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# Colored Wheats for Functional Food Candidates with Enhanced Nutrition

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**Abstract:** Wheat, the primary cereal crop, supplies 20% of humanity's protein and caloric intake. Colored blue, purple, and black wheats specifically represent a breakthrough in functional foods due to their exceptionally high phytochemical content, especially anthocyanins. These natural pigments create vibrant hues: purple concentrates in the pericarp, blue in the aleurone, while black wheat features pigments in both layers. Genetically, purple traces to Ethiopian emmer wheat, and blue originates from wild and relative crops. Nutritionally, colored wheats outperform modern wheat cultivars. They deliver significantly elevated protein, essential minerals, and vitamin E. Anthocyanin levels are substantially higher in black, purple, and blue wheats. They are also rich sources of phenolic compounds, flavonoids, and carotenoids, forming a potent bioactive profile. These phytochemicals offer major health benefits. Anthocyanins and phenolics act as powerful antioxidants, neutralizing harmful reactive oxygen species (ROS). This reduces oxidative stress and cellular damage to lipids, proteins, and DNA, thereby lowering risks of developing major chronic conditions, such as diabetes, cardiovascular disease, cancer, and age-related degeneration. This makes colored wheats vital tools against micronutrient deficiencies and hidden hunger. Technologically, despite variable gluten strength, they are versatile for functional food production. Applications include nutrient-dense, visually appealing muffins, noodles, biscuits, pasta, crackers, nutrition bars, and chapati bread, often boasting extended shelf-life and natural pathogen resistance. Agronomically, targeted breeding programs enhance their yield potential, stress tolerance, and adaptation especially for dryland farming. The ultimate goal is integrating their superior nutrition and health benefits into mainstream diets, providing natural alternatives to synthetic additives and contributing significantly to improved global nutrition.

**Keywords:** Colored wheat, Anthocyanin, Functional food, Breeding

## Introduction

Wheat constitutes a significant portion of the human diet, contributing 20% of daily caloric and protein intake (Sharma & Sharma, 2025). Given this central dietary role, there is growing interest in enhancing wheat's nutritional profile, with a concept that aligns with the functional food movement, which originated in Japan in the late 1980s and is now widely embraced as individuals increasingly choose diets that promote well-being (Padhy et al., 2022). Colored wheat, fortified with anthocyanins, has arisen as a compelling functional food, providing a natural alternative to synthetic additives and nutraceuticals owing to its rich nutritional makeup and bioactive constituents (Padhy et al., 2022).

Colored purple, blue, and black wheat genotypes display distinct grain coloration associated with improved antioxidant capacity, higher protein levels, and a more favorable micronutrient composition (Sharma et al., 2023; Akman et al., 2025; Reddy et al., 2025). These qualities position colored wheat as a strong candidate for alleviating micronutrient deficiencies and improving dietary standards via biofortification strategies (Padhy et al., 2022). This review offers a thorough analysis of the genetic foundations, health-promoting attributes, antioxidant potential, agronomic features, technological uses, and breeding progress pertaining to colored wheat, underscoring its significance as a key component in the production of functional foods.

## Method

This study was structured as a comprehensive review, synthesizing and analyzing existing scientific literature and recent research findings on colored wheats (blue, purple, and black). The methodology involved a systematic examination of published research articles, reviews, and conference proceedings to gather information on the genetic origins, nutritional composition, health benefits, antioxidant properties, agronomic traits, and food applications of these wheats. Data from various international breeding programs and nutritional studies were compared and consolidated. Specific genetic studies and analytical methods from the cited literature, such as antioxidant capacity assays (DPPH, ABTS, FRAP) and compositional analyses, form the basis of the comparative assessment. The review also incorporated findings from agronomic evaluations and food technology research to present a holistic overview of the potential of colored wheats as functional food candidates.

### Genetic Origins of Colored Wheat

The distinctive colors observed in colored wheat species result from specific genetic contributions inherited from different ancestral wheat species; for instance, the purple color is due to anthocyanins derived from an Ethiopian emmer wheat, *Triticum turgidum* L. subsp. *abyssinicum* (also known as *T. aethiopicum*), that later became established in Yemen and Eritrea (Lachman et al., 2017; Badaeva et al., 2018). The purple color in the pericarp is determined by two genes that work together. The *Pp3* gene is on chromosome 2A, and the *Pp1* gene is on the short arm of chromosome 7B. (Khlestkina et al., 2010).

In contrast, the blue coloration in wheat originates from *Ba1*, the gene encoding the transcription factor ThMyc4E from *Thinopyrum ponticum*, and the *Ba2* gene from *Triticum boeoticum* Boiss. (syn. *T. monococcum* L. ssp. *aegilopoides*) (Dubcovsky et al., 1996; Zhang et al., 1996; Singh et al., 2007; Li et al., 2017). Black wheat, a pigmented variety developed from crossing purple and blue wheat, derives its color from anthocyanins in its outer layer and is rich in phenolic compounds, carotenoids, vitamins, essential amino acids, dietary fibers, and minerals (Dhua et al., 2021). These genetic characteristics not only contribute to visual appeal but also improve the functional quality of colored wheat, establishing it as an excellent choice for foods designed to support health.

### Nutritional Composition and Health Benefits

Colored wheats offer a nutritional profile that exceeds that of conventional modern wheat, providing more protein, dietary fiber, minerals, and vitamins. For example, chapattis prepared from colored wheat (purple, blue, and black) contain more dietary fiber and protein but fewer carbohydrates than those made from white wheat, making them better aligned with health-oriented eating patterns (Garg et al., 2016; Kumari et al., 2020). These wheat genotypes are abundant in anthocyanins, flavonoids, and carotenoids, compounds that are located in different parts of the grain; notably, whole flour and bran from blue wheat have been found to contain higher levels of anthocyanins than flour from purple wheat (Abdel-Aal et al., 2006; Ficco et al., 2014; Paznocht et al., 2018). The presence of a blue aleurone layer in blue and black wheat is linked to increased levels of micronutrients. Purple wheat can show mineral (Zn, Fe, Mg, K) increases of up to 100%, and blue wheat contains 5–36% more vitamin E than conventional wheat (Guo et al., 2013; Lachman et al., 2018).

Previous research has revealed that a diet in rats incorporating anthocyanin-rich wheat improved serum antioxidant status and reduced kidney protein oxidation. However, it also increased lipid peroxidation in the kidney and induced behavioral changes associated with anxiety (Janšáková et al., 2016). Sharma et al. (2023) have also stated a protective role for anthocyanin consumption against a range of chronic diseases, including diabetes, cardiovascular conditions, and inflammatory disorders. These positive health outcomes are largely due to the high concentrations of anthocyanins, phenolics, and carotenoids, which help counteract oxidative stress by neutralizing reactive oxygen species (ROS) involved in the development of heart disease, cancer, diabetes, and aging-related conditions (Valko et al., 2006; Halliwell, 2012). Moreover, these phytochemicals play a role in protecting the plants themselves from biotic challenges (such as fungal diseases and insect damage) and abiotic stresses (like drought, high salinity, and extreme temperatures), thereby increasing the overall hardiness of the crop (Mierziak et al., 2014; Tuladhar et al., 2021).

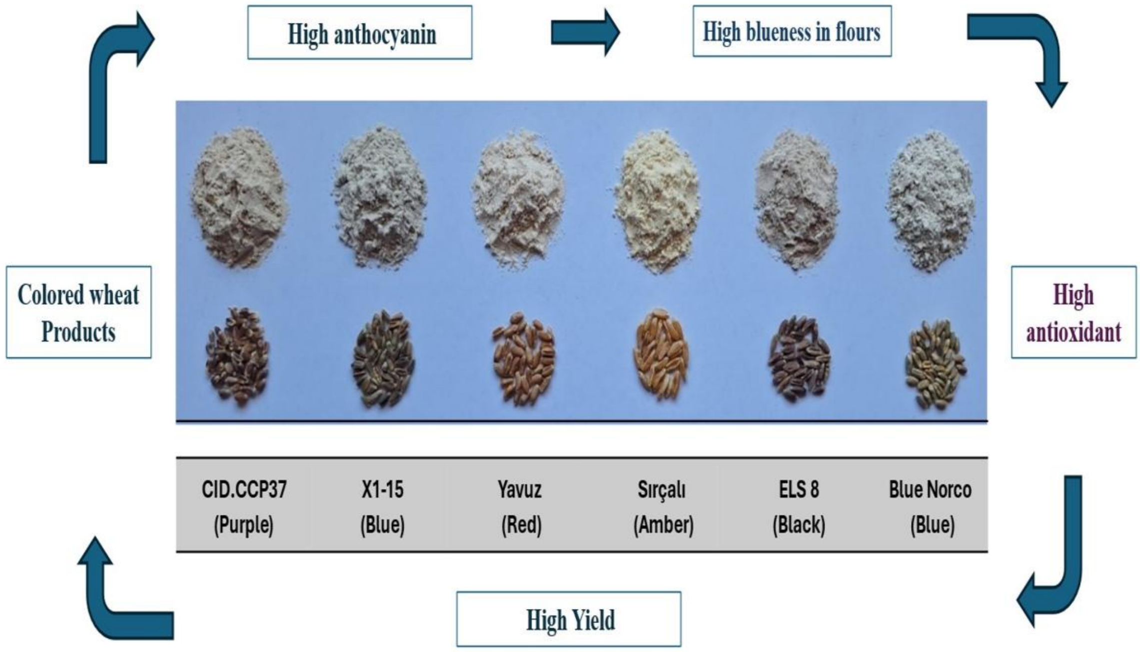


Figure 1. Selection of colored-wheats in comparison to modern wheats for health-benefit, quality, and yield traits in breeding program. The genotypes studied included the *T. aestivum* genotypes CID.CCP37 (Purple), X1-15 (Blue), and Blue Norco (Blue); the *T. durum* genotype ELS 8; and the modern *T. durum* cultivars Yavuz (Red) and Sırçalı (Amber) (Akman et al., 2025).

**Antioxidant Capacity and Phytochemical Content**

The antioxidant strength of colored wheat is primarily due to its high levels of anthocyanins and phenolic compounds. Total anthocyanin content differs considerably among different genetic lines: while red wheat contains only 7–10 mg $kg^{-1}$, values for black wheat range between 95 and 277 mg $kg^{-1}$, purple wheat between 22 and 278 mg $kg^{-1}$, and blue wheat between 72 and 211 mg $kg^{-1}$, (Liu et al., 2010; Kumari et al., 2020; Wang et al., 2020). Food products derived from purple isogenic lines can be 2.5 times richer in anthocyanins than white wheat, highlighting their enhanced functional quality (Usenko et al., 2018). The total phenolic content in colored wheat is roughly 30% higher than in conventional wheat, with black wheat typically having the highest total phenolic content with blue and purple genotypes containing the next highest levels (Liu et al., 2015; Kumari et al., 2020). For instance, bread made from the purple genotype 'Purple 8' displayed a higher total phenolic content relative to bread made from other colored and conventional wheat genotypes (Koksel et al., 2023). Total carotenoid content and total flavonoid content also show variation; generally, black and purple wheat have higher total phenolic content than blue wheat, while purple genotypes tend to have slightly higher total carotenoid content (Feng et al., 2022; Paznocht et al., 2020).

Variations at the genotypic level further illustrate the diversity in phytochemical composition. For example, the 'Charcoal' purple wheat genotype has a higher total phenolic content than other purple, red, and white genotypes, though some red and yellow genotypes can surpass certain purple ones, such as 'Indigo' (Liu et al., 2010). Total phenolic content values reported for black wheat lines range from 11.56 to 152.00 mg 100 $g^{-1}$ (Sharma et al., 2023). According to standard antioxidant assays (DPPH, ABTS, FRAP, MC), the typical order of potency is black > purple > blue. Purple wheat frequently shows stronger antioxidant activity than red wheat in DPPH tests (Feng et al., 2022; Sharma et al., 2023; Koksel et al., 2023; Sytar et al., 2018). These characteristics make colored wheat a powerful ingredient for decreasing oxidative stress and increasing the health benefits in food products.

**Agronomical Traits, Technological Quality and Food Applications**

Colored wheat genotypes display unique agronomic and physical traits that affect their cultivation and processing. Thousand grain weight shows considerable variation: purple genotypes typically weigh between 32.9 g and 34.0 g, blue genotypes average 29.2 g, and red genotypes 31.4 g. (Koksel et al., 2023). Purple isogenic lines often have a higher thousand grain weight than red lines (Morgounov et al., 2020). Hectoliter weight (HL) is similar among blue, purple, and red genotypes, generally falling within the range of 72.2 to 73.2 kg $hl^{-1}$ (Koksel et al., 2023).

The large-scale cultivation of colored wheats has historically been limited by a significant yield penalty (Garg et al., 2016). This is clearly demonstrated by the Austrian blue wheat 'Skorpion', which yields 25% less than conventional cultivars (Garg et al., 2016), and by the general performance of purple and blue wheats, whose yields typically reach only 60.1–85.6% and 76.2–84.3%, respectively, of modern bread wheat cultivars (Akman et al., 2025). However, recent breeding advances are successfully addressing this challenge. Newly developed black, biofortified wheat lines exemplify this progress, combining promising yield potential with elevated health-beneficial traits (Sharma et al., 2018). Furthermore, recent studies on improved purple lines derived from the cross BW/2*PBW621 have reported yields of 4.71–4.69 t $ha^{-1}$. This result not only exceeds the yield of the black donor parent BW (2.68 t $ha^{-1}$) but also approaches that of the high-yielding, white recipient parent PBW621 (5.15 t $ha^{-1}$), marking a critical step toward competitive agronomic performance for colored wheats.

Color measurements of the grain, expressed as $L^*$, $a^*$, and $b^*$ values, affect both the appearance and processing behavior of products made from colored wheat. A lower bran content results in higher $L^*$ values (indicating lightness); while a higher bran content is associated with increased $a^*$values (indicating red-green spectrum) (Singh & Singh, 2010; Seo et al., 2021). Garg et al. (2016) also report that blue wheat genotypes have higher $L^*$ values and lower $a^*$ values compared to purple genotypes.The $b^*$value (indicating blue-yellow spectrum) varies between 8.5 and 12.0 across different genotypes (Punia et al., 2019). These physical attributes are essential for milling and product development, as the grain's structure must conform to standard milling requirements (Pena, 2012).

The processing quality of wheat, especially its gluten content and characteristics, is critically important for industrial food production. Colored wheat genotypes generally contain more grain protein and wet gluten than conventional wheat (Giordano et al., 2017; Morgounov et al., 2020; Sebestiková et al., 2023; Akman et al., 2025). Blue and purple genotypes show grain protein values between 15.06% and 16.35%, whereas red genotypes average around 13.47% (Fan et al., 2020). However, some research indicates that white and red genotypes may have higher wet gluten levels than blue and purple ones, and in certain cases, black wheat exhibits the highest grain protein (9.17–10.18%) among the colored genotypes (Koksel et al., 2023; Sharma et al., 2022). Despite this generally high protein and wet gluten content, Akman et al. (2025) reported that colored wheats can have low gluten quality parameters.

Colored wheat has been effectively used in a wide array of food products, such as muffins, noodles, bread, biscuits, pasta, crackers, and snack bars, capitalizing on its rich content of anthocyanins and phenolics (Pasqualone et al., 2015; Li et al., 2007; Saini et al., 2021). Biscuits made with purple wheat and spiral pasta incorporating it show increased antioxidant activity and mineral levels. Similarly, chapattis prepared from black and blue wheat are particularly suitable for traditional Indian cuisine, offering improved nutritional value and sensory qualities (Pasqualone et al., 2015; Verma et al., 2022; Kumari et al., 2020; Garg et al., 2016). A significant advantage of colored wheat products is their extended shelf life and enhanced resistance to mold growth, attributable to the high anthocyanin content (Khlestkina et al., 2017; Dziki et al., 2014). This addresses a major weakness of conventional wheat products, which often have limited antioxidant activity The beneficial amino acid profile and elevated protein level of colored wheat further increase its appropriateness for manufacturing nutritious foods (Guo et al., 2013).

## Breeding and Global Adoption

The development of new colored wheat cultivars rich in anthocyanins is an international effort, involving initiatives in 16 countries and 60 research institutions that have collectively produced 40 blue, purple, and black germplasms, breeding lines, and officially registered cultivars (Padhy et al., 2022). However, the successful expression of these pigments is not solely genetic, as environmental conditions, including light exposure, temperature, disease pressure, soil nutrient content, fertilizer use, and planting time, have a significant impact on the accumulation of anthocyanins (Abdel-Aal, 2008; Lachman, 2017; Fan et al., 2020; Beleggia et al., 2021). Genetic differences lead to substantial variation in total anthocyanin content; purple wheat can range from 14 to 2304 µg $g^{-1}$ and black wheat from 248.7 to 2902 µg $g^{-1}$, representing differences of up to twentyfold between genotypes (Eticha et al., 2011; Zhang et al., 2021).

The recommended daily intake of anthocyanins differs based on factors like sex, age, and ethnic background (CDC, 2015). China has established a daily target intake of 50 mg (Wallace & Giusti, 2015). The worldwide interest in adopting colored wheat is fueled by its potential to fight hidden hunger through biofortification, coupled with a growing consumer trend toward nutrient-rich food choices (Padhy et al., 2022). These breeding activities highlight the important role colored wheat can play in improving the nutritional value of staple foods and tackling public health issues on a global scale.

## Conclusion

Colored wheat signifies a major innovation in the field of functional foods, providing a distinctive blend of attractive color, improved nutritional value, and strong antioxidant activity. Its rich content of anthocyanins, phenolics, flavonoids, and essential micronutrients makes it a valuable component for creating health-promoting foods, with documented benefits including the reduction of oxidative stress, better regulation of blood sugar, and lowered risk of chronic diseases. Progress in genetics has enabled the successful integration of bioactive compounds, while evaluations focusing on agronomy and food technology confirm its adaptability for a wide range of uses, from traditional flatbreads to modern pasta and biscuit formulations. Breeding programs are steadily increasing the diversity and availability of colored wheat cultivars, taking into account how both environmental and genetic factors influence phytochemical levels. As the demand for sustainable and healthful food options continues to rise, colored wheat presents a viable strategy for improving overall diet quality and addressing global nutritional challenges, thereby securing its importance in contemporary food production systems through ongoing scientific exploration and technological innovation**.**

## Scientific Ethics Declaration

*The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

## Conflict of Interest

*The author declares that he has no conflicts of interest

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