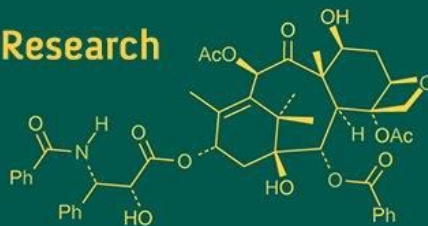


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Nutritional security and the importance of ancient wheat species

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Abstract

Triticum sphaerococcum (Indian dwarf wheat) is an ancient wheat species recognized for its superior nutritional composition and enhanced physiological resilience compared with modern bread wheat (*Triticum aestivum*). The present framework highlights the biochemical and nutritional attributes that contribute to its status as a nutrient-dense and stress-tolerant cereal crop. Dwarf wheat exhibits significantly higher grain protein content and gluten concentration, improving both nutritional quality and functional properties of wheat-based foods. In addition, it possesses greater concentrations of essential micronutrients such as iron and zinc, which are critical for human health and may support biofortification strategies aimed at combating micronutrient deficiencies. The grain is also enriched with bioactive phytochemicals including phenolic acids, flavonoids, and alkylresorcinols that provide antioxidant protection and promote health benefits. Higher levels of dietary fiber and resistant starch further enhance its functional food potential by improving gut health and metabolic regulation. From a physiological perspective, *T. sphaerococcum* demonstrates elevated proline accumulation and greater activity of antioxidant enzymes such as superoxide dismutase, catalase, and peroxidase, which contribute to improved tolerance against environmental stresses such as drought and heat. These combined nutritional and biochemical traits suggest that *T. sphaerococcum* represents a valuable genetic resource for developing climate-resilient and nutritionally enriched wheat varieties.

Keywords: *Triticum sphaerococcum*, nutritional quality, antioxidant compounds, micronutrient, stress tolerance

Introduction

Global food systems are currently facing a dual challenge of ensuring adequate food production while simultaneously improving the nutritional quality of staple crops. Despite significant progress in agricultural productivity, micronutrient malnutrition commonly referred to as “hidden hunger” continues to affect more than two billion people worldwide. Deficiencies of essential minerals such as iron and zinc remain widespread, particularly in developing countries where cereal-based diets dominate daily food consumption (FAO, 2023) [3]. Wheat is one of the most important staple crops globally, contributing nearly 20% of the total caloric and protein intake of the human population, making it a critical component of global food and nutritional security (Shewry & Hey, 2015) [19]. Over the past century, wheat breeding programs have largely focused on improving grain yield, disease resistance, and processing qualities. While these efforts have substantially increased productivity, the intense selection pressure on yield-related traits has often resulted in the dilution of micronutrients and reduction of genetic diversity in modern wheat cultivars. Consequently, there is growing interest in exploring traditional and ancient wheat species as alternative genetic resources for improving nutritional quality and stress resilience (Guzmán *et al.*, 2020) [2].

Among these ancient wheat species, *Triticum sphaerococcum* Percival, commonly known as Indian dwarf wheat represents a unique and underutilized germplasm. This species is characterized by its compact spherical grains, short plant stature, and strong adaptation to marginal environments. Historically cultivated in parts of the Indian subcontinent, *T. sphaerococcum* has received renewed attention due to its superior nutritional composition and potential contribution to climate-resilient agriculture (Budak *et al.*, 2013) [10]. Recent comparative studies indicate that *T. sphaerococcum* possesses higher levels of grain protein, essential micronutrients, dietary fiber, and antioxidant compounds compared with modern

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bread wheat (*Triticum aestivum*). In addition, this ancient wheat species exhibits enhanced accumulation of stress-related metabolites such as proline and stronger antioxidant defense systems, suggesting improved tolerance to abiotic stresses including drought and heat (Garg *et al.*, 2023; Hussain *et al.*, 2025) [6, 11]. Such characteristics make *T. sphaerococcum* an important candidate for breeding programs aimed at enhancing both nutritional value and environmental resilience.

Furthermore, the presence of bioactive phytochemicals such as phenolic acids, flavonoids, and alkylresorcinols in higher concentrations contributes to the functional food potential of dwarf wheat. These compounds are associated with antioxidant activity, anti-inflammatory effects, and protection against chronic diseases such as cardiovascular disorders and diabetes (Skrajda-Brdak *et al.*, 2019; Ross *et al.*, 2023) [1, 16, 23, 24]. Therefore, incorporating nutrient-rich ancient wheat species into modern cropping systems could provide an effective strategy to address both agricultural sustainability and human health challenges. Given the increasing demand for nutritionally enhanced staple crops, the exploration and utilization of traditional wheat germplasm has become a priority in global breeding programs. In this context, *Triticum sphaerococcum* offers a promising genetic resource for the development of wheat varieties with improved nutritional profiles and stress tolerance. *Triticum sphaerococcum* (Indian dwarf wheat) is often ignored for large-scale cultivation despite its rich nutritional profile mainly due to its low yield potential, short grain size, and poor adaptability to modern intensive farming systems. Compared to high-yielding bread wheat varieties, it produces less grain and shows limited response to fertilizers and irrigation. Additionally, it has weaker agronomic traits such as lodging susceptibility and less uniformity, making it less suitable for mechanized agriculture and commercial markets. Lack of awareness, limited breeding efforts, and absence of strong market demand for its nutritional benefits have further contributed to its underutilization. The present review aims to synthesize current knowledge on the biochemical composition, nutritional significance, and potential role of *T. sphaerococcum* in strengthening global nutritional security.

Nutritional Superiority of *Triticum sphaerococcum*

The nutritional advantages of *Triticum sphaerococcum* arise from its unique biochemical composition and adaptive physiological traits. Compared with modern wheat species, dwarf wheat demonstrates a favorable balance of macronutrients, micronutrients, antioxidant compounds, and functional dietary components. These attributes collectively contribute to both human health benefits and plant resilience under environmental stress conditions. One of the most prominent features of *T. sphaerococcum* is its higher grain protein content, which often exceeds that of common wheat by 3-5%. Increased protein concentration enhances the nutritional value of wheat-based foods and improves functional properties such as dough elasticity and bread-making quality (Garg *et al.*, 2023) [6]. In addition, higher gluten protein content contributes to better structural properties in processed wheat products. Micronutrient enrichment is another key characteristic of dwarf wheat.

Studies have consistently reported elevated concentrations of iron and zinc in *T. sphaerococcum* grains compared with modern bread wheat (Khokhar *et al.*, 2020) [13, 14, 15]. These minerals play vital roles in human physiology, including oxygen transport, immune function, and enzyme activation. Therefore, incorporating dwarf wheat into breeding programs could significantly contribute to wheat biofortification initiatives aimed at combating micronutrient deficiencies. Beyond macronutrients and minerals, *T. sphaerococcum* is also rich in bioactive compounds such as phenolic acids, flavonoids, and alkylresorcinols. These phytochemicals function as natural antioxidants and help protect plant tissues from oxidative damage caused by environmental stresses. Their presence in wheat grains also provides health-promoting properties for consumers, including reduced oxidative stress and improved cardiovascular health (Skrajda-Brdak *et al.*, 2019; Ross *et al.*, 2023) [1, 16, 23, 24].

Another important component is resistant starch, which is present in higher concentrations in dwarf wheat compared with common wheat. Resistant starch behaves similarly to dietary fiber and escapes digestion in the small intestine, reaching the colon where it is fermented by beneficial gut microbiota. This process produces short-chain fatty acids that support intestinal health and improve insulin sensitivity, thereby contributing to the prevention of metabolic disorders (Singh *et al.*, 2022) [21, 22]. In addition to its nutritional benefits, *T. sphaerococcum* demonstrates enhanced biochemical mechanisms for stress tolerance. Elevated levels of proline and increased activities of antioxidant enzymes such as Superoxide Dismutase (SOD), Catalase (CAT), and Peroxidase (POX) help protect plant cells from oxidative damage under drought or heat stress (Hussain *et al.*, 2025) [11]. These traits suggest that dwarf wheat possesses a more efficient protective metabolism that supports adaptation to challenging agro-climatic environments.

Thus, the nutritional superiority of *Triticum sphaerococcum* can be conceptualized through the integration of four key attributes

- Higher protein and gluten content improving food quality
- Enhanced micronutrient concentration supporting human nutrition
- Rich phytochemical composition providing antioxidant benefits
- Strong physiological defense mechanisms enabling stress resilience

Together, these characteristics position *T. sphaerococcum* as an important crop for developing nutrient-dense and climate-resilient wheat varieties.

The comparative study highlights why *Triticum sphaerococcum* is frequently regarded as a "super-grain" compared to the high-yielding *Triticum aestivum* (Common Bread Wheat). While *T. aestivum* has been optimized for industrial baking and high volume, *T. sphaerococcum* retains an ancient genetic architecture that prioritizes nutrient density and environmental resilience.

Table 1: Comparative Biochemical and Nutritional Profile of *Triticum aestivum* and *Triticum sphaerococcum*

Sr. No.	Component	<i>Triticum aestivum</i> (Common Wheat)	<i>Triticum sphaerococcum</i> (Dwarf Wheat)	Reference
1	Total Protein	10.5% - 14.0%	13.5% - 19.0%	Garg <i>et al.</i> (2023) ^[6]
2	Gluten Content	25% - 32% (Wet Gluten)	28% - 35% (Wet Gluten)	Sharma <i>et al.</i> (2021) ^[20]
3	Carbohydrates	68% - 75%	62% - 68%	Singh <i>et al.</i> (2022) ^[21, 22]
4	Iron	30-40 mg/kg	45-60 mg/kg	Khokhar <i>et al.</i> (2020) ^[13, 14, 15]
5	Zinc	20-30 mg/kg	35-50 mg/kg	Khokhar <i>et al.</i> (2020) ^[13, 14, 15]
6	Proline	8.5% - 10.2% of protein	10.5% - 12.8% of protein	Gupta & Malik (2019) ^[7]
7	Dietary Fiber	1.8% - 2.5%	2.5% - 3.2%	Kaur <i>et al.</i> (2024) ^[8]
8	Total Phenolic Acids	600 - 850 mg/kg	950 - 1250 mg/kg	Skrajda-Brdak <i>et al.</i> (2019) ^[16, 23]
9	Flavonoids	18.0 - 22.0 mg/kg	35.0 - 48.0 mg/kg	Ozkose <i>et al.</i> (2022) ^[18]
10	Superoxide Dismutase	120 - 150 Units/g	180 - 210 Units/g	Hussain <i>et al.</i> (2025) ^[11]
11	Catalase (CAT)	0.02 - 0.05 Units/ml	0.08 - 0.15 Units/ml	Gaikwad <i>et al.</i> (2024) ^[4, 5]
12	Peroxidase (POX)	0.06 - 0.20 Units/ml	0.35 - 0.60 Units/ml	Gaikwad <i>et al.</i> (2024) ^[4, 5]
13	Alkylresorcinols (ARs)	480 - 650 mg/kg	750 - 980 mg/kg	Ross <i>et al.</i> (2023) ^[1, 24]
14	Phytic Acid	0.8% - 1.2%	1.1% - 1.4%	Khokhar <i>et al.</i> (2020) ^[13, 14, 15]
15	Resistant Starch	1.0% - 1.5%	2.5% - 4.0%	Singh <i>et al.</i> (2022) ^[21, 22]

Nutritional profiling and quality traits of *Triticum sphaerococcum*

The nutritional composition of wheat grains plays a central role in determining their suitability for food use, processing quality, and contribution to human health. A comparison of *Triticum aestivum* (common bread wheat) and *Triticum sphaerococcum* (Indian dwarf wheat) reveals significant differences in protein quality, antioxidant machinery, and micronutrient density that may underpin the superior stress tolerance often attributed to *T. sphaerococcum* (Table 1).

1. Total Protein

Protein content ranged from 10.5-14.0% in *T. aestivum* compared with 13.5-19.0% in *T. sphaerococcum*, indicating a significantly higher storage protein accumulation in dwarf wheat (Garg *et al.*, 2023) ^[6]. Higher grain protein enhances nutritional value, dough strength, bread-making quality, and stress tolerance, as protein fractions such as gliadins and glutenins contribute to both rheology and osmoprotection.

2. Gluten Content

Wet gluten was 25-32% in *T. aestivum* and 28-35% in *T. sphaerococcum* (Sharma *et al.*, 2021) ^[20]. Gluten determines viscoelastic properties of dough, with higher gluten content supporting superior bread-making performance. Biologically, gluten storage proteins act as nitrogen and sulfur reserves, contributing to seedling growth during germination.

3. Carbohydrates

Carbohydrate content was greater in *T. aestivum* (68-75%) than in *T. sphaerococcum* (62-68%) (Singh *et al.*, 2022) ^[21, 22]. Carbohydrates primarily comprise starch, serving as the main energy store for germination and the major caloric source for human nutrition. Lower carbohydrate and higher protein in dwarf wheat indicate a nutrient-dense compositional shift.

4. Iron and Zinc

Micronutrient density was higher in *T. sphaerococcum*, with iron at 45-60 mg/kg and zinc at 35-50 mg/kg, compared with 30-40 mg/kg Fe and 20-30 mg/kg Zn in *T. aestivum* (Khokhar *et al.*, 2020) ^[13, 14, 15]. These minerals are essential cofactors in enzyme systems, oxygen transport, immune

regulation, and antioxidant defense. Higher concentrations in dwarf wheat indicate potential value for biofortification and combating micronutrient malnutrition.

5. Proline

Proline constituted 8.5-10.2% of total protein in *T. aestivum* and 10.5-12.8% in *T. sphaerococcum* (Gupta & Malik, 2019) ^[7]. Proline is a critical osmoprotectant, ROS scavenger, and stabilizer of proteins and membranes under abiotic stress. Elevated proline in dwarf wheat supports its enhanced drought and salinity tolerance.

6. Dietary Fiber

Dietary fiber levels ranged from 1.8-2.5% in *T. aestivum* and 2.5-3.2% in *T. sphaerococcum* (Kaur *et al.*, 2024) ^[8]. Fiber contributes to gut health, glycemic regulation, cholesterol reduction, and reduced chronic disease risk. Higher fiber reflects greater cell wall polysaccharide deposition in dwarf wheat.

7. Phenolic acids and Flavonoids

Total phenolic acids and flavonoids were markedly higher in *T. sphaerococcum* (950-1250 mg/kg and 35-48 mg/kg, respectively) than in *T. aestivum* (600-850 mg/kg and 18-22 mg/kg) (Skrajda-Brdak *et al.*, 2019; Ozkose *et al.*, 2022) ^[16, 18, 23]. These secondary metabolites exert potent antioxidant activity, contributing to

- ROS detoxification
- anti-inflammatory properties
- protection against oxidative stress-induced tissue damage
- reduced risk of cardiovascular and metabolic disorders

Their elevated levels strongly suggest adaptation toward harsh agro-ecological environments.

8. Antioxidant Enzymes (SOD, CAT, POX)

Antioxidant enzyme activity was consistently higher in dwarf wheat. Superoxide dismutase (SOD) activity reached 180-210 Units/g in *T. sphaerococcum* versus 120-150 Units/g in *T. aestivum* (Hussain *et al.*, 2025) ^[11]. Catalase (CAT) and Peroxidase (POX) also exhibited 3-5-fold higher activity in dwarf wheat (Gaikwad *et al.*, 2024) ^[4, 5].

These enzymes form the primary enzymatic antioxidant defense system, converting toxic reactive oxygen species into harmless molecules.

- Elevated antioxidant enzyme activity
- Prevents oxidative membrane damage
- Protects cellular metabolism
- Enhances environmental stress tolerance

This provides biochemical support for the robust adaptability of *T. sphaerococcum*.

9. Alkylresorcinols

Alkylresorcinols (ARs) were 750-980 mg/kg in dwarf wheat compared to 480-650 mg/kg in common wheat (Ross *et al.*, 2023) ^[1, 24] are bioactive phenolic lipids concentrated in bran layers and act as:

- natural antifungal compounds
- membrane stabilizers
- markers of whole-grain intake in human nutrition

Higher levels indicate richer protective phytochemistry.

10. Phytic Acid

Phytic acid content was greater in dwarf wheat (1.1-1.4%) than in common wheat (0.8-1.2%) (Khokhar *et al.*, 2020) ^[13, 14, 15]. Although phytic acid acts as an antinutrient by chelating minerals, it is also a powerful antioxidant and anticancer-linked compound. Its higher content is therefore nutritionally dual-functional.

11. Resistant Starch

Resistant starch was 2.5-4.0% in *T. sphaerococcum* versus 1.0-1.5% in *T. aestivum* (Singh *et al.*, 2022) ^[21, 22]. Resistant starch behaves like soluble fiber, promoting:

- colonic fermentation
- prebiotic effects
- improved insulin sensitivity
- lower glycemic response

This positions dwarf wheat as a potential functional food crop.

Future Research Directions and Breeding Strategies

Despite its promising nutritional and agronomic attributes, *Triticum sphaerococcum* remains largely underutilized in modern wheat improvement programs. Future research should prioritize the integration of this ancient wheat species into breeding pipelines aimed at enhancing nutritional quality and stress resilience. Identification of genomic regions and candidate genes associated with nutrient accumulation using advanced molecular tools such as Genome-Wide Association Studies (GWAS), marker-assisted selection, and genomic selection could accelerate the transfer of beneficial alleles into elite wheat cultivars (Guzmán *et al.*, 2020) ^[2].

Further research is also needed to elucidate the metabolic pathways regulating antioxidant compounds, including phenolic acids, flavonoids, and alkylresorcinols, which contribute to both plant stress tolerance and human health benefits. Comprehensive agronomic evaluations under diverse environmental conditions will help determine the adaptive potential of *T. sphaerococcum*, particularly in relation to drought and heat stress (Budak *et al.*, 2013) ^[10].

In addition, exploring the role of dwarf wheat in sustainable cropping systems and functional food markets could promote its wider cultivation. Nutritional and clinical studies are also required to validate the health benefits of dwarf wheat-based foods. Overall, the strategic utilization of *T. sphaerococcum* offers significant potential for developing nutritionally enriched and climate-resilient wheat varieties.

Conclusion

The comparative analysis indicates that *Triticum sphaerococcum* possesses a nutritionally superior and biochemically robust grain profile compared with *Triticum aestivum*. Higher protein content, enhanced micronutrient concentrations (iron and zinc), and elevated levels of dietary fiber, phenolic compounds, and resistant starch highlight its potential as a nutrient-dense cereal. Increased proline accumulation and greater antioxidant enzyme activity further suggest improved tolerance to abiotic stresses. Although *T. aestivum* remains the dominant wheat species for global food production due to its higher carbohydrate content and yield potential, *T. sphaerococcum* offers valuable traits for improving nutritional quality and stress resilience. Therefore, its incorporation into modern breeding programs could contribute significantly to climate-resilient agriculture, nutritional security, and the development of functional wheat-based foods.

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