Purple Wheat Products

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Colored wheats such as black, blue, or purple wheat are receiving a great interest as healthy food ingredients due to their potential health-enhancing attributes. Purple wheat is an anthocyanin-pigmented grain that holds huge potential in food applications since wheat is the preferred source of energy and protein in human diet. Purple wheat is currently processed into a variety of foods with potent antioxidant properties, which have been demonstrated by in vitro studies and few human studies. Since anthocyanins are vulnerable molecules, special stabilization treatments are required during processing to diminish the loss of anthocyanins.

Keywords: colored wheat ; purple-wheat-baked products ; anthocyanins stability

1. Introduction

Colored wheats such as black, blue, or purple wheat are receiving a great interest by the food industry, researchers, and consumers due to their potential health-enhancing attributes. The kernel outer layers of colored wheat contain anthocyanin pigments along with other polyphenols, which are responsible for their health benefits. The pigments in the grain possess different anthocyanin profiles, e.g., blue versus purple [1][2], and a wide range of anthocyanin concentrations that are subjected to genotype, phenotype, and environment interactions [3][4]. The predominant anthocyanin pigments in blue wheat are delphinidin-3-glucoside, delphinidin-3-galactoside, delphinidin-3-rutinoside, and malvidin-3-glucoside [1][5][6]. In purple wheat, cyanidin-3-glucoside, cyanidin-3-(6-malonyl glucoside), cyanidin-3-rutinoside, peonidin-3-glucoside, and peonidin-3-(6-malonylglucoside) are the major anthocyanins [1][7][8][9]. Compared to purple or blue wheat, black wheat has received less attention, perhaps due to the availability of only few genotypes. The main anthocyanin compounds in black wheat are derivatives of the six common anthocyanidins (delphinidin, cyanidin, pelargonidin, peonidin, petunidin, and malvidin (**Figure 1**)) with glucose and rutinose sugar moieties [10]. On the other hand, the red, common bread wheat, has very little or no anthocyanin pigments [8]. The total anthocyanin content varies widely among colored wheats being 95–277, 22–278, 72–211, and 7–10 µg/g in black, purple, blue, and red wheat, respectively [11]. In Canada, several purple wheat cultivars such as CDC Prime-Purple and CDC Ultra-Prime Purple with exceptionally high contents of anthocyanins (up to 400 µg/g) were developed and are now commercially processed.

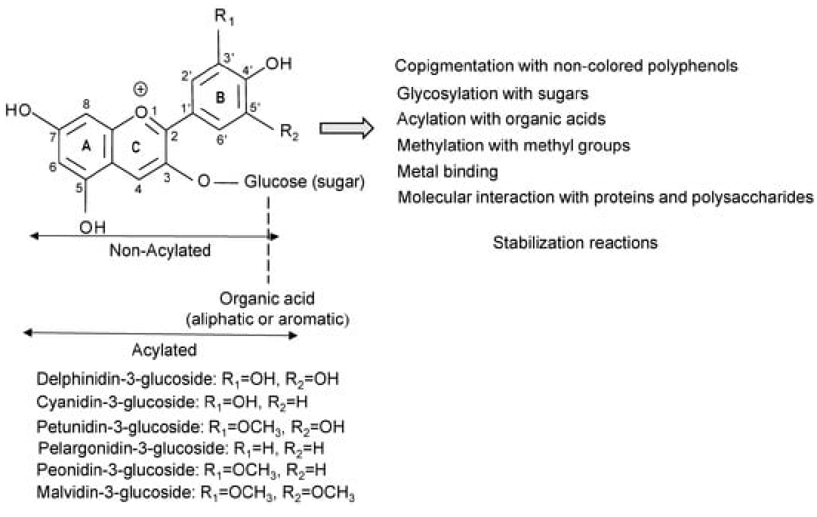

Figure 1. Structures of common anthocyanidins, their anthocyanins-3-glucoside, and possible stabilization reactions.

In general, consumption of anthocyanins has been associated with lowering the risk of chronic diseases and health promotion [12][13][14][15][16][17][18]. Anthocyanins are important components of the human diet with a daily intake of 12.5 mg in the United States, which is mainly delivered from eating fruits and vegetables [19]. The study has also shown that cyanidin, delphinidin, and malvidin derivatives are the most consumed anthocyanins, accounting for about 45, 21, and

15% of the total anthocyanin intake, respectively. The consumption of anthocyanins varies among countries and regions subject to the type of diet and gender. In Australia, the average daily intake is 24.2 mg [20], and it is 19.8–64.9 mg for men and 18.4–44.1 mg for women in Europe [15]. Nevertheless, anthocyanins are vulnerable molecules and require special stabilization treatments during food preparation and processing. Several review articles have discussed a number of approaches for enhancing the stability of anthocyanin, primarily in fruits and vegetables, including co-pigmentation, self-association, encapsulation and metal binding [21], extraction with advanced extractors [22], interactions with food proteins and polysaccharides [23], or adjustments of processing conditions [24]. In addition, several reports have unveiled the composition and potential health impacts of anthocyanins from cereal grains [13][25] and colored wheats [11][13][26][27][28][29].

2. Purple Wheat Products

Colored wheat foods and products have recently emerged as a true promise to improve human health due to their contents of bioactive components, especially anthocyanins, carotenoids, flavonoids, and phenolic acids. In particular, developing a variety of novel nutrient-dense and health-enhancing staple foods from colored wheat such as breads, pastas, breakfast cereals, and convenience bars would boost healthy eating among general populations and help with reducing the risk factors of chronic diseases. Different food products that have been developed from purple wheat milling fractions are shown in **Figure 2**. In Canada, several purple wheat products including wholegrain flour, bran, flakes, and others are commercially available under the brand “Anthograin”.

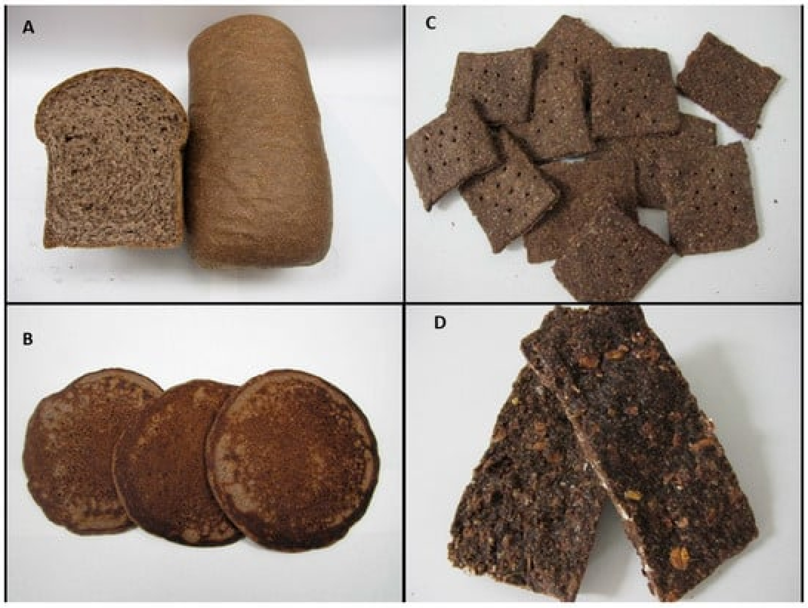

Figure 2. Selected food products made from wholegrain purple wheat: (**A**) Bread, (**B**) Pancakes, (**C**) Bran-enriched crackers, and (**D**) Bran-enriched convenience bars. Crackers and convenience bars were assessed in human studies.

2.1. Bread

Bread is the most widely consumed bakery product worldwide providing calories, proteins, fibers, vitamins, minerals, and antioxidants in the human diet. Processing purple wheat into bread products would provide superior nutritional quality over regular wheat bread. For instance, bread made from purple wheat exhibits better nutritional properties due to its content of phenolic acids and anthocyanins and its antioxidant properties compared with regular wholegrain or white wheat bread [30]. In another study, bread made from black wheat has shown a better quality due to its protein characteristics compared with purple or blue wheat bread [31]. Currently, colored wheats are being produced for various food applications, and, undoubtedly, research is needed to breed colored wheat for a specific end use and to guarantee product quality. Chapatti is a non-leavened flat bread commonly prepared from whole wheat and widely consumed in India, Pakistan, and Bangladesh. Chapatti made from black, blue, and purple wheat flours has been found to have higher amino acid retention compared with white wheat chapatti [32]. The average reduction in amino acids content was minimal in chapatti made from black wheat (11.4%) followed by 12.4, 19.0, and 23.8% reductions in the cases of blue, purple, and white wheat chapattis, respectively. The study suggests that anthocyanins in colored wheats may mask and protect proteins and amino acids against thermal and oxidative damages during chapatti production. The sensory properties of colored wheat breads seem exceptional due to the presence of anthocyanins. Chapatti prepared from black, blue, and purple wheat has nicer flavors, softer textures, acceptable quality, and higher contents of dietary fiber and phenolic compounds than white wheat chapatti [32][33]. In spite of reduction during processing, anthocyanin content and antioxidant capacity were highest in black wheat chapatti, followed by blue, purple, and white wheat chapattis. In a study on purple wheat, different milling fractions were prepared and baked into breads to investigate their color properties [34]. Breads made from purple wheat wholegrain flour had a reddish crumb color, while those prepared from the inner milling fractions of purple wheat exhibited a yellowish crumb color.

Anthocyanin compounds are susceptible to heat and oxygen, thus baking affects their composition and content. Breads made from blue wheat wholegrain flour using a traditional Czech recipe baked at 240 °C for 21 min have shown 7.1% reductions in anthocyanin content in comparison with their original flour, whereas a greater reduction (61%) has been found in case of purple wheat bread under the same baking conditions [35]. Breads baked for longer time at lower temperature (e.g., 31 min at 180 °C) have exhibited even greater reductions of 40.8 and 72.8% in anthocyanin content in blue and purple wheat, respectively. Studies have indicated that longer baking time, rather than baking temperature, had a greater impact on the anthocyanin content of bread. Two prototypes of purple wheat breads, wholegrain bread and bran-enriched wholegrain bread, were developed as part of several purple wheat products to investigate their anthocyanin composition and antioxidant activity [36]. The bran-enriched bread had about 17 µg/g anthocyanin content, while the wholegrain purple wheat bread had 10 µg/g, as measured by HPLC. Higher values of anthocyanin content, 80 and 65 µg/g, were observed in both type of bread when the measurement was conducted by a spectrophotometric method [36]. These results indicated significant reductions of anthocyanin during bread production compared with the original flours. Similar observations have been reported for the concentration of anthocyanins in breads made from blue and purple wheat [37]. The majority of the anthocyanin loss in blue wheat occurs during baking (45–51%), whereas the biggest loss in purple wheat takes place during dough preparation (26–39%). When making bread, the blue wheat loses an average of 75–77% of its anthocyanins, whereas the purple wheat loses an average of only 50–53%. Among the individual anthocyanin compounds, peonidin-, cyanidin- and petunidin-glycosides are the most stable during bread production, while delphinidin-glycoside is the lowest stable anthocyanin [37]. Peonidin-3-glucoside has a loss percentage of 44%, cyanidin-3-glucoside of 52%, cyanidin-3-rutinoside of 61%, and delphinidin-3-rutinoside of 80%. Another study looked into how the bread making process affected the phenolic content and antioxidant qualities of purple wheat [38]. The free phenolic content significantly increased ($p < 0.05$) after mixing, fermentation, and baking, while no significant changes have been found in bound phenolics after fermentation for 30 min. However, a longer fermentation time (65 min) and baking for 25 min at 200 °C resulted in a significant increase ($p < 0.05$) in bound phenolic compounds by 16% to 27%. A similar trend has been observed for the antioxidant properties. After dough mixing, total anthocyanin content (TAC) significantly decreased ($p < 0.05$) by 21%, then it gradually increased to 90% of the original level after fermentation. Baking resulted in a significant reduction ($p < 0.05$) in TAC by 55%. The overall loss of TAC is greater in bread crust than that of bread crumb. Similarly, the anthocyanin concentration dramatically dropped after mixing and baking of purple and blue wheat bread doughs, but not after the fermentation or proofing steps [39]. Although the anthocyanin loss during baking cannot be completely prevented, it can be slowed down or controlled by altering the variables of the bread-making process. This may include using high-temperature, short-time baking processes, as well as a dough making process at a low pH [39][40]. For example, the fermentation of purple wheat with *Lactiplantibacillus plantarum* No. 35 resulted in improved DPPH free radical scavenging capacity, and it has been recommended for acrylamide reduction in bread [41]. Thus, the application of the sourdough processing technique could be an effective method to protect anthocyanins and other phenolic compounds during the production of fermented baked products from colored wheats. Other bran-enriched products with no fermentation steps and minimal baking conditions (shorter time and lower temperature), such as crackers, may have higher anthocyanin content and lower reduction percent than breads. In general, the baking process could induce positive and/or negative effects on product quality and nutritional properties of breads made from colored wheat subject to bread type, fermentation method, and baking temperature and time.

Purple wheat milling fractions were used to create ready-to-bake flour mixtures suitable for bread production [42]. The mixtures contained wholegrain purple wheat flour and/or purple wheat white flour enriched with fiber sources such as inulin, chia seed flour, and psyllium husk flour to increase their fiber content and biological value. The purple wheat white flour mixture contained 263 µg/100 g total phenols and produced bread with a light color, acceptable texture, taste, and flavor, while the mixture made from 70% wholegrain and 30% white flour had a higher level of total phenols (897 µg/100 g) and produced bread with enhanced consistency, flavor, and aroma. The overall quality of both breads was acceptable. Purple and blue wheat flours were successfully used in the production of buns, a type of bread roll used mainly in making sandwiches [43]. The doughs and buns were prepared with wholegrain flour from regular wheat, purple wheat, or blue wheat, either by itself (100%) or in combination with white flour (90/10 and 80/20). Purple wheat flour had the maximum dough stiffness, while blue wheat exhibited the lowest dough stiffness among flours. Buns made from blue wheat had significantly lower crumb hardness ($p < 0.01$) than control buns made from ordinary wheat, which had the maximum crumb hardness. The study results suggested that the buns made from reduced levels of colored wheat flour were springier. Overall, these studies suggested that colored wheat, including purple wheat, is a promising flour ingredient in making different types of breads, but it requires special preparation and baking conditions to minimize the loss of anthocyanins.

2.2. Pasta and Noodle

Pasta is a popular food around the globe, which is produced either in fresh or dry form. It is considered a low glycemic index food that elicits low postprandial blood glucose and insulin responses [44]. The inclusion of colored wheat ingredients in pasta recipes would add further nutritional value to pasta products. At a pilot plant scale, a fiber-rich fraction obtained from purple wheat through the debranning process was added to semolina or flour formulations at a 25% level to produce nutritious pasta [45]. The fiber-enriched pasta products were found to contain reasonable amounts of total anthocyanin (89–122 µg/g) and total phenols (3000–3100 µg/g). Cooking of pasta dropped the total anthocyanin and phenol contents significantly, by about 58–65% and 51–60%, respectively. The HPLC data has shown that the abundant glycosylated anthocyanin moieties are more likely to be released during cooking than their aglycones. The anthocyanin aglycones could be retained by the pasta dough matrix, regardless of whether the enriched pasta was based on semolina or wholegrain flour. In another study, purple wheat was debranned into two fractions, fraction 1 (F1, 3.7% of outer layers was removed) and fraction 2 (F2, additional 6% of outer layers was removed), and compared with conventional milling bran (CB) in making fiber-enriched pasta [46]. Pasta enriched either with F1 or F2 had significantly higher amounts of anthocyanins than those enriched with the CB bran. Additionally, pasta enriched with F1 had the highest antioxidant capacity. In another study, purple durum and non-anthocyanin-pigmented durum wheats were milled by roller or stone mill, and the milled products were compared in the pasta making process [47]. Stone milling has been found to preserve health-enhancing compounds such as dietary fiber, carotenoids, and anthocyanins (for purple durum wheat) than roller milling. During the pasta making process, the total anthocyanin content showed a gradual decline from 66.5 µg/g in the raw material to 49.3 µg/g after extrusion. The drying process resulted in significant ($p < 0.05$) reductions in the content of anthocyanins (21.4 µg/g vs. 46.3 µg/g) and carotenoids (3.77 µg/g vs. 4.04 µg/g), but slight changes in antioxidant capacity have been observed. It has been suggested that some modifications in the processing conditions such as moisture content and drying temperature could be made to preserve more anthocyanins and carotenoids. Pasta made from either pigmented or ancient wholegrain wheats have shown acceptable quality due to low cooking losses and comparable physical characteristics to semolina pasta [48]. In comparison to durum and ancient wheat semolina, pasta made with pigmented wheat have much higher total phenolic contents and antioxidant activities [48]. Despite the reduction in anthocyanins, the remaining portion of anthocyanins in purple durum pasta could be beneficial to human health.

Noodles are a staple food in several parts of the world. The color of noodles is a key quality characteristic and has a significant role in influencing consumer acceptance. Purple wheat milling fractions were used in making noodles to study their impact on product appearance [34]. The color of noodles made from wholegrain purple wheat flour or a combination of 10% bran and middle fraction exhibits a strong red hue. The addition of black, blue, purple, and white wheat bran powders, prepared by ultrafine grinding into Chinese noodles formula at levels of 2–6%, has resulted in better texture and lower cooking loss compared with the control noodles with no fiber added [49]. The addition of bran powder reduced the degree of whiteness (L* values) of wet dough sheets, which is mostly due to the presence of carotenoid and anthocyanin pigments. The study highlighted the possibility of producing fiber-enriched noodles with potential antioxidant capacity by using wheat bran powder with different colors. Another study examined the phenolic antioxidant properties of noodles prepared from whole wheat, partially debranned grain, and refined flours of three colored wheats (dark purple, light purple, and black) [50]. The total phenol and flavonoid contents and antioxidant capacity of the noodles were lower compared to their original flours. Noodles prepared from a blend of regular and black or purple wheat flours have been found to possess higher amounts of total phenols and anthocyanins than that made from regular wheat flour alone [51]. These studies show that adding colored wheat milling fractions to pastas and noodles improve their content of anthocyanins, polyphenols, and antioxidant properties.

2.3. Other Cereal Products

Purple wheat flour has been considered in making biscuits and crackers with the intention to improve their nutritional properties and supply the market with healthy food products. Anthocyanin-enriched biscuits made from wholegrain purple wheat flour were developed [52]. The product contains 2.6 mg/g total phenol content and 13.9 µg/g total anthocyanins, which indicates an improved nutritional profile compared with the control biscuits. Due to their superior antioxidant qualities, the purple wheat biscuits had lower levels of lipid-derived carboxylic acids, indicating a slower rate of oxidative degradation of lipids. On the other hand, the purple wheat biscuits showed lower texture quality than the conventional biscuits, perhaps due to the higher gluten index of the purple wheat flour, which impacts biscuits dough rheological properties.

Crackers made from wholegrain purple and blue wheat flours have been found to contain 37–45 µg/g anthocyanins [39]. This level is about 70% lower than that of the initial flour. The majority of the anthocyanin content of purple wheat flour (50%) is lost during dough mixing, whereas blue wheat flour loses more anthocyanin during baking than during mixing. This might be explained by the location of anthocyanin pigments in both types of wheat (e.g., in the pericarp of purple wheat and in the aleurone layer of blue wheat) and their interactions with other components during mixing, where oxidative stress damage takes place, while heat damage occurs during oven baking [39]. A bran-enriched high fiber cracker with a high amount of anthocyanins (56 µg/g) was developed as a functional food [36]. In spite of this high level, a significant decline in anthocyanin content occurred through the processing, with more than 80% reduction compared with the starting material (blend of whole flour and bran at 1:1 ratio). The crackers had acceptable sensory properties and exhibited high antioxidant activity, as demonstrated by in vitro assays based on ABTS, DPPH, and peroxyl radical activity. Four servings of the crackers provided 6.7 mg anthocyanin and 176 mg phenolic acids and have the potential to maintain positive health impacts.

Several purple wheat products (**Figure 2**), including bran-enriched convenience bars, crackers, pancakes, and porridge, were also developed [36]. These products were developed with the intention to study their potential impact on metabolic markers and health conditions. The products were significantly different in their nutrient level, in particular their anthocyanins and dietary fibers. The purple wheat bran was incorporated to increase the amount of dietary fiber and anthocyanins in the bars. As a result, the bars had a great anthocyanins concentration (41.7 µg/g) compared to 16.0 and 7.0 µg/g for pancake and porridge.

Purple wheat bran-enriched muffins were developed as healthy foods to assess the impact of thermal processing on their antioxidant properties [53]. The muffin-making process had significant adverse effects on the phenolic compounds of wheat, especially anthocyanins. In spite of the complete decay of anthocyanins, the purple wheat muffins exhibited good DPPH scavenging activity after thermal processing. Home- and laboratory-made infant cereals prepared from whole purple wheat, unpolished red rice, and partially polished red rice were evaluated in terms of their total phenol and anthocyanin contents and total antioxidant capacity [54]. Infant cereals made from colored grains, purple wheat, or red rice have a higher phenol content and greater ORAC values than commercial infant cereals ($p < 0.05$). Moreover, the unpolished red rice cereals have a total phenol content and peroxyl radical scavenging capacity higher than those made from purple wheat, while the latter has a higher total antioxidant capacity, suggesting that giving infants this grain in their diets may improve their antioxidant status as well as the overall body wellness.

2.4. Anthocyanin-Rich Powder

Purple wheat can be a sustainable source of anthocyanin pigments, as they are concentrated in the outer layers of the kernel. A mechanical–chemical process was developed to isolate anthocyanins from purple wheat [7]. Firstly, the grains were milled and fractionated to obtain the bran fraction with a 2-fold increase in anthocyanin concentration, then the anthocyanins were extracted from the bran with acidified ethanol. The extract was concentrated by evaporation at 40 °C using a rotary evaporator and purified on a chromatographic column filled with amberlite XAD-7HP packing material. The ethanol elution from the column was concentrated again in a rotary evaporator and then dried in a solvent proof oven at 45 °C to obtain the anthocyanin-rich powder, with an 81- to 135-fold increase in anthocyanin concentration, subject to batch size. The powder had an exceptionally high content of anthocyanins (3.4–5.7 g/100 g), with 7.9–9.9% moisture content. Cyanidin was the main aglycone, along with glucose as the dominant sugar, and malonyl being the main acyl substituent in the acylated pigments present in the purple wheat bran or powder. Peonidin came second after cyanidin, and the other common aglycones (delphinidin, petunidin, pelargonidin and malvidin) were also present, but at very low concentrations. The purple wheat bran and powder products exhibited potent antioxidant capacities based on the scavenging of DPPH, ABTS, and peroxyl radicals compared with wholegrain flour. The study suggested that processing of purple wheat into bran and anthocyanin-rich powder would add value to the bran and expand its use as a renewable source of anthocyanin pigments for the functional foods, nutraceuticals, cosmetics, and healthcare industries. The same process was previously used to isolate anthocyanins from blue wheat, which was further fractionated into individual anthocyanin components using preparative HPLC equipped with an analytical fraction collector [55]. These studies indicated that it is feasible to covert colored wheat bran into value-added products.

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