein digestibility, increase bioavailability of micronutrients, and improve flavor (Caplice & Fitzgerald, 1999). Extrusion, widely used in the food industry, produces ready-to-eat products with improved palatability and texture while retaining nutrient content (Alvarez-Martinez, Kruk, LeBail, & Barbut, 2010).

Frias, Vidal-Valverde, and Hernández (2017) demonstrated that combined methods—such as germination followed by extrusion—yield products with reduced anti-nutrients and improved consumer acceptability. These techniques also open opportunities for product diversification, including legume-based flours, snacks, meat substitutes, and fortified foods.

In Nepal, processing remains a significant constraint. Farmers and consumers primarily use legumes in traditional dishes, with limited innovation in product development. Lack of infrastructure, technology, and investment in value addition restricts the integration

of legumes into modern food systems. However, increasing urbanization and demand for convenient, nutritious foods present an opportunity for scaling legume-based innovations if supported by research and private sector engagement (Dhakal, 2021).

Globally, the shift toward plant-based diets has spurred interest in developing legume-based protein isolates and functional foods. Underutilized species, with their superior functional properties (e.g., water absorption, gelation, emulsification), offer competitive advantages for the food industry (Samal et al., 2023). Harnessing these processing opportunities could significantly increase the visibility and marketability of neglected legumes.

Consumer Acceptance and Market Barriers

One of the most significant challenges facing underutilized legumes is consumer acceptance. Limited awareness of their nutritional and environmental benefits, combined with cultural unfamiliarity, reduces demand. In many societies, these crops are perceived as “poor man’s food” or traditional staples unsuited to modern diets (Poutanen, Shepherd, Appelqvist, & Conner, 2008). Such perceptions perpetuate a cycle of low demand, restricted market infrastructure, and limited cultivation (Mayes et al., 2012).

Market barriers further constrain adoption. Weak value chains, absence of structured markets, and lack of supportive policies discourage farmers from investing in underutilized legumes. Economic studies show that without consumer demand and market incentives, smallholder farmers struggle to scale production profitably (Langyintuo et al., 2016).

Nevertheless, evidence suggests that targeted interventions can shift consumer behavior. Graham, Padulosi, and Hadley (2021) emphasize the importance of awareness campaigns, school curricula, and culinary innovations in reshaping perceptions. Information about nutritional and environmental benefits has increased consumer willingness to purchase legume-based products (Verbeke, 2005). Furthermore, developing innovative, convenient, and appealing products—such as snacks, fortified flours, and plant-based meat analogs—can improve acceptance, particularly among urban populations.

In Nepal, market barriers are compounded by inadequate infrastructure, poor access to improved varieties, and weak extension services. Although lentils are a significant export, other legumes remain underdeveloped due to a lack of commercialization strategies and consumer awareness (Upadhyaya et al., 2022). However, the growing recognition of legumes as climate-resilient “Himalayan superfoods” suggests potential for niche marketing and

value chain development that links indigenous farmers to high-value markets (FAO, 2012).

Lessons from Africa and Asia show that improving seed systems, investing in processing industries, and promoting public-private partnerships are effective strategies for scaling underutilized legumes internationally. Integrating such approaches into Nepal's agricultural policies could strengthen domestic production, create livelihood opportunities, and improve food security.

Synthesis

The literature clearly establishes underutilized legumes as nutrient-dense, climate-resilient crops with significant potential to improve food security, particularly in rural and resource-poor contexts. Their agronomic strengths make them suitable for sustainable farming systems, while their nutritional qualities address macronutrient and micronutrient deficiencies. However, significant barriers persist regarding processing challenges, consumer acceptance, and weak market structures.

National evidence from Nepal underscores both the opportunities and limitations of legume production. While lentils have become a staple food and export commodity, other legumes remain neglected despite their potential to enhance food sovereignty and climate adaptation. International experiences demonstrate that research, technological innovation, and awareness-building can overcome these barriers, creating pathways for underutilized legumes to become integral to sustainable food systems.

Ultimately, scaling the contribution of underutilized legumes requires a holistic approach that integrates nutritional science, agronomy, food processing, consumer behavior, and policy reform. Such integration would enable these crops to advance multiple Sustainable Development Goals, particularly Zero Hunger, Responsible Consumption and Production, and Climate Action.

Methodology

This study employs a multidisciplinary research design to explore the potential of underutilized legumes as sustainable protein sources for enhancing food security, nutrition, and livelihoods. Qualitative and quantitative approaches combine laboratory-based nutritional analysis, processing innovations, consumer research, and socioeconomic assessments. The methodology is structured into six interlinked components, as described below.

Selection of Legumes

The study begins with the systematic identification and selection of underutilized legume species. Selection criteria include:

- Nutritional Value – Species with high protein concentrations ($\geq 20\%$ dry weight), balanced amino acid profiles, and notable micronutrient content (e.g., iron, zinc, folate, calcium).
- Agroecological Adaptability – Species capable of thriving in marginal environments, exhibiting drought tolerance, pest resistance, and low input requirements.
- Cultural and Indigenous Relevance – Crops traditionally cultivated by local communities but currently marginalized in mainstream agricultural systems.
- Market and Livelihood Potential – Species with emerging or niche market opportunities that can provide additional income for smallholder farmers.

Based on these criteria, Bambara groundnut (*Vigna subterranea*), moth bean (*Vigna centifolia*), winged bean (*Sporocarpus tetragonolobus*), and lupins (*Lupinus* spp.) will be prioritized for in-depth study. Commonly consumed legumes such as lentils and chickpeas will be used as reference controls to benchmark nutritional and functional properties.

Nutritional and Functional Analysis

Advanced laboratory techniques will be used to evaluate selected legumes' nutritional and bioactive properties.

- Proximate Composition: Protein, fat, carbohydrate, fiber, and ash content will be quantified using standard AOAC methods. Protein will be estimated using the Kjeldahl method.
- Amino Acid Profiling: High-Performance Liquid Chromatography (HPLC) will determine essential and non-essential amino acids, providing insights into protein quality.
- Micronutrient Analysis: The levels of iron, zinc, folate, and calcium will be measured using atomic absorption spectrophotometry (AAS).
- Bioactive Compounds: Antioxidant activity, polyphenols, and flavonoid concentrations will be assessed through spectrophotometric assays.
- Functional Properties: Water absorption capacity, oil-holding capacity, gelation, foaming, and emulsification properties will be analyzed, highlighting suitability for diverse food applications.

These analyses will establish a comparative nutritional and functional database for underutilized legumes against commonly consumed species.

Processing and Product Development

Recognizing that anti-nutritional factors and sensory limitations constrain adoption, the study will investigate traditional and modern processing methods to enhance palatability and digestibility.

- **Traditional Methods:** Soaking, boiling, and roasting will be evaluated for their effectiveness in reducing phytates and tannins.
- **Germination and Fermentation:** Germination will improve the bioavailability of micronutrients, while fermentation (using lactic acid bacteria and yeasts) will enhance flavor and protein digestibility.
- **Extrusion Technology:** High-temperature, short-time extrusion will be tested to produce legume-based flours and ready-to-eat products with improved sensory qualities.
- **Food Prototypes:** Legume-based snacks, composite flours, porridges, and plant-protein analogs (e.g., meat substitutes) will be developed. Nutrient retention post-processing will be measured.

This phase aims to fine-tune processing methodologies, create culturally acceptable products, and demonstrate practical applications of underutilized legumes.

Sensory and Consumer Acceptance Studies

Training sensory panels and community-based consumer trials will be conducted to assess acceptability and willingness to consume legume-based products.

- **Sensory Analysis:** A 9-point hedonic scale will be used to evaluate taste, texture, aroma, color, and overall acceptability of legume products.
- **Consumer Surveys:** Structured questionnaires will capture consumer perceptions, willingness to pay, and preferences for legume-based products.
- **Information Provision Experiments:** Testing whether providing nutritional and environmental benefit information increases consumer willingness to adopt underutilized legumes.
- **Cultural Familiarity Assessment:** Exploring how prior cultural exposure to specific legumes influences acceptance.

Data will be analyzed statistically using ANOVA and regression models to identify determinants of consumer acceptance.

Environmental and Economic Assessment

A sustainability framework will be applied to measure environmental and economic feasibility.

- **Life Cycle Assessment (LCA):** Carbon footprint, water use, and energy use of selected legumes will be compared with conventional protein sources (soybeans, animal proteins).
- **Soil Fertility Contribution:** Nitrogen fixation and potential to reduce synthetic fertilizer dependency will be assessed through literature data and field-level surveys.
- **Economic Viability:** Production costs, gross margins, and potential for value addition will be analyzed.
- **Comparative Analysis:** Profitability and sustainability of underutilized legumes will be benchmarked against conventional cereals and legumes.

The outcomes will provide evidence for policymakers, development agencies, and industry actors regarding integrating these legumes into sustainable food systems.

Feasibility for Rural Nutrition Promotion and Livelihood Support

A final component of the methodology focuses on translating scientific findings into practice for poor and rural populations. Pilot interventions will be designed in collaboration with local communities in Nepal:

- **Nutrition Promotion:** Integration of underutilized legumes into community-based nutrition programs, school feeding initiatives, and maternal-child health interventions.
- **Livelihood Support:** Training programs for smallholder farmers on cultivation practices, seed systems, and post-harvest handling.
- **Market Linkages:** Partnerships with cooperatives and private enterprises to develop value chains and niche markets for domestic and export legume products.
- **Participatory Research:** Engaging farmers and women's groups in product development and dissemination, ensuring cultural acceptability and long-term sustainability.

By emphasizing both scientific rigor and community-based application, the study seeks to demonstrate how underutilized legumes can directly improve dietary quality, household incomes, and environmental sustainability in low-resource settings.

Case Study: Legumes and Food Security in Nepal

Status of Legume Production

Agriculture is the backbone of Nepal's economy, employing more than 60% of the population and contributing approximately one-quarter of the national GDP (MoALD, 2023). In this context, legumes are integral to the country's farming systems, dietary patterns, and export economy. During the fiscal year 2019/20, legumes were cultivated on about 333,740 hectares, producing roughly 381,987 metric tonnes with an average productivity of 1,151 kg/ha (MoALD, 2020). Although modest in scale compared to cereals such as rice and maize, legumes contribute uniquely to nutrition, soil fertility, and income diversification.

Lentil (*Lens culinaris*) dominates Nepal's production landscape among grain legumes. It accounts for about 62.9% of total legume area and 65.8% of national production, making it both the most widely consumed and the most significant export legume. Other major legumes include soybeans (25,179 ha; 31,567 Mt; 1,254 kg/ha), mung beans, chickpeas (9,653 ha; 10,675 Mt; 1,106 kg/ha), pigeon peas (16,753 ha; 16,538 Mt; 987 kg/ha), black gram (23,492 ha; 19,928 Mt; 848 kg/ha), and horse gram (MoALD, 2020). Collectively, these crops provide a diverse yet underexploited foundation for Nepal's food and nutrition security.

Despite these contributions, productivity remains well below international benchmarks. While experimental plots demonstrate potential yields of up to 3 t/ha, national averages rarely exceed 1.2 t/ha (Shrestha, 2023). This productivity gap is a significant constraint to realizing the full potential of legumes in Nepal's agricultural system.

Nutritional Contribution to Food Security

Legumes provide 20–25% protein by weight, making them the primary source of plant-based protein for millions of Nepalese households. They are often called "poor people's meat" for poor and rural populations, compensating for limited access to expensive animal proteins (Dhakal, 2021). They also provide essential micronutrients, including iron, zinc, and calcium, vital in addressing widespread nutritional deficiencies.

Nepal faces a high prevalence of micronutrient malnutrition. Approximately 35% of women and 46% of children under five are iron-deficient, while zinc deficiency affects 87% of children and 61% of pregnant women (Karki et al., 2024). Legumes, particularly lentils, mung beans, and traditional pulses, provide a cost-effective and culturally accepted means of addressing these deficiencies. Lentils alone are a staple

in almost every household, consumed daily as dal, forming a critical component of the national diet.

Underutilized indigenous legumes, such as cowpea, field pea, and horse gram, play an equally important role in the diets of indigenous and rural mountain communities. These crops are adapted to harsh environments, require minimal inputs, and ensure a reliable protein supply during lean seasons. They also provide dietary diversity, which is linked to improved nutritional outcomes and reduced vulnerability to malnutrition (FAO, 2012).

Key Species and Their Roles

- **Lentils (*Lens culinaris*):** Nepal's most important legume contributes to domestic consumption and exports. Its short growing cycle allows it to be rotated with rice and wheat, making it vital for food security and soil fertility.
- **Soybeans (*Glycine max*):** A nutrient-dense legume rich in protein and oil, primarily used in animal feed, processed foods, and increasingly in soy-based products for health-conscious consumers.
- **Mung Beans (*Vigna radiata*):** Widely grown in Terai and mid-hill regions, mung beans are drought-tolerant, quick-maturing, and consumed in sprouted form. They provide valuable vitamins and minerals.
- **Pigeon Peas (*Cajanus cajan*):** Grown in warmer lowland areas, pigeon peas are resilient to drought and provide essential food security during dry seasons.
- **Underutilized Pulses (e.g., horse gram, cowpea, field pea):** Traditionally grown in hill and mountain regions, these crops support indigenous food systems, soil fertility, and climate resilience, though they remain neglected in research and policy agendas.

Together, these species contribute to the dual objectives of improving human nutrition and strengthening agroecosystem sustainability.

Role in Food Security, Livelihoods, and Soil Fertility

Food Security and Nutrition

Legumes are indispensable for household food security in Nepal, especially among poor and vegetarian populations. Their affordability ensures access to quality protein, while their micronutrient density combats "hidden hunger." By diversifying diets beyond cereals, legumes enhance resilience against nutritional deficiencies and chronic diseases.

Livelihoods and Rural Incomes

Legume cultivation generates employment and income opportunities for smallholder farmers. Lentils, in particular, are a significant export crop, with Nepal ranking among the top global exporters. This trade provides valuable foreign exchange earnings and strengthens farmer incomes in Terai regions where production is concentrated (Upadhyaya et al., 2022).

Soil Fertility and Climate Resilience

Legumes play a vital ecological role by fixing atmospheric nitrogen, reducing dependence on chemical fertilizers, and restoring soil fertility. This is crucial in Nepal's cereal-dominated farming systems, where soil nutrient depletion is widespread. Intercropping legumes with rice and maize reduces pest and disease pressures, enhances biodiversity, and increases farm productivity. Their drought resilience and adaptability to marginal lands further position legumes as climate-smart crops for Nepal's changing agro-ecological landscape.

Constraints and Challenges

Despite its potential, Nepal's legume sector faces several systemic constraints:

- **Low Productivity:** Yields are significantly below global averages due to outdated varieties, limited mechanization, and poor agronomic practices.
- **Weak Seed Systems:** Farmers lack access to improved, disease-resistant varieties and quality seed distribution networks.
- **Limited Research and Extension:** Investment in legume breeding, agronomy, and extension services lags behind cereals, reducing farmer adoption of improved practices.
- **Market and Value Chain Gaps:** Poor infrastructure, weak market linkages, and a lack of value addition limit farmer incentives and consumer access to diversified legume products.
- **Processing Constraints:** Minimal investment in modern processing and product innovation restricts the integration of legumes into urban and global food systems.
- **Perceptions and Awareness:** Many underutilized legumes remain culturally neglected or perceived as "inferior foods," reducing consumer demand.

Comparing Global and Nepal-Specific Insights

At the global level, underutilized legumes such as Bambara groundnut, moth

bean, and winged bean are acknowledged for their resilience to drought, adaptability to marginal lands, and potential to diversify diets (Cullis & Kunert, 2017). However, their neglect in breeding programs, limited consumer awareness, and weak markets have curtailed wider adoption. Similar dynamics are evident in Nepal, where lentils dominate production and exports, while indigenous pulses such as horse gram, cowpea, and field pea remain underutilized. Productivity in Nepal averages around 1.1 t/ha-significantly below international benchmarks-mirroring global concerns over underinvestment in legume research and development (MoALD, 2020; Shrestha, 2023).

Global and Nepal-specific evidence demonstrates that legumes provide affordable protein and micronutrients essential for addressing malnutrition. In South Asia and sub-Saharan Africa, legumes are often the only accessible protein source for poor households. In Nepal, lentils and mung beans form the backbone of diets, complementing cereal-based staples and directly tackling protein-energy malnutrition and iron and zinc deficiencies (Karki et al., 2024). The convergence of global and Nepal-specific experiences underscores that underutilized legumes represent a strategic, overlooked solution for improving dietary diversity and resilience in vulnerable communities.

Policy Implications

The persistent neglect of underutilized legumes reflects broader policy biases toward major cereals and cash crops. In many countries, including Nepal, agricultural policies prioritize rice, maize, and wheat, with limited investment in pulses and minor crops. This policy gap discourages farmers from cultivating diverse legumes and undermines national food security goals.

Policy interventions are needed to reposition legumes as central to sustainable food systems. Integrating legumes into national agricultural development strategies, food-based nutrition programs, and climate-smart agriculture frameworks is critical in Nepal. Subsidies for improved seed varieties, crop insurance schemes, and incentives for intercropping legumes with cereals could encourage adoption among smallholders. Export policies must also balance the commercial success of lentils with the need to ensure affordable domestic availability for rural consumers.

Globally, legumes are increasingly recognized in sustainable development agendas, as evidenced by initiatives like the International Year of Pulses (2016) and the promotion of plant-based diets for planetary health. Aligning Nepal's agricultural and nutrition policies with these global frameworks would enhance synergy and attract international collaboration and investment.

Role of Research, Extension, and Markets

Research plays a pivotal role in unlocking the potential of underutilized legumes. Globally, efforts are being made to improve genetic resources, develop climate-resilient varieties, and explore processing technologies that enhance consumer acceptability. However, such research is still fragmented and underfunded. In Nepal, limited breeding programs and weak seed systems constrain productivity and farmer adoption. Expanding public research institutions' capacity to focus on legume improvement, particularly indigenous species, would provide smallholder farmers with varieties better suited to local agroecological conditions.

Research must go beyond laboratory trials to include participatory approaches for rural and indigenous populations. Integrating indigenous knowledge, traditional practices, and local food cultures ensures that interventions are culturally acceptable and community-driven. Participatory breeding, community seed banks, and farmer-led trials can empower marginalized groups and promote ownership of legume innovations.

Extension services are equally vital in bridging the gap between research and practice. Current extension efforts in Nepal remain cereal-focused, leaving legume farmers with limited technical support. Tailored extension programs on legume agronomy, integrated pest management, and soil fertility management could substantially improve yields. Farmer cooperatives and women's groups should be prioritized as channels for disseminating improved practices and strengthening farmer capacity.

Market development is another crucial dimension. Smallholder farmers face low returns and limited incentives to cultivate underutilized legumes without structured markets. Investments in value chains, including storage, processing, and transportation infrastructure, are essential. Developing legume-based value-added products, such as fortified flours, snacks, and plant-based protein analogs, can increase demand among urban consumers. Public-private partnerships offer promising avenues to link smallholder farmers with domestic and international markets, turning legumes into profitable livelihood opportunities.

Link to the Sustainable Development Goals

Underutilized legumes align strongly with the United Nations Sustainable Development Goals (SDGs), making them strategic crops for addressing global development challenges.

- SDG 2 (Zero Hunger): Legumes directly address malnutrition and improve dietary diversity in poor and rural communities by providing affordable protein and essential micronutrients.
- SDG 12 (Responsible Consumption and Production): Their ability to fix nitrogen and thrive in marginal environments reduces reliance on synthetic inputs and promotes sustainable farming practices.
- SDG 13 (Climate Action): Legumes' resilience to drought and contribution to soil fertility enhance climate adaptation and mitigation efforts.
- SDG 1 (No Poverty): Strengthening legume-based value chains and market linkages can generate income and livelihood opportunities for smallholder farmers, especially women and indigenous groups.

Governments and development agencies can leverage international funding, research collaboration, and policy support to scale their impact by positioning underutilized legumes within these global goals.

Conclusion and Recommendations

Summary of Findings

This study underscores the transformative potential of underutilized legumes in addressing food security, nutrition, and climate challenges at both global and national scales. Globally, legumes are nutrient-dense, environmentally resilient, and culturally significant, yet remain marginalized in agricultural and food systems. In Nepal, lentils dominate production and exports, while other legumes-soybean, mung bean, pigeon pea, and indigenous pulses such as horse gram and cowpea-provide critical but underappreciated contributions to nutrition and livelihoods.

Legumes' nutritional profile makes them vital in combating protein-energy malnutrition and micronutrient deficiencies, particularly iron and zinc, which remain prevalent in Nepal. Agronomically, legumes enhance soil fertility through nitrogen fixation, support crop diversification, and offer resilience in the face of climate variability. Despite these advantages, systemic challenges persist, including low productivity, weak seed systems, inadequate processing infrastructure, limited research investment, and market barriers. Addressing these constraints requires coordinated action across multiple stakeholders.

Future Research Needs

Although evidence demonstrates the value of legumes, significant gaps remain.

Future research should prioritize:

- **Breeding and Genetic Improvement** – High-yielding, drought-tolerant, and nutrient-rich varieties are developed, focusing on underutilized indigenous legumes.
- **Processing and Product Innovation** – Exploration of fermentation, extrusion, and fortification technologies to reduce anti-nutritional factors, improve palatability, and create diverse, value-added products.
- **Participatory Research with Indigenous Communities:** Integrating traditional knowledge and local practices to ensure culturally relevant innovations and strengthen food sovereignty.
- **Impact Assessments** –Rigorous evaluations of nutritional, economic, and environmental impacts of integrating underutilized legumes into farming systems and diets.
- **Consumer Behavior Studies** - Research on perceptions, barriers, and incentives to increase consumer acceptance of legume-based foods.

Future studies can generate evidence-based strategies that enhance local and global food systems by closing these knowledge gaps.

Call to Action

The findings of this research highlight the need for multi-level, collaborative interventions:

- **Government:** National policies must elevate legumes from marginal crops to central components of agricultural and nutrition strategies. Investment in research, extension, and seed systems should be scaled up, alongside incentives for intercropping, crop insurance, and legume-based market development. Policies should also promote legumes in school feeding programs and maternal-child health initiatives.
- **Academia:** Universities and research institutions should strengthen interdisciplinary legume research, from breeding and agronomy to food technology and consumer sciences. Academic partnerships with international research centers can accelerate innovation, while participatory research with farmers ensures relevance and adoption.
- **Industry:** Private-sector actors are pivotal in creating value-added legume products, investing in processing technologies, and linking smallholder farmers

to national and international markets. The industry can expand consumer demand by marketing legumes as nutritious, climate-smart foods while supporting farmer incomes.

- **Communities:** Farmer cooperatives, women's groups, and indigenous organizations must be empowered as custodians of local legume biodiversity. Their active involvement in seed production, processing, and local marketing ensures sustainable adoption. Community-driven nutrition education can further enhance awareness of legumes' health benefits.

Closing Statement

Underutilized legumes offer a unique opportunity to bridge nutrition gaps, strengthen rural livelihoods, and foster environmentally resilient agriculture. For Nepal and similar contexts, scaling their production and consumption is not merely an agricultural challenge but a societal imperative that touches health, economy, and environment. By aligning efforts across government, academia, industry, and communities, these neglected crops can be transformed into engines of sustainable development, directly advancing the global commitment to Zero Hunger, Responsible Consumption and Production, and Climate Action.

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