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Winged Bean (*Psophocarpus tetragonolobus* L. DC.): A Nutrient-Rich Underutilized Legume for Future Food and Nutritional Security

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ABSTRACT

Winged bean (*Psophocarpus tetragonolobus* L. DC.) is a multipurpose tropical legume of the family Fabaceae, widely recognized as the "one-species supermarket" due to the edibility of its pods, seeds, leaves, flowers, and tubers. The seeds contain 28-45% protein, 16-21% oil, and 34-40% carbohydrates, along with essential minerals, making it nutritionally comparable to major grain legumes. Despite its high protein content, nitrogen-fixing capacity, and adaptability to tropical climates, the crop remains underutilized. Recent genomic advances, including chromosome-level assembly and QTL mapping, have enhanced its breeding potential. Additionally, winged bean contains bioactive compounds with antioxidant and anti-inflammatory properties. This review highlights its nutritional value, genetic diversity, breeding prospects, processing applications, and significance in sustainable agriculture and food security.

Keywords: Bioactives; Genomics; Protein; Sustainability; Underutilized; Wingedbean

1. Introduction

Global food and nutritional security are increasingly challenged by population growth, climate change, soil degradation, and reduced agro-biodiversity. Diversification of cropping systems through underutilized legumes offers a sustainable strategy to enhance dietary quality and resilience (Lepcha *et al*., 2017; Kaur *et al.*, 2025). Winged bean (*Psophocarpus tetragonolobus*) has long been recognized as a promising tropical legume with exceptional agronomic and nutritional attributes. The crop is widely cultivated in Southeast Asia, Papua New Guinea, India, Malaysia, Thailand, Sri Lanka, and the Philippines (Singh *et al.*, 2022). It is often referred to as the "soybean of the tropics" due to its comparable protein and oil content (Ho *et al.*, 2024). Despite international recognition since the 1970s, commercial expansion remains limited due to lack of improved varieties, indeterminate growth habit, and inadequate research investment (Mohanty *et al.*, 2020).

2. Botanical Description and Reproductive Biology

Winged bean (*Psophocarpus tetragonolobus* L. DC.) belongs to the family Fabaceae and subfamily Papilionoideae and has a diploid chromosome number of $2n = 2x = 18$ (Harder & Smartt, 1992; Ho *et al.*, 2024). It is a vigorous climbing perennial legume, usually cultivated as an annual crop in tropical regions (Singh *et al.*, 2022). When provided with support, the plant can grow up to 3-5 meters in height. Morphologically, it is characterized by trifoliate leaves, axillary racemose inflorescence, papilionaceous flowers (purple, blue, or white), and distinctive four-winged pods measuring 15-30 cm in length. Each pod contains 5-20 seeds, and the plant also produces edible tuberous roots approximately 8-12 cm long (Sriwichai *et al.*, 2021). Reproductively, winged bean is predominantly self-pollinated, although limited cross-pollination occurs under natural conditions (Erskine, 1980). Pollen viability remains up to 24 hours after anthesis, and stigma receptivity lasts approximately 33 hours, allowing a brief opportunity for cross-fertilization (Senanayake & Sumanasinghe, 1978; Koshy *et al.*, 2013). These traits provide genetic stability while maintaining sufficient variability for breeding improvement.

3. Nutritional Composition

Winged bean seeds are nutritionally rich and show notable variability among genotypes. An evaluation of 138 genotypes reported average seed composition of 9.09% moisture, 34.98% protein, 18.01% fat, 26.81% carbohydrates, 10.24% crude fiber, and 4.16% ash (Bepary *et al.*, 2023). Other studies indicate protein levels ranging from 28-45%, oil content of 14-21%, and carbohydrate levels between 34-40%, demonstrating its nutritional comparability to major legumes such as soybean (Sriwichai *et al.,* 2021; Ho *et al*., 2024). The combination of high protein and lipid content makes winged bean a valuable plant-based source of energy and nutrition.

In addition to macronutrients, winged bean is a significant source of micronutrients. The leaves contain high levels of vitamin C (14.5-128 mg/100 g) and vitamin A (5,240-20,800 IU) (Bepary *et al.,* 2023), while the seeds provide essential minerals including calcium, iron, phosphorus, and zinc (Sriwichai *et al*., 2021). The tuberous roots also contain 12-19% protein, further enhancing its dietary value (Sriwichai *et al*., 2021). These attributes highlight the crop's potential to support dietary diversification and address protein and micronutrient deficiencies.

4. Anti-Nutritional Factors

Like other grain legumes, winged bean contains anti-nutritional compounds that may affect nutrient utilization and digestibility. Reported constituents include trypsin inhibitors (40-99.5 TIU/mg protein), chymotrypsin inhibitors (86.4–109.6 CIU/mg protein), phytic acid (4.09-9.96%), tannins (0.77-0.97%), and saponins (0.6%) (Bepary *et al*., 2023; Ho *et al*., 2024). These naturally occurring compounds serve protective roles in plants but may reduce protein digestibility and mineral bioavailability when consumed in high quantities.

Protease inhibitors interfere with digestive enzymes, while phytic acid chelates essential minerals such as calcium, iron, and zinc. Tannins and saponins may also affect nutrient absorption and palatability (Bepary *et al.,* 2023). However, traditional processing methods including soaking, boiling, roasting, germination, and fermentation significantly reduce these anti-nutritional factors and improve overall nutritional quality, making winged bean safe and suitable for human consumption.

5. Bioactive Compounds and Therapeutic Potential

Winged bean contains a diverse range of bioactive phytochemicals, including flavonoids, phenolic acids, and other antioxidant compounds that contribute to its functional value (Kaur *et al.,* 2025). Ethanolic pod extracts have shown high total phenolic content (237.33 mg GAE/g) and flavonoid content (180.53 mg QE/g), indicating strong antioxidant potential (Dhumtanom *et al*., 2025). These compounds help neutralize free radicals and reduce oxidative stress, which is linked to various chronic diseases. In vitro studies further demonstrate its therapeutic promise. Pod extracts exhibited dose-dependent inhibition of colorectal cancer (HT-29) cell viability with an IC_{50} value of approximately 117.86 µg/mL and induced apoptosis through programmed cell death pathways (Dhumtanom *et al.,* 2025). Additionally, suppression of pro-inflammatory cytokines such as IL-1β, IL-6, and TNF-α suggests notable anti-inflammatory activity. These findings support the potential of winged bean as a functional food and nutraceutical ingredient.

6. Genetic Diversity and Breeding Advances

Substantial genetic variability exists among winged bean genotypes for yield, quality, and agronomic traits, providing considerable scope for crop improvement. Studies conducted under diverse agro-climatic conditions have reported significant variation in pod yield, seed yield, vine length, and biochemical attributes (Thapa *et al.*, 2024; Gadi *et al.*, 2025). High heritability estimates have been recorded for key economic traits, including green pod yield (98.8%), protein content (94.1%), and seed yield per plant (93.9%), indicating strong genetic control and the potential effectiveness of selection-based breeding strategies (Thapa *et al*., 2024). Such high heritability values suggest that phenotypic performance can reliably reflect genotypic potential, thereby accelerating breeding progress.

Recent genomic advancements have significantly strengthened the scientific foundation for winged bean improvement. Recent genomic studies have generated a high-quality reference genome of approximately 586 Mb, organized into nine chromosome-scale assemblies corresponding to its diploid structure (Ho *et al.*, 2024). Additionally, quantitative trait loci (QTL) mapping has identified genomic regions associated with plant architecture, protein content, and phytonutrient accumulation. These molecular tools facilitate marker-assisted selection and genomic-assisted breeding approaches, enabling the development of improved cultivars with enhanced yield stability, nutritional quality, and agronomic performance (Ho *et al*., 2024).

7. Processing and Industrial Applications

Processing plays a crucial role in enhancing the nutritional quality and consumer acceptability of winged bean products. Traditional methods such as soaking, boiling, roasting, fermentation, and germination have been shown to improve protein digestibility and reduce anti-nutritional factors (Bepary *et al.,* 2023). Winged bean is widely utilized in traditional cuisines as curries, soups, and pickles, while modern processing techniques have enabled the development of value-added products such as plant-based milk, tofu, tempeh, and protein isolates or concentrates (Bepary *et al.,* 2023). These applications demonstrate its versatility as a functional ingredient in plant-based food systems. Beyond food applications, winged bean holds potential for diverse industrial uses. The seed oil exhibits a favorable fatty acid composition and has been evaluated for biodiesel suitability, indicating prospects for renewable energy production (Sriwichai *et al.*, 2021). Additionally, winged bean proteins have demonstrated promising functional properties for biodegradable film formation, and the defatted seed cake can serve as a nutrient-rich component in animal feed formulations (Kaur *et al.*, 2025).

8. Constraints and Future Prospects

Despite its nutritional and agronomic advantages, winged bean remains underutilized due to several constraints. The indeterminate growth habit and excessive vegetative branching often complicate harvesting and reduce yield uniformity (Mohanty *et al.*, 2020). The hard-to-cook phenomenon associated with mature seeds, along with the presence of anti-nutritional factors, can affect consumer acceptance and processing efficiency (Ho *et al.*, 2024). Future research efforts should focus on genomic-assisted breeding strategies to develop determinate, high-protein, and stress-tolerant varieties. Advances in nutritional phenotyping, molecular marker development, and QTL-based selection can accelerate cultivar improvement (Ho *et al.*, 2024).

9. Conclusion

Winged bean (*Psophocarpus tetragonolobus*) is a nutritionally rich, climate-resilient, and multifunctional legume with immense potential to contribute to global food and nutritional security. Its high protein content, bioactive compounds, nitrogen-fixing ability, and adaptability to tropical environments make it a strategic crop for sustainable agriculture. With advancements in genomics and breeding, along with improved awareness and value addition, winged bean can transition from an underutilized crop to a mainstream component of diversified and resilient food systems.

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