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Review Article



A Review on Nutritional Composition and Bioactive Compounds of Black Wheat (*Triticum aestivum* L)

Muhammad Khalid Saeed^{1*}, Naseem Zahra¹, Asma Saeed¹, Shaheena Anjum², Hattaf Khan³, Muhammad Zeshan Kazim⁴, Qurtulain Syed¹ and Syed Hussain Imam Abdi¹

¹Food and Biotechnology Research Center, Pakistan Council of Scientific and Industrial Research Laboratories Complex, Lahore, Pakistan

²Department of Chemistry, Riphah International University, Faisalabad, Pakistan

³College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan

⁴Institution of Food Science and Nutrition, Gomal University, Dera Ismail Khan, Pakistan

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*Corresponding Author:

Muhammad Khalid Saeed
Food and Biotechnology Research Center,
Pakistan Council of Scientific and Industrial
Research Laboratories Complex, Lahore,
Pakistan
rosefbre1@gmail.com

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ABSTRACT

Black wheat (*Triticum aestivum* L) is a pigmented wheat type that is nutritionally superior. It is packed with bioactive chemicals, such as anthocyanins. Black wheat has different nutritional properties and medicinal potential, and more iron (60%), zinc (35% more), vitamin B3, vitamin B5, vitamin E, vitamin K, dietary fiber, and antioxidants than the average food. The high concentrations of phenolic acids, carotenoids, flavonoids and essential amino acids in black wheat provide it with powerful antioxidant, anti-inflammatory and antibacterial capabilities. With anthocyanin levels up to 28 times greater than standard white wheat, this kind of wheat is effective against oxidative stress-related metabolic syndrome and chronic medical issues like diabetes, cancer, obesity and heart disease. Additional compounds like tricin derivatives, ferulic acid, quercetin and luteolin present in black wheat help neuroprotection, manage blood sugar and boost immunity. Due to its diverse composition, black wheat shows promise as a nutritional supplement, therapeutic diet, and long-term answer to today's food problems.

INTRODUCTION

The hybridization of purple and blue wheat cultivars produces black wheat, a colored variety of wheat. Black wheat gets its colour from anthocyanins in the pericarp and aleurone layers. The Shanxi College of Agricultural Science's Institute of Crop Genetics was the first to cultivate black wheat 20 years later. In 1970, the long-term endeavor began. His name was "Black 76." It was the original black wheat type ever developed. The gradual creation of this variety was achieved by uniting "blue-purple 114" with

"purple 12-1" in a cross-pollination that occurred as a result of a pericarp mutation. Black wheat, instead of a whole grain, is a type of seed that is consumed as food. Their speciality is that they do not grow on grass like other cereals. These are included in the group of other common pseudo-cellular grains, quinoa and amaranth [1]. Because of its high nutrient density, pleasant flavour, and beneficial effects on health, black wheat has become the most talked-about pigmented wheat type. It is also used to



manufacture functional meals and colorants, with the main goal of creating items that are much better than conventional wheat [2]. Nevertheless, studies are being carried out using the given data to enhance its nutritional and functional properties, economic value, and outcomes to the fullest extent possible. Despite increasing interest in pigmented wheat varieties, the nutritional and therapeutic potential of black wheat remains underexplored compared to conventional white wheat. Limited comprehensive reviews exist that consolidate its bioactive compounds, antioxidant activity, and health benefits in a single study. Moreover, variations among different cultivars and the influence of environmental factors on its nutritional composition are not fully understood. Therefore, a systematic analysis is needed to provide an updated understanding of black wheat's functional properties (Figure 1).



Figure 1: Black Wheat Plant and Seed

This study aims to compile data on the bioactive components and nutritional profile of black wheat. In addition to highlighting the health advantages of black wheat, this study will compare it to conventional white wheat.

Nutritional Composition of Black Wheat

Black wheat contains high nutritional compounds like protein, carbohydrates, dietary fiber and minerals (Figure 2).

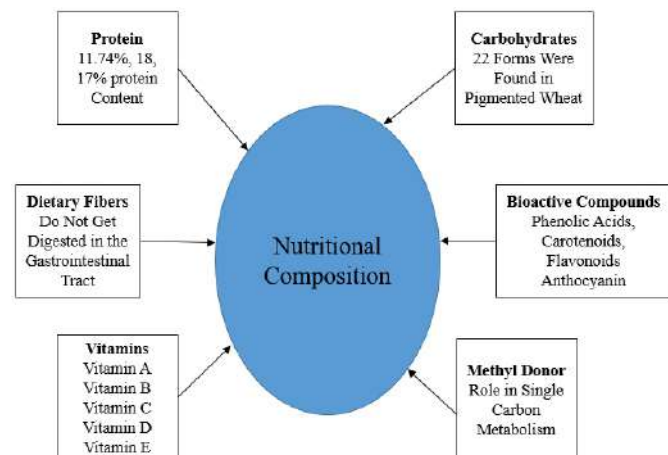


Figure 2: Nutritional Composition of Black Wheat, Source: [Ref: 25]

Protein

A good source of all ninety-six amino acids and their byproducts is black wheat. The bulk of the storage proteins found in black wheat are glutamine and gliadin, which are prolamins that are soluble in alcohol. The calculated total amino acid content is 15.74%, but the required concentration is around 4.45%. A lower gelatin index of 69.74 is used to evaluate the ultimate quality of black wheat flour, as compared to regular wheat, which has a higher value of 98–99. However, black wheat flour may still be used to make bread as its antigen index is still within the optimal range of 60 to 90. Because of this, black wheat may now be processed into low-gluten food products that those suffering from celiac disease can consume instead [3].

Carbohydrates

One of the most important components that provide energy is starch, the primary carbohydrate found in wheat. In the kernel, it is found in the endosperm, also called the flour. A total of 22 different carbohydrate types were discovered in wheat cultivars with red, blue, purple, and black coloring. Black wheat has a higher polysaccharide content compared to white wheat and 75% of the carbohydrates in black wheat are found in the endosperm [4]. It was found that moved lines and black donor lines had a greater amount of sugars and carbohydrates compared to blue and white wheat lines, as well as lines generated through crossing white with pigmented types of wheat (purple, black and blue) [5].

Dietary Fibers

The gastrointestinal tract's enzymes are unable to break down several polysaccharides, including cellulose, hemicellulose, pectin and others that are part of dietary fiber, which increases the food's bulk and, as a result, makes starch granules less accessible to the digestive tracts enzymes. Total dietary fibers (TDF) make up approximately 1.15 % of the weight of black wheat, and insoluble fiber, which makes up a larger portion [6]. Constipation can be avoided and intestinal transit can be stimulated by insoluble fiber, which gives the body and faces volume.

Vitamins

Black wheat contains 19 different vitamins. Bone metabolism and blood coagulation are mediated by vitamin K. A particularly good source of vitamin K is black wheat. Energy metabolism, DNA synthesis, and the preservation of healthy skin are all impacted by vitamin B3 [7]. The main focus of vitamin E is preventing hemolysis of the red blood cell. Vitamin B5 is involved in gland function, hormone release, blood cell development, and the transformation of food into energy. The BGW 76 variety has a vitamin K content of 11.47 mg/. Significant levels of B3, B5, and E have been found in black wheat.

Minerals

A person's normal development depends on the creation of bones, which in turn requires calcium. It was found that compared to Jinchun 9 (a conventional wheat variety), black-grained grains 76 (BGW-76) have four times the amount of calcium [8]. A person's teeth and bones would not exist without the mineral phosphorus. The phosphorus levels in Jinchun 9 were 2.41 g/kg, but in BGW 76 they were 4.10 g/kg. The immune system, inflammation and oxidative stress may all benefit from selenium (Se). Black wheat has 1.04 mg/kg of Se, which is much more than normal wheat's 0.26 mg/kg. Colored wheat, as opposed to white wheat, has a greater concentration of zinc and iron elements and benefits from double-fortification [9].

Functional Compounds

Several bioactive chemical compounds are found in black wheat, which is higher than in normal wheat (Table 1). Wheat is primarily composed of carbohydrates, protein, and fat, but wheat also contains phenolic acids, flavonoids, anthocyanins, and carotenoids, among other useful compounds. Both flavonoids and PAs include hydroxyl groups and one or more aromatic rings. One kind of flavonoid is anthocyanin, which is a naturally colored flavonol. The anthocyanin, antioxidants, folic acid, the elements selenium, magnesium, calcium, and the metals manganese, zinc, iron, calcium, magnesium, copper, potassium, a mineral fiber, and amino acids found in black wheat are some of its fascinating health benefits. The anthocyanine content of black wheat is twenty-eight times higher than that of white wheat [10].

Phenolic Acids

The bioactive chemicals known as phenolic acids protect plants from both biotic and abiotic stresses. Furthermore, phenolic acids govern gastronomic properties like astringency, colour, flavour, aroma, bitterness, and resistance to lipid oxidation. Phenolic acids have several beneficial effects, including reducing inflammation, killing germs, slowing cell growth, preventing cancer and reducing free radicals [11]. Phytochemicals known as phenolic acids may be present in wheat in two forms: free (soluble reactive) and bound (insoluble). Phenolic chemicals are more typically found on the outside of wheat grains compared to the endosperm. This means that the bran extracts consistently had greater TPC levels [12]. The accumulation of amethyst in the outermost portion of the grain is responsible for the formation of colour on the grain [13]. The first category of PAs consists of compounds derived from hydroxybenzoic acid, whereas the second category includes compounds derived from hydroxycinnamic acid. The extraction of soluble phenolic acids is simpler than that of bound ones. Antioxidant activity is shown by both of such substances when attached to or dissolved in phenolic acid [14]. The phenolic

acids found in black wheat in the highest concentrations were protocatechuic acid and gentisic acid. There are several phenolic acids found in black wheat. These include o-coumaric, p-hydroxybenzoic, ferulic, gentisic, syringic, and Gallic acids. The percentage of phenolic acid in the bran is greater than that in the whole meal. The majority of black wheat's phenolic acid content is ferulic acid. The soluble phenolic content of black wheat is greater than that of white wheat. It was found that, in contrast to purple and yellow cultivars, black wheat has 1.6 times more linked total phenolic chemicals (TPC) and 6 times greater quantities of free TPC. To manage innate immune processes, dividing cells, apoptosis, and cell survival, the PAs found in wheat modify a transcriptional factor called nuclear factor kappa B (NF- κ B) [15].

Flavonoids

Fruits, vegetables, bark, stems, roots, grains, flowers, tea, and wine are all good sources of flavonoids, which are naturally occurring compounds with varying phenolic structures. Plants produce flavonoids as a byproduct of aerobic metabolism. C6-C3-C6 is an abbreviation for the skeleton of a flavonoid, which consists of a three-carbon heterocyclic ring containing two rings of phenol rings with six carbon atoms each. Many subgroups of flavonoids have positive impacts on health. These subgroups include isoflavones, flavones, flavan-3-ols, flavanones, flavanonols, flavonols, anthocyanidins, and chalcones. Flavonoids assist in strengthening the immune system and have an anti-inflammatory impact [16]. Flavonoids and anthocyanins have several positive impacts on health, including preventing cardiovascular disease, reducing the risk of cancer, lowering blood pressure, preventing diabetes, protecting neurons, and improving eye health [17]. Wheat contains the following flavonoids: apigenin, naringenin, tricetin, luteolin, a substance known as quercetin, and vitexin. Black wheat contains around 174 flavonoids. In the investigation, found that at 876 μ g/g dry weight, BW had the greatest total flavonoid concentration. Thanks to the presence of apigenin, tricetin, anthocyanins, and luteolin, black wheat has a high concentration of flavonoids. Several black wheat types have antioxidant-rich tricetin derivatives, such as O-glucuronic acid [2].

Antioxidants

Some species contribute to the development of several illnesses via inducing oxidative stress; they include peroxide anions, hydroxyl radicals, superoxide anion radicals, and singlet oxygen [18, 19]. Because of their ferric reducing capabilities and ability to scavenge free radicals, phenolic and flavonoid chemicals mitigate oxidative stress-induced cell damage [20]. In one research, [9] showed that, in comparison to white wheat, colored wheat flour and anthocyanin-rich wheat grass juice had a significant antibacterial activity and a good antioxidant

value against free radicals. Black wheat has a greater Trolox equivalent (TE) content (450.92 $\mu\text{mol}/100\text{ g DW}$) compared to lavender grains (273.40 $\mu\text{mol}/100\text{ g DW}$), turquoise wheat (159.66 $\mu\text{mol}/100\text{ g DW}$), plus yellow wheat (89.93 $\mu\text{mol}/100\text{ g DW}$). Another research found that compared to purple and white grain wheat, complete meal black-grained wheat had a DPPH radical scavenging activity of 33.51%. This is 1.31 times greater and 1.41 times when compared to blue-grained wheat [8].

Carotenoids

The bioactivity and colour of the majority of fruits and vegetables are caused by carotenoids, which are fat-soluble plant pigments. Xanthophylls are hydrocarbon carotenoids, whereas carotene is an oxygen derivative. Carotenoids are isoprenoids with 40 carbon atoms and a lengthy conjugated polyene chain. Like ordinary wheat and other tinted wheat varieties (blue, red, purple), BW contains carotenoids. Compared to white and red wheat, BW had a higher net carotenoid content value [21]. The process of converting alpha-carotene, beta-carotene, gamma-carotene, and nor beta-cryptoxanthin into retinol (vitamin A) utilizes four different types of carotenoids. Although they do not convert to tretinoin (vitamin A), other carotenoids, including lutein, lycopene, and zeaxanthin, do have antioxidant properties. Durum wheat is valued for its high carotenoid content, which is responsible for the colour of wheat products. Carotenoids shield cells from harmful oxidative stress by acting as antioxidants. Carotenoids promote immunological activities, reduce LDL cholesterol levels via cholesterol synthesis, and increase iron absorption in humans by binding iron to its aromatic ring [22].

Anthocyanin

Anthocyanins, which are found in the outermost levels of the wheat kernel, are crucial for the formation of grain colour. Compared to other wheat varieties, BW had a significantly higher concentration of 13 of the 14 anthocyanins studied [7]. The researchers compared the antibacterial efficacy of white wheat extracts with coloured wheat amethyst extracts against human infections. For every pathogen tested, black wheat gluten had a minimum inhibitory concentration (MIC) between 50 and 150 mg/mL; the highest MIC value was 50 mg/mL against *S. aureus* and *P. aeruginosa*. Black wheat flour extract at concentrations of 100 and 150 mg/mL completely inhibited the formation of *Staphylococcus aureus* and *Pseudomonas aeruginosa*, respectively. The higher dose of 200 mg/mL was the only one that reduced *Candida albicans* and *Escherichia coli* [9]. Several bioactive chemical compounds are found in black wheat, which is higher than in normal wheat (Table 1) [2].

Table 1: Bioactive Compounds and Their Chemical Structures [2]

Compounds	Phytochemical Name	Structures
Phenolic acids	Hydroxybenzoic Acid	
	Hydroxycinnamic Acid	
Flavonoids	Flavones	
	Flavanones	
	Flavonols	
	Isoflavones	
	Flavan-3-ols	
	Flavylium salts (anthocyanins)	
	Carotenoids	B-Carotene
Xanthophyll		

Comparison of Black Wheat and White Wheat

Black wheat is an improved variety of conventional yellow wheat that is richer in protein, fiber, calcium, vitamin K,

antioxidant activity, total flavonoid content, and phenolic content. The quantity of anthocyanins is the primary differentiator between white and black wheat. Black wheat has 28 times more anthocyanins than white wheat. There are fewer than five parts per billion (ppm) of anthocyanin in a normal wheat grain. On the other hand, 100-200 ppm is found in black wheat grain. Increasing one's intake of antioxidants improves one's health in general by assisting the body in flushing out harmful pollutants and free radicals. Approximately 225 metabolites, mostly flavonoids, are responsible for the colour variation across black and yellow wheat. Zinc, which is present in black wheat at a 35% higher concentration than white wheat, aids in metabolic and immune system processes. In addition, most wheat cultivars contain around 25% iron. In contrast, the iron content of black wheat is 60% higher, leading to a significant elevation of hormone and hemoglobin levels in the body. The protein content of black wheat was 17.71% higher than that of the control wheat. Vitamin K levels in black wheat 76 were 1.6 times higher than in conventional wheat [8]. Comparative Analysis of Nutritional Composition of Different Colored Wheat [1] (Table 2).

Table 2: Comparative Analysis of Nutritional Composition of Different Colored Wheat [1]

Parameters	Black Wheat	White Wheat
Anthocyanin (ppm)	100-400	5
Energy (kcal)	318	322
Carbohydrate (g)	64.8	67.8
Protein (g)	12	10
Dietary fiber (g)	12	11
Fat (g)	1.2	1.2
Moisture (%)	10	10
Iron (mg)	45	38
Zinc (mg)	35	28

Health Benefits of Black Wheat

Heart disease, inflammation, cancer, diabetes, and obesity are all prevented by consuming whole black wheat. Black wheat's high anthocyanin content helps diabetes patients' blood sugar metabolism and cholesterol levels. Black wheat types' high anthocyanin content serves as a protective barrier against lifestyle diseases. Wheat flour's total anthocyanin content ranges from 6.61 to 95.04 mg k⁻¹, with the following sequence: black > blue > purple > white. According to epidemiological studies of whole grains, black wheat has emerged and serves as a better choice in the form of dietary supplements for anyone suffering from breast, colon, liver, ovarian, or prostate cancer [23]. Whole grain consumption and the risk of obesity are inversely correlated, according to numerous observational studies. Naturally occurring antioxidants that form in the grain fill

the void and enhance the nutritional value of colored wheat, particularly black wheat. Eye-related issues among adults can be resolved with black wheat. Furthermore, by reducing age-related neurodegeneration and psychological deterioration, it aids in the cerebrum's proper function. Compared to conventional wheat, black wheat has more anthocyanins and antioxidants, which help our bodies regulate free radicals and antibodies while also enhancing immunity. Malnutrition can also be alleviated with black wheat. Additionally, black wheat limits body weight gains and dramatically lowers fat pads [24]. Health benefits of black wheat are analyzed [25](Figure 3).

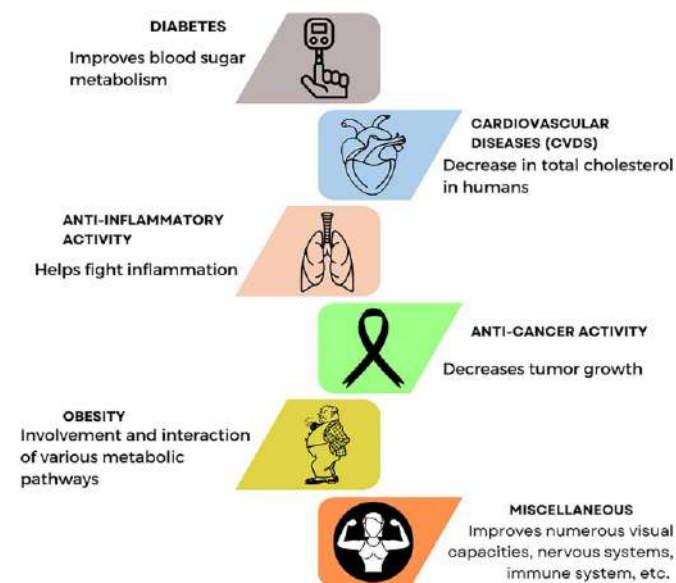


Figure 3: Health Benefits of Black Wheat [25]

Limitations and Future Prospects

Although black wheat demonstrates significant nutritional and therapeutic potential, most studies are limited to in vitro analyses, with few clinical or long-term dietary intervention studies available. Future research should focus on human trials, cultivar-specific evaluations, and bioavailability of bioactive compounds. Additionally, exploring industrial applications in functional foods and nutraceuticals could maximize its health benefits and economic value.

CONCLUSIONS

Black wheat has emerged as a nutritionally superior alternative to conventional white wheat due to its rich composition of proteins, minerals, vitamins, and bioactive compounds like anthocyanins, flavonoids, phenolic acids, and carotenoids not only improve metabolic and cardiovascular health but also offer antimicrobial and anti-inflammatory. Prevent obesity, diabetes, cancer, neurodegeneration effects, while also alleviating malnutrition and eye-related disorders. Its health-

promoting attributes make it an ideal candidate for inclusion in dietary supplements, functional foods, and specialized therapeutic diets. In short, black wheat offers enhanced nutritional value and represents a promising avenue for health-focused agricultural innovation.

Authors' Contribution

Conceptualization: MKS

Methodology: MKS, NZ, SA

Formal analysis: AS, HK, MZK

Writing and Drafting: QS, SHIA

Review and Editing: QS, SHIA, AS, HK, MZK

All authors approved the final manuscript and take responsibility for the integrity of the work.

Conflicts of Interest

All the authors declare no conflict of interest.

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