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Georgian Endemic Wheat: Agrobiological Diversity and Prospects for Innovative Applications

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ABSTRACT

Georgian endemic wheat represents a unique genetic resource, integrating ancient agrobiodiversity with high nutritional and functional potential. This review highlights the historical cultivation, genetic diversity, and distinctive agronomic traits of five endemic species: Triticum timopheevii (Chelta Zanduri), T. zhukovskyi (hexaploid Zanduri), T. palaeocolchicum (Colchic/Georgian wheat), T. macha (Macha), and T. carthlicum (Dika). These cultivars exhibit remarkable adaptation to diverse climatic conditions, resilience against complex diseases, and high-quality grain, including elevated protein content and significant levels of essential amino acids. Georgian endemic wheat and its by-products (kato, sprouts) demonstrate functional properties, such as antioxidant, anti-inflammatory, immunomodulatory, and antimicrobial activities. The bioactive compounds contribute to gastrointestinal health, reduction of cardiovascular risk, and present potential for incorporation into innovative functional foods, non-alcoholic beverages, and cosmetic products. Conservation and scientific utilization of these endemic varieties are crucial for sustainable breeding programs, agrobiodiversity preservation, and the development of high-value, health-promoting products.

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"Georgian Endemic Wheat: A Unique Genetic Resource Integrating Cultural Heritage and Ensuring Food Security"

Introduction

Georgia represents one of the earliest centers of wheat cultivation, with a species- and cultivar-level diversity that is particularly remarkable and unique. largely due to the country's distinctive geographic location and the heterogeneity of its climatic and geomorphological conditions [1,2]. It is noteworthy that the term "wheat" has historically been referred to by different names in various dialects: "Kovali" in Chan, "Kobali" in Mingrelian, and "Kvetsen" in Svan. Initially, the term "wheat" encompassed all cereal crops, but over time, it was gradually replaced by "bread," referring both to the cereal grain itself and its baked product. It should also be noted that Georgians originally used the term "diars" specifically for bread and cereal crops, a nomenclature now preserved only among the Laz and Svan communities [3]. Archaeological evidence confirms an ancient tradition of wheat cultivation in Georgia, as demonstrated by the discovery of carbonized grains dating back to the 6th-4th millennia BCE at sites such as [4].

Of the 20 wheat species known globally, 15 have been documented in Georgia, including five endemic, aboriginal species: (Colchic/ Georgian wheat), and [5]. This genetic diversity, along with the abundance of endemic species and forms, positions Georgia as a leading country in global wheat biodiversity [6]. Georgian endemic wheat varieties constitute invaluable material for breeding programs, as they possess unique traits and considerable potential for future selective programs aimed at enhancing wheat yield and improving resilience [7].

Research has revealed that, compared to modern wheat varieties, Georgian endemic wheats contain genes encoding low-molecular-weight glutenins, which are critical determinants of both wheat quality and allergenicity [2,7-9]. Bread remains a staple product in the human diet and today, balancing bread composition and improving its nutritional value has become increasingly important [10-13]. There is a growing demand for bread baked from local grains and ingredients [14,15]. Geographical conditions and endemic food products influence the gut microbiome of the population and, consequently, human health [16]. The microbiota of the Georgian population has evolved in accordance with local food products, particularly those derived from endemic Georgian wheat varieties.

However, it is noteworthy that since the 1950s, Soviet policies led to a catastrophic reduction of local wheat genetic resources.

By the 1990s, most endemic species and local varieties were no longer cultivated in local farms and survived only in seed banks and collections of scientific institutions. Currently, the biological farming association "ELKANA" undertakes conservation and promotion of Georgian wheat, such as Akhaltsikhe Red Doli and Dika, seeking to involve as many enthusiastic farmers as possible in this effort. Despite the efforts of scientists and dedicated farmers, the majority of Georgian endemic wheat varieties are today scarcely cultivated [17].

Interest in Georgian wheat varieties is growing worldwide for several reasons: (1) food security - these varieties exhibit exceptional disease resistance; (2) health - their low gluten content is advantageous for individuals with allergenic predispositions; (3) development of organic production - endemic varieties are ideal for organic farming; and (4) agrotourism and culinary tourism - traditional varieties represent a unique cultural heritage. The American researcher and organic farmer Eli Rogosa, founder of the Heritage Grain Conservancy in Massachusetts, who cultivates Georgian wheat on his land, emphasizes the importance of conserving these varieties. His studies confirm that Georgian wheat is an elite, distinctive crop with excellent disease resistance, superior flavor, and gluten that is safe for individuals with gluten sensitivity. He regards it as a "gift of nature," thriving on rich cultural soils [18].

According to experts, Georgian endemic wheat species represent a unique genetic resource for breeding due to their high adaptability to local climatic conditions. The attention of global tritologists has been drawn to endemic and local Georgian wheat varieties such as Chelta Zanduri and Dika, which exhibit remarkable multi-disease immunity, the endemic Colchic wheat, which is resistant to various fungal pathogens, and Macha, notable for its abundant leaf biomass, strong stems, and the production of bread with distinctive aroma and taste [9].

Chelta Zanduri (Triticum Timopheevii): Chelta Zanduri is a hulled wheat genetically classified within the group of durum wheats. Biologically, it is a spring-type wheat, though it matures relatively late and was therefore traditionally sown in autumn. Zanduri is distinguished by a robust root system, enabling it to yield over a ton of grain even on poor soils and under adverse climatic conditions, such as drought, excess moisture, or frost. It exhibits lodging resistance, produces a productive number of tillers (4-7), and possesses a remarkable, broad-spectrum immunity against all types of diseases [3]. Historically, its strong stems were used in constructing fences and other structures. The grains of Zanduri are large, horn-shaped, and have excellent baking quality, producing bread with a unique taste, traditionally baked for holidays and esteemed guests [19]. Due to its comprehensive disease resistance, Georgia is often regarded as the homeland of immune wheat [20]. Zanduri was primarily cultivated in Racha ("Gobeja"), Lechkhumi, Imereti, and Samegrelo ("Pita Kobali") at elevations of 400-800 m, though it also thrives in eastern Georgia (Table 1) [21,22].

Hexaploid Zanduri (Triticum Zhukovskyi): Based on morphological and phylogenetic analyses, the 42-chromosome form of Zanduri was classified as a separate species, named in honor of the renowned cultural flora researcher Zhukovsky [23]. Morphologically similar to Chelta Zanduri, hexaploid Zanduri is less tolerant to drought and prefers humid conditions. Its stem reaches approximately 30 cm taller than that of Chelta Zanduri, and its spike is more elongated, less compact, and less prone to shattering (Table 1) [3].

Colchic/Georgian Wheat (Triticum Palaeocolchicum): This is a two-grained, hulled wheat with a tall, sturdy stem and a flat, broad, compact, and slightly brittle spike. Biologically, it is a late-maturing, autumn-sown wheat. Morphologically, it resembles Macha and is considered a progenitor of that species, historically growing as a minor component within Macha-associated wheat communities in the Racha-Lechkhumi [3]. In western Georgia, the first documented occurrence of this wheat was in Lechkhumi meadows by who classified it as [24]). Colchic wheat exhibits lodging resistance, is resilient against leaf rust and strong smut, and its grains are rich in protein, particularly lysine, yielding high-quality flour with excellent baking properties [25]. Historical records indicate that in the 1940s, Colchic wheat was still sown in Racha-Lechkhumi and neighboring areas of Imereti [21].

Macha (Triticum Macha): Macha is one of Georgia's oldest endemic wheat species, belonging to the group of hulled wheats. It has strong stems, ranging from 60 to 120 cm in height, exhibits no lodging, and adapts well to high moisture, poor, and calcareous soils. It demonstrates resistance to fungal diseases and smut, cold tolerance, and high protein and lysine content [20,26]. Macha is unique in retaining key traits of wild wheat while also carrying characteristics of cultivated varieties, making it a paleo-relict and a living monument of wheat culture [3]. It was traditionally cultivated in the mountainous Racha-Lechkhumi region at altitudes of 900-1,200 m. Its growth cycle is autumn-sown or semi-autumn-sown. Plants are medium in height (80-120 cm), resistant to lodging, and compact. Fourteen distinct Macha forms have been described. Bread made from Macha flour was white, flavorful, aromatic, and retained softness for several days. According to oral tradition, Macha grain decoctions were consumed to improve vision, and its flour was used to make "Khabizgina," a bread mixed with walnuts and onions [20]. Currently, both Macha and Zanduri are rarely cultivated (Table 1).

Dika (Triticum Carthlicum): Archaeological, historical, and ethnographic studies confirm that Dika is a Georgian endemic wheat, representing one of the oldest wheat forms developed in Georgia and a remnant of ancient mountain agriculture [27-30]. Genetically, Dika belongs to durum wheat but morphologically resembles soft wheat. It is a spring-type, hulled, naked-grain wheat. Dika originated in the Georgian highlands and can be cultivated from elevations below 1,000 m up to 2,000 m, with marginal agriculture extending to 2,200-2,300 m [30]. Adapted to mountainous conditions, Dika tolerates excessive moisture, requires minimal heat, is lodging-resistant, exhibits broad-spectrum immunity to fungal diseases, resists grain shattering, and is robust. Its grains are high in protein, possess excellent baking qualities, have a short vegetative period, and are frost-resistant. Historically, Dika was cultivated across almost all regions, including Inner and Lower mountainous areas [31]. According to the elders of Telavi, in the area of the present-day Nadikvri recreational park, Dika was traditionally grown, and the area was called "Nadikari," from which the park's name is believed to have originated (Table 1).

Georgian Endemic Wheat in the Context of Climate Change

Climate change represents one of the most pressing challenges for modern agriculture. Numerous international studies have demonstrated that rising global temperatures are directly associated with reductions in the yields of major crops, including wheat report that each 1°C increase in temperature corresponds to a statistically significant decline in global wheat yields [32,33]. Emphasize that agronomic interventions and modeling alone are insufficient, and particular attention must be paid to genetic resources that are naturally adapted to variable climatic conditions [34].

Research conducted within the European context has shown that the most detrimental factor for wheat is not drought per se, but heat stress during critical phases of plant development [35]. This underscores the importance of genotypes characterized by tolerance to high temperatures, excessive moisture, and thermal fluctuations.

In this regard, Georgian endemic wheat species and local landraces represent a unique genetic resource. Their long-term evolution across diverse ecological niches-including mountainous, excessively wet, arid, and harsh climatic environments-confers high adaptive potential. Species such as exhibit complex immunity to fungal diseases, lodging resistance, strong stems, short vegetation periods, and adaptability to both drought and excessive moisture [3,21,26,27,28].

Notably, Georgian mountain wheats, such as Dika and Macha, thrive at altitudes exceeding 2,000 meters above sea level, reflecting their high ecological plasticity and frost tolerance [29,30,31]. Highlight that these endemic species constitute invaluable material for breeding due to their high adaptability and resilience, while emphasize their critical role in maintaining wheat productivity under climate change conditions in Georgia [36,37].

Thus, Georgian endemic wheat species are not only a historical legacy of agrobiodiversity but also constitute an essential genetic resource for current and future breeding programs. Their study, conservation, and integration into breeding processes may provide an effective strategy to ensure wheat production resilience at both regional and global scales [32,33,36-38].

Table 1: Agrobiological and Functional Characteristics of Georgian Endemic Wheat Species

Species (Latin name)	Georgian name	Chromosomal level	Biological type	Key agro-biological traits	Nutritional and functional potential	Main areas of application
Triticum timopheevii	Chelta Zanduri	Tetraploid	autumn-sown	Strong root system; comprehensive resistance to fungal diseases; lodging tolerance; adaptation to climatic stresses	High protein content; excellent bread-making quality	Breeding programs; organic farming; traditional bread production
Triticum zhukovskyi	Hexaploiduri Zanduri	Hexaploid	autumn-sown	High biomass; moisture-demanding; strong stems	Potential for high-quality flour	Genetic research; breeding
Triticum palaeo-colchicum	Kolchuri asli	Tetraploid	autumn-sown	lodging resistance; tolerance to powdery mildew and leaf rus	Potential for high-quality flour	Functional flour; health-oriented bakery products
Triticum macha	Macha	Tetraploid	autumn-sown / semi-autumn-sown	winter hardiness; strong stem; adaptation to excessive moisture	Potential for high-quality flour	Specialty products; agro-culinary tourism
Triticum carthlicum	Dika	Tetraploid	spring-sown	Frost tolerance; short vegetation period; adaptation to high-altitude conditions	High protein content; excellent bread-making quality	Mountain farming; breeding programs; traditional bread production

Causes of Endangerment of Endemic Wheat Varieties and Their Advantages

The decline and potential extinction of endemic Georgian wheat varieties can be attributed to several factors, primarily in comparison with modern industrial cultivars: lower yield potential, susceptibility of the spike to shattering, and the need for grain dehulling (except for Dika). Nonetheless, the Georgian endemic wheats offer numerous significant advantages, including:

- High adaptability to the adverse effects of climate change;
- Consistent production of good-quality yields under poor soils and unfavorable climatic conditions, including drought, excessive moisture, and frost;
- Broad-spectrum resistance to diseases;
- High content of proteins, essential amino acids, vitamins, and minerals in the grain;
- Superior taste, palatability, medicinal properties, and long shelf-life of the bread;
- The production of high-quality, traditional products based on local genetic resources and cultural traditions, which is of critical importance for the development of agro- and culinary tourism.

The revival and conservation of Georgian wheat varieties today is of utmost importance not only for bread quality but also as a valuable resource for breeding programs and the development of environmentally sustainable agroecosystems [39,40]. Moreover, their application potential is both long-term and highly promising. Studies indicate that Georgian wheat varieties contain bioactive compounds, rendering them potential components of functional foods. For example, wheat bran extracts may serve as modulators of gut microbiota, exhibiting anti-inflammatory and immunomodulatory effects. Additionally, these extracts demonstrate antimicrobial activity, enhancing product quality and functioning as natural preservatives [41].

Analyses from multiple studies have evaluated the potential applications of wheat extracts in extending shelf life and as natural additives in functional foods [42]. The dietary fiber, vitamins, and minerals present in wheat bran support digestive health, improve intestinal motility, and prevent constipation [43]. Regular consumption of whole-grain wheat, including bran, has been associated with a 20-40% reduction in cardiovascular disease risk [44].

The application of wheat bran extracts as safe and environmentally sustainable natural alternatives to synthetic compounds has also shown considerable promise for the cosmetic industry. Studies demonstrate that wheat bran extracts contribute to skin whitening, reduction of wrinkles, antioxidant protection, and improvement of hair structure [45]. The phenolic compounds in wheat bran are directly associated with delaying the skin aging process.

There is a growing market demand for functional, non-alcoholic beverages that promote human health. Wheat and its by-products (bran, germ) represent rich sources of biologically active substances and nutritional components, including phenolic compounds, dietary fiber, minerals, and antioxidants. The application of innovative technological processes such as germination and fermentation significantly enhances the bioavailability of these food components, increases antioxidant potential, and ensures a unique sensory profile (flavor and aroma). These characteristics make wheat and its by-products highly promising raw materials for the production of functional, plant-based, health-promoting non-alcoholic beverages, thereby enabling both the creation of novel products and the development of sustainable production systems [46-47].

A critical direction for future research involves the comprehensive investigation of the physicochemical parameters of Georgian endemic wheat species. This includes the assessment of grain and flour moisture content, ash content, protein fractions, amino acid profiles, starch rheological properties, and both quantitative and qualitative analyses of phenolic compounds. Such data are essential not only for the optimization of technological processes but also for the targeted application of specific wheat species in bread production, functional foods, and innovative products.

Furthermore, a promising research avenue is the evaluation of the bioavailability of bioactive compounds in Georgian endemic wheat using modern technological approaches such as germination, fermentation, and microbial transformation. These processes enhance the functional activity of phenolic compounds, dietary fiber, and antioxidants, significantly increasing the potential of wheat and its by-products for use in health-promoting foods and non-alcoholic beverages.

Equally important is the integration of Georgian endemic wheat genotypes into modern breeding programs to develop resilient and ecologically adapted agroecosystems under climate change conditions. Such research will contribute not only to the conservation of agrobiodiversity but also to the creation of high value-added local products, thereby strengthening Georgia's competitive advantage in the international agri-food market.

Conclusion

The present review clearly demonstrates that Georgian endemic wheat varieties constitute a unique agrobiodiversity and nutritional resource, whose significance extends far beyond traditional bread production. Their genetic diversity, adaptability to local environmental conditions, and resilience to both biotic and abiotic stresses render them particularly valuable for contemporary breeding programs, especially in the context of climate change.

The high content of biologically active compounds in Georgian wheat - such as phenolic compounds, dietary fiber, vitamins, and minerals - confirms their potential as raw materials for functional foods. Literature evidence indicates that wheat bran and germ not only enhance gastrointestinal health but also exhibit antioxidant, anti-inflammatory, immunomodulatory, and antimicrobial properties, positioning them as bioactive components that support human health. These effects play a critical role in the prevention of chronic non-communicable diseases as well as in improving food quality and storage stability.

Beyond the food industry, the application potential of wheat bran extracts extends into the cosmetic and pharmaceutical sectors. The phenolic compounds and antioxidants present in bran are associated with delaying skin aging processes, highlighting the opportunity to transform wheat by-products into high-value raw materials.

Additionally, wheat and its by-products hold significant promise for the development of innovative, functional non-alcoholic beverages. Modern technological approaches such as germination and fermentation substantially increase the bioavailability of bioactive compounds, enhance antioxidant potential, and create a unique sensory profile, providing Georgian wheat and its derivatives with a competitive advantage in a market characterized by growing consumer demand.

In summary, the revival and scientifically guided utilization of Georgian endemic wheat varieties represent a strategically important direction for both the conservation of agrobiodiversity and the advancement of sustainable breeding, functional food production, and innovative product development. Their integration into modern food systems establishes a long-term framework for producing health-promoting, ecologically sustainable, and high-value-added products.

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