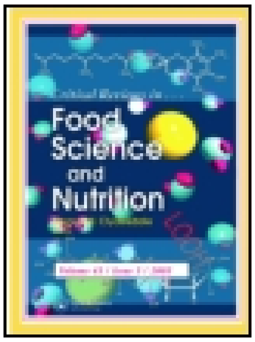

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REVIEW

Bioactive compounds, nutritional benefits and food applications of colored wheat: a comprehensive review

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ABSTRACT

The consumers' demands have changed from energy providing diet to a diet with a balanced nutrient profile along with metabolic, physiological and functional health benefits. They are seeking colorants derived from natural sources to enhance the nutritional and antioxidant value of foods. Colored wheat (*Triticum aestivum*) contains many phytochemicals, responsible for numerous health benefits. Colored wheat (blue, black, purple and red) contains a good amount of anthocyanins and carotenoids that are primarily located in the outer aleurone layer. Food regulatory and safety authorities and food processing industries are trying to minimize the usage of synthetic food colorants and dyes. Colored wheat is imperative for food processing industries as high-value pigments present in the bran layer (milling industry co-product) can easily be extracted and utilized as functional foods and natural colorants. The extracted pigments such as anthocyanin can replace synthetic dyes currently used in food, drug and cosmetics. Additionally, natural additives improve the nutritional value, appearance, texture, flavor, and storage properties of food products. This review presents a brief knowledge of the nutritional composition of colored wheat including phytochemicals and bioactive compounds like flavonoids, phenolic compounds, their health benefits, methods and technologies used for processing and extraction as well as the effects of processing on these compounds.

KEYWORDS
Anthocyanins; Bioactive compounds; Colored wheat; Health benefits; Natural colorants

Introduction

Wheat (*Triticum aestivum*), a cereal crop, belongs to *Poaceae* (*Gramineae*) family and occupies an important place among all food items. It is assumed to have originated and cultivated about 10,000 years ago as part of the "Neolithic Revolution," which saw the transition from hunting and gathering of food to settled agriculture (Shewry 2018). Nowadays, commonly cultivated wheat varieties are amber in color, but colored wheat rich in anthocyanins and other phytochemicals are getting popular around the world owing to the associated health benefits. Purple wheat came into existence in the 19th century while blue wheat was developed in the first half of the 20th century by crossbreeding interspecific crosses of *Triticum aestivm* with different wild wheat species: *Thinopyrum ponticum*, *Triticum monococcum* L. spp. *aegilopoides*, and *Th. bessarabicum* (Zeven 1991; Morrison, Metzger, and Lukaszewski 2004; Buresova et al. 2015).

Phytochemicals such as anthocyanin, carotenoids, flavonoids and some phenolic compounds (phenolics) are responsible for different colors in wheat. Anthocyanins are primarily located in the pericarp of the grain and account for blue, purple or a combination of both colors depending on its concentration (Garg et al. 2016). The yellow color is due to the presence of carotenoids found in the endosperm while red color is due to the presence of phlobaphenes in the outer layer (Lachman et al. 2017). The anthocyanin in purple wheat is mainly characterized by five pigments, namely, cyanidin-3-glucoside, cyanidin-3-(6-malonyl glucoside), cyanidin-3-rutinoside, peonidin-3-glucoside and peonidin-3-(6-malonylglucoside) (Abdel-Aal, Hucl, and Rabalski 2018). The concentration of anthocyanin is highest in black grained wheat and the concentration gradually reduces in the order of blue-purple-red-amber colored wheat, respectively (Sharma et al. 2018). Acylated anthocyanins containing malonyl and succinyl constituent are only present in purple wheat (Abdel-Aal et al. 2016).

Colored wheat has numerous health benefits and has proven to be helpful in the preventing and fighting various chronic diseases like cancer, cardiovascular disease (CVD), diabetes, inflammation, obesity and aging (Garg et al. 2016). They have a therapeutic effect against capillary fragility, hyperglycemia, and oxidative liver damage (Ficco et al. 2014). According to Tyl and Bunzel (2014), regular intake of

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Table 1. Nutrient content of different wheat varieties.

Type	Protein (%)	TDF (%)	Ash (%)	Fat (%)	TKW (g)	Starch (%)	References
Purple	10.3–19.3	9.8–15.1	1.2–2.60	1.21	22.9–46.4	48.7–59.9	Gamel et al. (2020); Giordano et al. (2017); Ficco et al. (2014); Sharma et al. (2018); Guo et al. (2013); Zanoletti et al. (2017); Ma et al. (2018); Tian, Chen, and Qiao (2018b); Ficco et al. (2016); Garg et al. (2016); Hailu Kassegn (2018)
Blue	12.3–15	12.7–13.5	1.91–2.4	1.2	26.5–50.1	12.3–15	Giordano et al. (2017); Ficco et al. (2014); Tian, Chen, and Wei (2018a); Sharma et al. (2018); Garg et al. (2016)
Black	11–12.9	13–13.3	1.8–2.2	1.7	27.2–37.3	—	Tian, Chen, and Wei (2018a); Sharma et al. (2018); Garg et al. (2016)
Red	15.7	—	2.22	—	43.6	—	Giordano et al. (2017); Ficco et al. (2014)
Green	12.2–20.7	1.11	2.08	1.4	31.32	—	Tian et al. (2017); Tian, Chen, and Wei (2018a)
Common	10.8–14.6	12.5–15.7	1.56–1.9	1.5	36.1-47.4	58.9	Ficco et al. (2014); Tian et al. (2017); Tian, Chen, and Wei (2018a); Tian, Chen, and Qiao (2018b); Sharma et al. (2018); Brandolini et al. (2015); Giordano et al. (2017); Garg et al. (2016)

TDF, total dietary fiber; TKW, thousand kernel weight.

blue colored wheat can regulate high blood glucose levels (diabetes). Abdel-Aal, Hucl, and Rabalski (2018) reported that the health benefits of colored wheat are attributed to their high anthocyanin and phenolic content linked with their high antioxidant activity. The effect of antioxidants and other health benefits have been proven through various in vivo and in vitro studies (Chen et al. 2013; Pérez-Gregorio et al. 2014; Fan et al. 2017; Gamel et al. 2020; Ariza et al. 2018). Besides phytochemical compounds, colored wheat is rich in macro and micronutrients which are essential for the normal functioning of the human body (Onipe, Jideani, and Beswa 2015; Tian, Chen, and Wei 2018a).

Wheat bran, an important co-product obtained during wheat processing, is a rich source of dietary fiber. The dietary fiber is very effective in the prevention of various diseases such as the formation of gallstones, colon cancer and diabetes (Yan, Ye, and Chen 2015). Moreover, bran has minerals, vitamins and bioactive compounds such as phenolic acids, arabinoxylans, alkyl resorcinol and phytosterols which have a preventative effect for CVD (Onipe, Jideani, and Beswa 2015). Colored wheat bran has smaller particles compared with the common wheat thereby making it an important ingredient in the noodles industry to improve their dietary fiber and other nutritional properties (Song et al. 2013). Colored wheat bran is obtained by simple pearling (debranning) techniques meant to remove the outer covering of cereal grains. Somavat et al. (2016) reported that the colored pigments (anthocyanins) can easily be extracted by soaking the bran powder in water.

Colored wheat serves as a healthy ingredient in the bakery industries whether used as whole grain or separately as bran and polished grains (Duchonova, Vargovicova, and Sturdik 2012; Gamel et al. 2020). Nutritional components such as protein and essential amino acid and tensile strength of dough are the basic criteria for deciding flour's suitability for bread and noodle making. Accordingly, colored wheat exhibits high nutritional components and high tensile strength, making it a prime ingredient for the bakery industry (Tian, Chen, and Wei 2018a). The products prepared from colored wheat contain high carotenoids, total dietary fiber (TDF), total phenolic compounds (TPCs), total anthocyanin compounds (TACs) thus, they exhibit high antioxidant activity (Pasqualone et al. 2015; Ficco et al. 2016). This paper presents the nutritional composition, phytochemicals and bioactive compounds present in colored wheat illustrating its potential as a source of antioxidants and an ingredient for the bakery and functional food industries.

Nutritional composition

Wheat grains are considered to have a significant amount of macronutrients which include carbohydrates, fats and proteins; micronutrients such as vitamins and minerals; phytochemicals, TDF and various bioactive compounds. Natural pigments are present in colored wheat as carotenoids and anthocyanins (Ficco et al. 2014). Due to health promoting and disease-preventing effects, colored wheat is attracting a lot of attention from researchers and food processors.

Macronutrients

A balance of protein and amino acid are the key determinants of the nutritional quality of wheat. Starch, present in the endosperm, acts as the major carbohydrate. According to Zilic et al. (2012) common wheat contains 2.15% ash, 12.93% protein, 3.33% oil, 61.85% starch and 2.29% cellulose content, which are considerably lower than colored wheat values, both qualitatively and quantitatively. Compared to common wheat, approximately 11.74% to 18.17% higher protein content, 7.31% to 18.13% higher essential amino acids, and 8.88% to 18.91% higher total amino acids were recorded in colored wheat (Tian, Chen, and Wei 2018a).

Table 2. Mineral profile of colored wheat with their health benefits.

Type	Sodium	Magnesium	Calcium	Iron	Manganese	Cupper	Zinc
Blue	30.1	430	310	38.3–46.1	14.8–40.9	6.0–9.6	33.1–40
Green	15.5	337	272	50.2	—	—	39.8
Black	21.4	450	184	39–79.3	12.7	3.17	28–80
Purple	—	—	419.6	36.7–46	15–40.1	4.1–6.9	25–41.7
Red	—	—	—	36.71	41.25	6.71	31.54
Durum	9.2	1160	368	29.2–32.8	29.1–38	3.5–7.4	25.5–37.3
Common	7.7–27.3	320–1160	270–345	26–35.6	10–28.2	3.2	16.4–40.8
Health benefits	Regulation of osmotic pressure; maintenance of acid-base balance; essential in the absorption of carbohydrate	Magnesium is an essential component of bone, cartilage and the crustacean exoskeleton	Calcium is an essential component of bones	Beneficial in checking anemia, heart palpitations, gastrointestinal heath, pale skin and pregnancy issues	Helpful in preventing osteoporosis, osteoarthritis and useful in wound healing	Deficiency can lead to cardiovascular and Alzheimer's disease; helpful in maintaining healthy bones and immune system	Helpful in checking age related macular degeneration, osteoporosis, infertility and pregnancy complications

Compiled from: Bienkowska et al. (2019); Tian, Chen, and Wei (2018a); Sharma et al. (2018); Tian et al. (2017); Ficco et al. (2014); Guo et al. (2013).

Purple wheat bran powder contains 28 g/100 g of protein content, 4.3 g/100 g of ash content and a small amount of sugars majority of which is glucose. Moreover, the bran powder is detected to have arabinoxylan and β-glucan gums (Abdel-Aal, Hucl, and Rabalski 2018). Zilic et al. (2012) studied the effect of debranning on macronutrients present in the bran and noted a 0.98%, 10.45%, 3.02%, 71.24% and 0.24% reduction in the concentration of ash, protein, oil, starch and cellulose content, respectively. Comparing debranned to whole durum wheat, Zilic et al. (2012) indicated a 60%, 18% and 90% reduction in the concentration of ash, protein and cellulose, respectively. Table 1 shows the different nutrient content present in different colored wheat varieties. The flour yield from colored wheat is comparatively lower than that of common wheat owing to its low volume, weight and plumpness which reduces the endosperm content. The fat and TDF content in colored and common wheat do not vary significantly because they are situated in embryo and seed coat, respectively (Giordano et al. 2017; Tian, Chen, and Wei 2018a).

Micronutrients

Colored wheat is a rich source of B-group vitamins [B1 (thiamine), B2 (riboflavin), B3 (niacin), B6 (pyridoxine), B9 (folate)] and vitamin E (tocopherol/tocotrienol). Apart from these, it also contains a minute concentration of provitamin A (β-carotene), vitamin D (calciferol) and vitamin K (phylloquinone) (Balyan et al. 2013).

Iron (Fe) is an important component of hemoglobin and a vital element for the overall development of the human body. Calcium is essential for bones while zinc (Zn) helps in the overall development of the brain. Zn, Fe and magnesium content in colored wheat is about 108.54% to 142.68%, 8.57% to 42.86% and 5.31% to 40.63% higher than common wheat, respectively. Green wheat contains the highest Zn while blue wheat contains the highest calcium content (Tian, Chen, and Wei 2018a). However, overall micronutrient content of colored wheat is not always higher than common wheat, especially under varying planting conditions. Ma et al. (2018) reported that under balanced application of nitrogen and phosphorus fertilizers, red wheat variety (Yangmai15) showed highest Fe content (68.88 mg/kg) while common variety (Yumai49-198) showed highest Zn content (40.43 mg/kg) when compared with purple variety (Zhouheimai1: Fe-55.59 mg/kg, Zn-38.50 mg/kg). The mineral profile of different types of colored wheat along with their health benefits is provided in Table 2.

Bioactive compounds

Bioactive ingredients play a crucial role in human health. Some of the important phytochemicals available in every wheat variety include phenolic acids, lignans, alkylresorcinols, folate, sterols and tocols. Bread and durum wheat bran contain an average of 9208.52 and 9798.52 mg gallic acid equivalent of TPC per kilogram, respectively, contributing about 99% of phenolic compounds in the bran layer (Zilic et al. 2012). According to Li et al. (2015), black wheat contains the highest amount of TPC, total flavonoid content (TFC) and antioxidant activity whereas light purple wheat has the lowest. The study noted the TPC and TFC content in black wheat to be 659.8 µg gallic acid equivalents g^{-1} and 319.3 µg rutin equivalents g^{-1}, respectively. The two components are highest in whole-wheat flour and partially debranned wheat flour than in refined flour ($p < 0.05$) highlighting the nutritional benefits of wheat bran layer (Li et al. 2015). The total phenolic composition of different colored wheat varieties is represented in Table 3.

Syed Jaafar et al. (2013) computed the TAC in different colored wheat with two different extraction methods; solvent extraction (SE) and accelerated solvent extraction method (ASE). They reported that TAC varies from 17.8 to 298.3 ppm (average 126.1 ppm) and 12.4 to 283.3 ppm (average 112.6 ppm) for SE and ASE techniques, respectively. The highest value of TAC was noted from deep purple, blue and purple wheat, respectively. Amber and red wheat recorded the lowest TAC (Syed Jaafar et al. 2013). Various colored wheat species including *T. aestivum* (bread wheat), *T. durum* (durum wheat), *T. monococcum* (einkorn), and wild wheat species (*T. monococcum* ssp. *monococcum*, *T. monococcum* ssp. *thaoudar*, *T. monococcum* ssp. *aegilopoides*, *T. urartu*, *T. turgidum* ssp. *dicoccum*, and *T. aestivum* ssp. *Spelta*) have significant anthocyanin content. Anthocyanin contents of

Table 3 Polyphenolic composition of colored wheat.

Wheat	TAC (mg/kg C3G eq)	TPC (g/kg)	TFC (mg/100g)	TAA (mmol TE/kg)	Reference
Purple	12.8–172	6.26 (CE)	21.6–102.9 (CE)	7.57–41.1	Gamel et al.(2020); Zilic et al. (2019); Hailu Kassegn (2018); Sharma et al. (2018); Giordano et al. (2017); Zanoletti et al. (2017); Garg et al. (2016); Ficco et al. (2014); Varga et al. (2013); Liu, Qiu, and Beta (2010); Knievel et al. (2009); Abdel-Aal, Young, and Rabalski (2006); Abdel-Aal and Hucl (2003)
Blue	68–211	6.8 (CE)	—	6.47–24.1	Sharma et al. (2018); Giordano et al. (2017); Lachman et al. (2017); Garg et al. (2016); Ficco et al. (2014); Varga et al. (2013); Abdel-Aal, Young, and Rabalski (2006); Knievel et al. (2009); Abdel-Aal and Hucl (2003)
Black	128–198	0.659.8 (GAE)	31.9 (RE)	—	Sharma et al. (2018); Lachman et al. (2017); Garg et al. (2016); Li et al. (2015)
Red	5.1–157	3.28 (CE)	10.7 (CE)	6.65–15.6	Giordano et al. (2017); Lachman et al. (2017); Garg et al. (2016); Ficco et al. (2014); Knievel et al. (2009); Abdel-Aal and Hucl (2003)
Common	0–13.0	4.79 (CE)	9.6 (CE)	6.9–19.4	Sharma et al. (2018); Giordano et al. (2017); Garg et al. (2016); Ficco et al. (2014); Knievel et al. (2009)

TAC, total anthocyanin content; TPC, total phenolic content; TFC, total flavonoid content; TAA, total antioxidant activity; C3G, cyanidin 3 glucoside; TE, trolox equivalents; CE, catechin equivalent; GAE, gallic acid equivalent; RE, rutin equivalent.

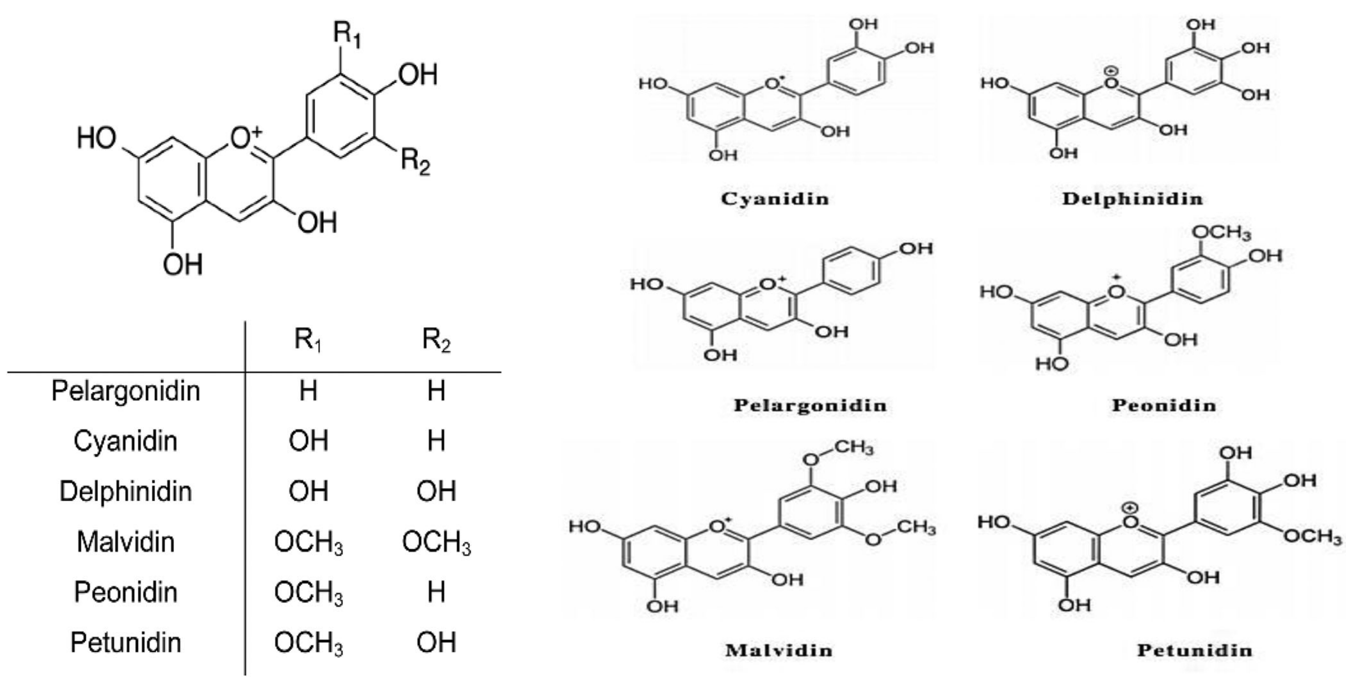

Figure 1. Major anthocyanins in colored wheat.

blue bread wheat, purple and red durum wheat ranges from 83 to 174 µg/g, 8 to 50 µg/g and 1 to 25 µg/g, respectively while that from wild species is in the range of 2.6 to 11.6 mg/kg on a dry basis (Zhu 2018).

Garg et al. (2016) identified 22 different types of anthocyanins in blue, 23 in purple and 26 in black wheat. Regrettably, only 13 of them have successfully been isolated from purple wheat (Hosseinian, Li, and Beta 2008; Abdel-Aal, Hucl, and Rabalski 2018). Out of the 13 anthocyanins isolated, five of them constitute the majority and account for about 93% of the TAC (Figure 1) These five compounds are cyanidin-3-(6-malonyl glucoside) (35.3%), cyanidin-3-glucoside (27.4%), cyanidin-3-rutinoside (20.0%), peonidin-3-glucoside (6.4%) and peonidin-3-(6-malonylglucoside) (4.3%). The most dominated anthocyanin pigment is cyanidin-3-glucoside and contributes about 19.3% to 30.5% of TAC in purple wheat (Abdel-Aal, Hucl, and Rabalski 2018). Král et al. (2018), compared three spring wheat varieties (Blue-UC66049, Purple-Konini and control-Vanek; German origin) for TAC values and found that blue and purple have approximately seven times more anthocyanins than the control variety. The study noted 6.70, 41.70 and 47.63 mg/kg of TAC in control, blue and purple wheat, respectively. Detailed description of different anthocyanins with their concentration in different colored wheat is provided in Table 4.

Flavonoids are important bioactive compounds with good antioxidant potential and several health benefits, generally found in colored fruits and vegetables (Chhikara et al. 2019; Devgan et al. 2019). In wheat grain, the highest concentration of flavonoids is found in the bran layer. Bread and durum wheat contain 213.04 and 259.31 mg catechin

Table 4. Anthocyanin profile of colored wheat and their health benefits.

Anthocyanin (characterstic color)	Health benefits	Derivatives	Chemical formula	Wheat type	Amount (mg/kg)	References
Cyanidin (Orange-red)	Offers protection against heart & liver diseases, improves metabolic syndrome; improves spatial memory; Suppression of ischemia/reperfusion liver oxidation damage; protective effect on DNA cleavage; inhibition of invasion and mortality of tumor cells; maintains meta-bolites in plasma; increase glucose uptake; Improves metabolic profile and mitochondrial energy metabolism; acts as a barrier against inflammation-induced permeabilization.	Cyanidin-3-arabinoside	$C_{20}H_{19}ClO_{10}$	Purple	23.2–25.1	Hosseinian, Li, and Beta (2008)
		Cyanidin-3-galactoside	$C_{21}H_{21}O_{11}^{+}$	Blue Purple	Dnq 0.98–72.0	Hosseinian, Li, and Beta (2008); Abdel-Aal and Hucl (2003)
		Cyanidin-3-glucoside	$C_{21}H_{20}O_{11}$	Blue Purple Black	1.17 – 28.14 0.63 – 116.2 Dnq	Gamel et al. (2020); Zilic et al. (2019); Garg et al. (2016); Bartl et al. (2015); Ficco et al. (2014); Knievel et al. (2009); Abdel-Aal, Young, and Rabalski (2006); Abdel-Aal and Hucl (2003)
				Red Common	0.59 – 10.23 Dnq	Ficco et al. (2014) Garg et al. (2016)
		Cyanidin di-glucoside	$C_{27}H_{31}O_{16}^{+}$	Purple	1.7	Abdel-Aal, Hucl, and Rabalski (2018); Ficco et al. (2014)
		Cyanidin-3-rutinoside	$C_{27}H_{30}O_{15}$	Blue	7.12 – 16.8	Ficco et al. (2014); Knievel et al. (2009); Abdel-Aal, Young, and Rabalski (2006)
				Purple Black	3.2–85.1 Dnq	Gamel et al. (2020); Abdel-Aal, Hucl, and Rabalski (2018); Tyl and Bunzel (2014)
				Common	Dnq	Garg et al. (2016)
		Cyanidin chloride	$C_{15}H_{11}ClO_{6}$	Purple	5.2–6.8	Bartl et al. (2015); Hosseinian, Li, and Beta (2008)
		Cyanidin-3-rutinoside-3′-glucoside	$C_{33}H_{40}O_{20}$	Blue Purple Black	Dnq	Garg et al. (2016)
		Cyanidin-3-(6′-malonylglucoside)	$C_{24}H_{22}O_{14}$	Purple Black	1.2–31.08 Dnq	Zilic et al. (2019); Garg et al. (2016); Abdel-Aal, Young, and Rabalski (2006)
		Cyanidin-3-(3′,6′-dimalonylglucoside	$C_{27}H_{24}O_{17}$	Purple	3.58–19.07	Zilic et al. (2019); Garg et al. (2016)
				Black	Dnq	Garg et al. (2016)
		Cyanidin-3-succinyl-glucoside	$C_{25}H_{24}O_{14}$	Blue Purple Black	Dnq 0.6–1.2 Dnq	Garg et al. (2016); Knievel et al. (2009); Abdel-Aal, Young, and Rabalski (2006); Abdel-Aal and Hucl (2003)
		Cyanidin-3-(2G-xylosylrutinoside)	$C_{32}H_{38}O_{19}$	Blue Black	Dnq	Garg et al. (2016)
		Cyanidin-3-(6′-feruloylglucoside)-5-glucoside	$C_{37}H_{38}O_{19}$	Blue Purple Black	Dnq	Garg et al. (2016)
Delphinidin (Blue-red)	Anti-inflammatory, bone protective, and neuroprotective effects; inhibits platelet activation and thrombosis; barrier against inflammation-induced permeabilization; inhibitory effect on human Glyoxalase	Delphinidin-3-arabinoside	$C_{20}H_{19}ClO_{11}$	Purple	15.1–16.7	Hosseinian, Li, and Beta (2008)
		Delphinidin-3-galactoside	$C_{21}H_{21}ClO_{12}$	Purple	38.3–36.4	
		Delphinidin-3-glucoside	$C_{21}H_{20}O_{12}$	Blue Purple Black	0.52–56.5 Dnq Dnq	Garg et al. (2016); Bartl et al. (2015); Ficco et al. (2014); Knievel et al. (2009); Abdel-Aal, Young, and Rabalski (2006)
		Delphinidin-3-sambubioside	$C_{26}H_{28}O_{16}$	Blue Black	Dnq Dnq	Garg et al. (2016)
		Delphinidin-3-rutinoside	$C_{27}H_{30}O_{16}$	Blue Purple Black	31.77 – 49.6 3.7 Dnq	Abdel-Aal, Hucl, and Rabalski (2018); Garg et al. (2016); Bartl et al. (2015); Ficco et al. (2014); Knievel et al. (2009); Abdel-Aal, Young, and Rabalski (2006)
		Delphinidin-3-(6′-malonylglucoside)	$C_{24}H_{22}O_{15}$	Purple Black	3.5 Dnq	Abdel-Aal, Hucl, and Rabalski (2018); Garg et al. (2016)
		Delphinidin-3-caffeoylglucoside	$C_{30}H_{26}O_{15}$	Blue Purple Black	Dnq	Garg et al. (2016)

(continued)

Table 4. Continued.

Anthocyanin (characterstic color)	Health benefits	Derivatives	Chemical formula	Wheat type	Amount (mg/kg)	References
Malvidin (Blue-red)	Antioxidant, anticancer, anti-inflammatory activity in endothelial cells; Alleviates postprandial hyperglycemia; cytotoxic to human leukemia cells	Malvidin-3-glucoside	$C_{23}H_{24}O_{12}$	Blue Purple Black Red	10.26 – 13.8 0.17 – 60.3 Dnq 0.06 – 0.43	Garg et al. (2016); Ficco et al. (2014); Hosseinian, Li, and Beta (2008); Abdel-Aal and Hucl (2003) Ficco et al. (2014)
		Malvidin-3-rutinoside	$C_{29}H_{34}O_{16}$	Blue Purple Black Common	2 2.6 Dnq Dnq	Abdel-Aal, Hucl, and Rabalski (2018); Garg et al. (2016); Bartl et al. (2015); Abdel-Aal, Young, and Rabalski (2006) Garg et al. (2016)
		Malvidin-3-(6′-p-caffeoylglucoside	$C_{32}H_{30}O_{15}$	Blue Purple Black	Dnq	Garg et al. (2016)
		Malvidin-3-rutinoside-5-glucoside	$C_{35}H_{44}O_{21}$	Blue Purple Black	Dnq	Garg et al. (2016)
Pelargonidin (Orange-red)	Have anti-inflammatory effects; allivates progression of postprandial hyperglycemia; prevents neurodegenerative disorders; effective in treatment of cancer and vascular diseases	Pelargonidin-3-arabinoside	$C_{20}H_{19}O_9^+$	Purple	9.3–11.3	Lachman et al. (2017); Hosseinian, Li, and Beta (2008)
		Pelargonidin-3-galactoside	$C_{21}H_{21}ClO_{10}$	Purple	22.1–26.1	Hosseinian, Li, and Beta (2008)
		Pelargonidin-3-glucoside	$C_{21}H_{20}O_{10}$	Blue Purple Black	Dnq 2.185–29.3 Dnq	Zilic et al. (2019); Garg et al. (2016); Bartl et al. (2015); Hosseinian, Li, and Beta (2008)
		Pelargonidin-3-(6′-malonylglucoside)	$C_{24}H_{22}O_{13}$	Blue Purple Black	Dnq 1.2 Dnq	Garg et al. (2016) Zilic et al. (2019); Abdel-Aal, Hucl, and Rabalski (2018); Garg et al. (2016) Garg et al. (2016)
		Pelargonidin-3-rutinoside	$C_{27}H_{30}O_{14}$	Blue Purple Black	Dnq	Garg et al. (2016)
Peonidin (Orange-red)	Prevention of vascular and cardiac diseases; Inhibits growth of tumor cells; inhibitory and apoptotic effects on human breast cancer cells	Peonidin-3-arabinoside	$C_{21}H_{21}ClO_{10}$	Blue Purple	0.95–3.49 28.4–29.3	Ficco et al. (2014); Hosseinian, Li, and Beta (2008)
		Peonidin-3-glucoside	$C_{22}H_{22}O_{11}$	Blue Purple Black	0.76 – 0.99 2.7–17.5 Dnq	Ficco et al. (2014) Gamel et al. (2020); Garg et al. (2016); Bartl et al. (2015); Ficco et al. (2014); Hosseinian, Li, and Beta (2008); Abdel-Aal, Young, and Rabalski (2006); Abdel-Aal and Hucl (2003)
		Peonidin-3-galactoside	$C_{22}H_{23}ClO_{11}$	Blue Purple Red	1.94 0.06 – 3.11 0.06 – 3.87	Ficco et al. (2014); Abdel-Aal and Hucl (2003)
		Peonidin-3-rutinoside	$C_{28}H_{32}O_{15}$	Blue Purple Black	0.40–1.2 9.36 Dnq	Giordano et al. (2017); Garg et al. (2016); Bartl et al. (2015); Abdel-Aal, Young, and Rabalski (2006)
		Peonidin-3,5-diglucoside	$C_{28}H_{32}O_{16}$	Blue Purple Black	Dnq	Garg et al. (2016)
		Peonidin malonyl-glucoside	$C_{25}H_{25}O_{14}^+$	Purple	0.6	Abdel-Aal, Young, and Rabalski (2006)
		Peonidin-3-rutinoside-5-glucoside	$C_{34}H_{42}O_{20}$	Blue Purple Black	Dnq	Garg et al. (2016)
Petunidin (Blue-red)	Stimulates osteoblastogenesis concomitant; reduces bone loss; anti-proliferative and anti-invasive properties; protects liver cancer	Petunidin 3-galactoside	$C_{22}H_{23}O_{12}^+$	Purple	38.3–40.4	Hosseinian, Li, and Beta (2008)
		Petunidin-3-glucoside	$C_{22}H_{22}O_{12}$	Blue Purple Black	2.2 Dnq Dnq	Garg et al. (2016); Abdel-Aal, Young, and Rabalski (2006); Abdel-Aal and Hucl (2003)
		Petunidin-3-rutinoside	$C_{28}H_{33}O_{16}^+$	Blue	4.5	Abdel-Aal, Young, and Rabalski (2006)
		Petunidin-3-rutinoside-5-glucoside	$C_{34}H_{42}O_{21}$	Blue Purple Black	Dnq	Garg et al. (2016)

Dnq, detected but not quantified.

equivalent of TFC per kilogram, respectively (Zilic et al. 2012). According to Liu, Qiu, and Beta (2010), purple wheat contains the highest TFC in the range of 21.59 to 102.95 mg of catechin equivalents per 100 g of wheat grain. Other varieties such as yellow, red and common wheat recorded 13.44, 10.72 and 9.6 mg/100 g, respectively. Carotenoids, also known as tetraterpenoids, constitute yet another group of polyphenolic compounds present in colored wheat and commonly found in fruits and vegetables (Rosa Perez-Gregorio and Simal-Gandara 2017). Major carotenoids present in wheat include α-Carotene, β-Carotene, β-Cryptoxanthin, lutein, lutein dilinooleate, and zeaxanthin. Other carotenoids that are present in minor concentrations are antheraxanthin, taraxanthin (lutein-5, 6-epoxide), triticoxanthin, and flavoxanthin. With regard to colored wheat, lutein is the most abundant among all other carotenoids (Lachman et al. 2017). Liu, Qiu, and Beta (2010) compared the phenolic acid content amongst red, yellow, purple and common wheat. The study noted that purple colored wheat contained the highest content of vanillic and ferulic acid, 2.58 mg/100 g and 81.38 mg/100 g, respectively. Red and yellow were highest in *p*-coumaric acid (2.38, 3.56 mg/100 g, respectively) while common wheat recorded the lowest value of all the compounds (vanillic 1.32, ferulic acid 74.35 and *p*-coumaric 2.73 mg/100 g). Different flavonoids and carotenoids present in various colored wheat varieties along with their concentration and health benefits are tabulated in Table 5.

Health benefits

Colored wheat being a rich source of dietary fiber and anthocyanin compounds have proven to have numerous health benefits, most of which are associated with their antioxidant properties (Lachman et al. 2017). These compounds are beneficial whether consumed directly or in the form of extracts. Nevertheless, their extraction and processing maximize the nutritional value of the finished product. Anthocyanin compounds are helpful in the prevention of CVD, diabetes, inflammation, cancer, obesity (by reducing body fat accumulation induced by high-fat meals), aging as well as antimicrobial and neuroprotective effect (protection of nerve cells from oxidative injury and neurotoxicity) (Tsuda 2012; Garg et al. 2016; Khoo et al. 2017; Chhikara et al. 2020). They also act as atherosclerosis fighters; therefore, incorporation of anthocyanin-rich foods in the human diet may help boost overall health (Yousuf et al. 2016). Inadequate quantities of protein, vitamins, essential macro and micronutrients including Fe and Zn in everyday diet is the major cause of various diseases for the larger population globally (Balyan et al. 2013). Fortunately, colored wheat contains a significant concentration of all these nutrients and so should be part of the human diet to improve health and wellness (Ficco et al. 2014; Onipe, Jideani, and Beswa 2015; Giordano et al. 2017; Sharma et al. 2018; Tian, Chen, and Wei 2018a).

Apart from the coloring properties of anthocyanins, many other health benefits are also attributed to them (Yousuf et al. 2016). As per the reviews of Tsuda (2012), an anthocyanin-rich diet helps in the correction and improvement of many visual functions, for example, inhibiting myopia, reducing eye fatigue, improving dark adaptation and enhancing retinal blood flow to reduce glaucoma. Moreover, it helps in the normal functioning of the brains by reducing age-related neurodegeneration and cognitive decline (Tsuda 2012). Likewise, Carotenoids as plant pigments are a vital dietary source of vitamin A, which is beneficial for healthy vision, skin, bones and other tissues in the body (Kumar, Kumar, and Garg 2015). The consumption and intake of carotenoids are associated with a reduced risk of CVD and help in prostate cancer prevention. Lutein and zeaxanthin have benefits of maintaining good eye health (Woodside et al. 2015).

Phenolic compounds are an essential part of the human diet and have potential health benefits due to their antioxidant properties (Shahidi and Ambigaipalan 2015). Various cereals, including colored wheat, have a significant concentration of several phytochemicals such as phenolics, flavonoids and anthocyanins. Phenolic compounds present in cereals have radical absorbance capacity, thus are helpful in inhibiting the oxidation of human low-density lipoprotein cholesterol and DNA, rancimat, photo-chemilumenescence and iron (II) chelation activity (Van Hung 2016). Antioxidants in phenolic compounds control rancidity development, maintain nutritional quality, retard the formation of toxic oxidation products, and therefore, they extend the shelf life of products (Kumar et al. 2020). Colored wheat exhibits all these properties subject to various phenolic compounds predominantly in their outer bran layer (Li et al. 2015). In addition, due to safety concerns, natural antioxidants are preferred over synthetic one (Shahidi and Ambigaipalan 2015), which can be obtained from natural plants and cereals including colored wheat.

Zhu (2018) reviewed and summarized in-vivo and in-vitro studies on the health effects of colored cereals. Some of the healthy benefits highlighted from the study include high antioxidant activity, retinal protection, inhibition of cholesterol absorption, glycaemic regulation, neuroprotection, anticancer action, cytoprotection, and anti-hypertension effects. Others included regulation of lipid profile, body fat reduction, hepatoprotection, relieved metabolic syndrome, anti-aging and enhanced immune response. Besides the various health benefit of colored pigments, they also serve as a safer substitute to the synthetic coloring compounds (FD&C dyes and lakes) (Somavat, Kumar, and Singh 2018), whose toxicity has a negative impact on human health (Leong et al. 2018). The detailed information about the health benefits of different colored wheat and their constituents are presented in Tables 1–3.

In vitro

In vitro study carried out by Gamel et al. (2020) indicated that bran from purple wheat has high antioxidant capacity with 74, 100, and 94% inhibition of free radical ion as determined by three assays; ABTS (2,2′-azino-bis(3-ethylbenzthiazoline − 6-sulphonic acid), DPPH (1,1 diphenyl − 2-picrylhydrazyl) and oxygen radical absorbance capacity (ORAC), respectively. Test by Tyl and Bunzel (2014) reported that blue wheat has the

Table 5. Carotenoids and flavonoids present in colored wheat and their health benefits.

Constituents	Health benefits	Wheat type	Amount (mg/kg)	References
Carotenoids				
α-Carotene	Antioxidant and anticancer effects	Durum	0.004–0.044	Blanco et al. (2011)
β-Carotene	Cardioprotective and anticancer effects	Durum	0.006–0.026	Blanco et al. (2011)
		Einkorn	0.195	
		Emmer	3.3–7.4	
		Purple	0.109	Guo et al. (2013)
β-Cryptoxanthin	Cardioprotective and chronic diseases protective	Durum	0.001–0.011	Lachman et al. (2017); Blanco et al. (2011)
		Spelt	0.006	
		Primitive cultivars	0.001	
		Common	Dnq	
Lutein	Beneficial for health of the eyes.	Red	2.18	Giordano et al. (2017); Woodside et al. (2015); Brandolini et al. (2015)
		Amber	3.62	
		Purple	1.67	
		Blue	1.24	
		Common	1.07–1.1	
Zeaxanthin	Protect and maintain healthy cells in the human eye.	Red	0.15	Giordano et al. (2017); Brandolini et al. (2015); Woodside et al. (2015)
		Amber	0.34	
		Purple	0.34	
		Blue	0.29	
		Common	0.3–0.37	Brandolini et al. (2015)
Total carotenoids	Synergistic effect of the above-mentioned parameters	Einkorn	1.63–4.90	Lachman et al. (2017); Brewer et al. (2014)
		Emmer	1.63–13.64	
		Durum	2.69–8.38	
		Spelt	1.62–2.98	
		Purple	1.65	Guo et al. (2013)
		Common	1.4	Brandolini et al. (2015)
Flavonoids				
Apigenin C-diglycosides	Shows antioxidant activity, anticancer and antitumor activity.	Durum and bread wheat	Dnq	Lachman et al. (2017)
Apigenin 6-C-glucoside-8-C-arabinosidea	Prevention of cardiovascular, gastric and ulcer problems; boosts immunity	Purple wheat	21.9 (μg/g apigenin eq)	Hirawan, Diehl-Jones, and Beta (2011)
Apigenin 6-C-arabinoside-8-C-hexoside	Positive effects to diabetes, amnesia and Alzheimer's disease	Bread wheat	Dnq	Lachman et al. (2017)

Dnq, detected not quantified.

ability to decrease the α-amylase-catalyzed starch digestion associated with postprandial blood glucose levels; hence, it controls diabetes. According to Urias-Lugo et al. (2015) acylated anthocyanins from blue maize extract exhibited strong viability to inhibit and reduce the growth of mammary, liver, colon and prostate cancer cells.

In vivo

Chen et al. (2013) assessed the anti-aging properties of purple wheat and found that anthocyanin-rich extract from purple wheat extended the mean life span of wild type and mev-1(hn1) mutant worms by 10.5% and 9.2%, respectively. These worms are generally sensitive to oxidative stress. Prokop et al. (2018) studied the effect of consumption of anthocyanin-rich diet from blue wheat on the ability of microsomal cytochromes P450 enzymes found in rat's liver to metabolize drugs and xenobiotics. At the end of the 72-day study period, there was a 20%–55% increase in enzyme activity and moderate antioxidant effect. However, no significant effect on the metabolism of drugs and xenobiotics was detected.

Fan et al. (2017) studied the effect of anthocyanin-rich black rice extract diet on the immune response of leukemia cells in rats and noted that the diet successfully enhanced T cell, B cell, monocyte and decreased natural killer cell activity in leukemia-induced mice. Feeding Wistar rats with blue maize anthocyanin extract exhibited a positive effect on their metabolic syndrome. Additionally, the diet effectively enhanced high-density lipoprotein cholesterol while significantly decreasing systolic blood pressure, levels of serum triglycerides, total cholesterol and epididymal adipose tissue weight (Guzmán-Gerónimo et al. 2017).

Antioxidant activity

Colored wheat has high antioxidant capacity against free oxygen radicals and DPPH radical. Antioxidant activity is commonly measured using three assays; DPPH, ABTS and PCL (Photochemiluminescence). DPPH assay measures the antioxidant activity as a percentage inhibition of DPPH free radicals by the extract. In this test, absorbance is measured at 517 nm. ABTS, on the other hand, measures the inhibition of ABTS radicals with absorbance being measured at 734 nm. Qualitative and quantitative analysis of phenolic acids and flavonoids from different colored wheat indicated that purple wheat has the highest antioxidant activity (up to 6899 μmol/100 g) compared to red and yellow wheat. Common wheat recorded the lowest content. The major phenolic compounds found in different colored wheat with the most effective antioxidant property include phenolic acids, flavones, flavonols, and anthocyanins (Liu, Qiu, and

Beta 2010). About 69% of free radical scavenging capacity from blue wheat is attributed to anthocyanin content while 19% is a result of phenolic acids (Hu et al. 2007). The bran layer from cereals exhibits natural antioxidants and can be used as an ingredient to functional food or as an additive to improve nutrition (Van Hung 2016).

Processing and extraction techniques

The selection of extraction procedures for anthocyanin and other bioactive compounds is important both environmentally and economically. Traditional extraction methods such as refluxing, boiling, soaking and soxhlet extraction are time-consuming and have low efficiency. Therefore, novel extraction techniques such as pressurized liquid extraction, subcritical fluid extraction, microwave and ultrasound-assisted extraction techniques can be adopted for increased extraction efficiency (Joana Gil-Chavez et al. 2013; Khoddami, Wilkes, and Roberts 2013).

Zanoletti et al. (2017) described a simple and effective procedure for the extraction of anthocyanin from colored wheat and entailed debranning (or pearling) to remove the outer bran layer from wheat grain. Thereafter, anthocyanin extraction from enriched bran powder is done using methanol or ethanol-based systems at varying pH levels with water acting as the solvent (Khoo et al. 2017). For rapid extraction of anthocyanin from colored wheat, a sample-to-solvent (water, acidified water, ethanol, and methanol) ratio of 1:8 at pH 1 and 25 °C is recommended (Abdel-Aal and Hucl 1999; Hosseinian, Li, and Beta 2008; Zanoletti et al. 2017; Giordano et al. 2017; Panghal et al. 2019; Gamel et al. 2020).

Capillary electrophoresis and chromatographic techniques are two of the commonly used techniques used for accurate quantification, separation, and analysis of the bioactive compounds in grains (Zeven 1991; Zhu 2018). However, separation, identification, and quantification of phenolic compounds can also be done using high-performance liquid chromatography and gas chromatography techniques, coupled with mass spectrometry and UV visible spectrophotometry (Khoddami, Wilkes, and Roberts 2013; Giordano et al. 2017). Apart from these techniques, nuclear magnetic resonance and near-infrared detections are the latest trends in structural elucidation, qualitative, and quantitative analysis of compounds present in wheat grains (Welch, Wu, and Simon 2008; Nicoletti et al. 2013).

With the advancement in technology, ultra-performance liquid chromatography (UPLC) is widely being used to separate anthocyanins from plant extracts. Unlike HPLC which operates at 2000–4000 psi and packing material in the range of 3–5 µm, UPLC is superior in that it operates at slightly higher pressure, 6000–15,000 psi, and a combined 1.7 µm reverse-phase packing material. Consequently, UPLC is more sensitive, can be used to separate complex mixtures and offers better chromatographic peak resolution with increased separation speeds (Trenerry and Rochfort 2010). Sharma et al. (2018) used UPLC to obtain chromatograms peaks for blue, purple and black wheat donor in an attempt to develop advanced colored wheat lines with higher anthocyanin content and antioxidant activity compared to the donor lines.

Joana Gil-Chavez et al. (2013) proved that microwave-assisted extraction (MAE) can positively be applied to improve the extraction efficiency of natural bioactive compounds from cereal grains. According to Abdel-Aal et al. (2014), accelerated solvent extraction (ASE) is the most appropriate method over MAE and common solvent extraction (CSE) with regard to extraction efficiency and their effect on anthocyanin composition. In comparison with ASE, MAE causes major structural changes in the resultant anthocyanin. The yield from MAE is highest at extraction temperature of 70 °C, microwave power of 300 W and an extraction time of 10 min while ASE works best at 50 °C and 2500-psi pressure for 10 minutes. The process ought to be repeated for 5 cycles (Abdel-Aal et al. 2014). Besides colored wheat, extraction of flavonoids, anthocyanin and phenolic compounds from black rice is done at a temperature of 34.7 °C for 80 min. A solid-liquid ratio of 1:30 is most appropriate for CSE (Pedro, Granato, and Rosso 2016). Ohmic heating-assisted extraction is also an efficient technique that has been used for the extraction of bioactive compounds from colored rice with high extraction yield of up to 20.28% (Loypimai et al. 2015).

Effect of processing

It's imperative to comprehend and evaluate the impact of various processing techniques and technologies on bioactive compounds, phytochemicals and their antioxidant properties. It facilitates the development of improved processes for retaining a higher concentration of these components in processed products for superior health benefits (Luthria, Lu, and John 2015; Birania et al. 2020; Mwaurah et al. 2020; Alam, Kumar, and Singh 2018). Various environmental factors like temperature, light, pressure, time, etc. during different processes like milling, fermentative proofing, baking, enzymatic reaction, extrusion, cooking, steaming and malting affects the stability of these compounds (Saleh et al. 2013).

Abdel-Aal and Rabalski (2013) reported that the baking process significantly affects the free and bound phenolic acids in whole grain bakery products depending on the type of phenolic compounds, baking recipe and heating conditions. It was concluded that baking significantly increases the free phenolic acid in bread, cookie and muffin, while bound phenolic acid content decreases in bread and is slightly affected in cookie and muffin products. Likewise, thermal processing also affects the antioxidant properties of colored wheat bran. Li, Pickard, and Beta (2007) observed a significant reduction in the TPC, oxygen radical absorbance capacity values, and TAC of heat-treated purple wheat bran and muffin products. According to Bartl et al. (2015), the baking process significantly affects the TAC of the baked product depending on the baking conditions. In their study, blue and purple wheat having TAC measuring 9.26 and 13.23 mg/kg were reduced to up to 8.33 to 5.31 mg/kg for blue wheat and 5.20 to 3.63 mg/kg for purple wheat after being subjected to baking conditions of 240 °C for

21 minutes and 180 °C for 31 minutes, respectively. According to Ficco et al. (2016), the milling process greatly affects the concentration of antioxidant compounds in the resultant milled product. The study noted a decrease in TAC (73.41 µg/g to 24.4 µg/g) from purple wheat as a result of milling.

During the extraction of antioxidants and phenolic compounds from wheat, the size of bran particles plays a significant role. Brewer et al. (2014) compared the effect of bran particle size on the extraction of various compounds such as antioxidants, phenolic compounds and carotenoids. Their study concluded that finer treatments resulted in higher phenolic acid, flavonoid, anthocyanin, and carotenoid content compared to coarse ones. Yu and Beta (2015) investigated the changes in free phenolic content, bound phenolic content, TAC and their antioxidant properties in purple wheat during various bread-making processes. Results showed that mixing, fermenting, and baking processes significantly increased free and bound phenolic contents, and a similar trend was observed in their antioxidant properties alike. While mixing and baking processes reduced the TAC, fermentation increased this value and therefore, the resultant bread exhibited increased TPC but decreased TAC (Yu and Beta 2015). Another study conducted by Nayak, Liu, and Tang (2015) stated that high-temperature processing significantly affects the phenolics and flavonoids from various fruits, vegetables, and grains and thus reduced their antioxidant activities. In addition, the degradation of higher molecular weight phenolics to lower phenolic compounds during various thermal and non-thermal processing operations was observed to affect antioxidant properties.

Adaptation of recommended and optimized processing technique to some extent can preserve the antioxidant compounds present in colored wheat. Ficco et al. (2016) recommended stone milling process over conventional roller milling process in debranning purple wheat. Between drying and pasteurization processes used in the production of fresh pasta, the later preserves more anthocyanin content (21.42 µg/g vs. 46.32 µg/g) and carotenoids (3.77 µg/g vs. 4.04 µg/g) (Ficco et al. 2016). The Pearling process is more effective compared to conventional roller milling since it results in minimal loss of bioactive compounds (Giordano et al. 2017). Additionally, high lutein content was observed in the pearled product over roller milled product (Blanco et al. 2011).

Utilization in food industry

Bread and bakery products have now become an important part of the human diet because they are a rich source of dietary fiber and nutrients. However, bakery products prepared from common wheat flour have low antioxidant capacity and therefore, they need to be fortified with colored wheat flour for improved nutritional benefits (Dziki et al. 2014). Colored wheat bran can potentially be used in various industrial processes for selective recovery of bioactive compounds which serve as antioxidants (Zanoletti et al. 2017). The addition of 2% to 6% of ultrafine-ground colored wheat bran to common wheat flour during noodles making can result in increased dietary fiber and antioxidant activity (Song et al. 2013).

Biscuits are one of the commonly consumed bakery items with a longer shelf life; hence, can be used to harbor functional ingredients for human health. Pasqualone et al. (2015) successfully demonstrated the use of purple wheat for producing anthocyanin-rich biscuits with high antioxidant activity and total phenolic compounds.

Colored wheat has higher nutritional content (carbohydrates, sugar, protein, ash, dietary fiber and vitamins) and similar processing parameters as common wheat, and therefore, can be commercialized to make different functional foods (Sharma et al. 2018). However, there is a need for optimization of process parameters and conditions for their incorporation into the commercial application (Ficco et al. 2016; Gamel et al. 2020).

Future prospects

This review gives an overview of the health benefits and recovery of bioactive compounds from colored wheat. Numerous bioactive compounds, usually found in dark colored fruits and vegetables, had been detected in colored wheat and many others are still unidentified. Lack of information and literature is evident on colored wheat, even though they exhibit an exceptional antioxidant activity (Abdel-Aal, Hucl, and Rabalski 2018) and corresponding health benefits. The extraction of anthocyanin from fruits and vegetables is proven to be costlier, which in comparison can be recovered economically from colored wheat (Zhu 2018; Song et al. 2013). But separation and effective use of these pigment compounds from colored wheat still lacks in research. According to Zhu (2018), there are some understudied aspects of anthocyanin from cereals in terms of genetics, chemistry, and biological activities. Therefore, there is a need for further research to identify, isolate and characterize these compounds for their ultimate contribution to the human health.

The role of anthocyanins with regard to human health cannot be overemphasized. Apart from negative perception and lack of knowledge that leads to repulsion of colored varieties by majority of the population, it is also evident that colored wheat varieties results in low yield compared to the common wheat. The negative perception is particularly so owing to the poor dissemination of information by the relevant bodies and authorities regarding the irreplaceable and indispensable role played by anthocyanins from these colored varieties. More research on wheat breeding is needed to improve on the existing varieties or breeding lines so as to increase on production yield, content of health-promoting substances and their resistance to diseases. Martinek et al. (2014) noted that blue colored wheat variety has low resistance to fusarium head blight (FHB) whereas purple wheat is generally characterized by small sized grains. Therefore, development of high yielding varieties that are resistant to diseases and harsh climatic conditions would play a significant role in transfiguring the perception by the public resulting in their adoption across the globe.

It is evident that consumption of various bioactive compounds, generally present in dark colored fruits, vegetables and cereal grains, may lower the risk of various diseases due to their high antioxidant properties. Colored wheat, apart from their antioxidant activity, is found to possess higher concentration of proteins, essential amino acids and other essential components like zinc, iron and magnesium than common wheat (Tian, Chen, and Wei 2018a) and have all the necessary characteristics required for their use in product making and commercial utilization (Sharma et al. 2018). So its adoption for everyday use, either solely or in combination with other cereal grains, can contribute further to the development of new functional food for improved nutrition and health benefits (Duchonova, Vargovicova, and Sturdik 2012). According to Giordano et al. (2017), a careful selection of most appropriate fractionation techniques should be done to facilitate the production of flours, naturally rich in bioactive compounds. Still, their processing techniques are required to be optimized and further develop for their economic commercial use and therefore, additional studies are warranted.

Conclusions

Over the last few decades, the presence of anthocyanin and other bioactive compounds such as carotenoids and flavonoids in colored wheat have attracted the attention of various food processors and researchers. Successful utilization of this wheat in disease prevention and health promotion is linked to its antioxidant property. Apart from their preventive effect on various diseases like cancer, CVD and various other oxidative stresses induced chronic diseases, extracted pigments from the outer bran layer, also has the potential to replace artificial colorants from the food industry. Anthocyanin-rich pigmented wheat can be useful in the development of novel food products when used directly as whole grain or the extracted bran layer. High nutrient content, antioxidant activity and better utilization of colored wheat for the production of high-value products like bread, biscuits, pasta, noodles, bars, crackers, is demonstrated by many researchers indicating their potential to substitute common wheat. Various methods of analysis and extraction of anthocyanin and other bioactive compounds from colored wheat are suggested. However, further research is needed to explore the effect of processing on various bioactive compounds and antioxidant properties of the colored wheat to facilitate their effective utilization by food industries.

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