Purple and Blue Wheat—Health-Promoting Grains with Increased Antioxidant Activity

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ABSTRACT

Anthocyanins are flavonoid pigments that are responsible for red, purple, and blue colors in diverse organs in a wide array of plants. Anthocyanins also act as antioxidants, for example by scavenging free radicals. In wheat, anthocyanins can be present in the pericarp (purple anthocyanins) or aleurone (blue anthocyanins) layer of the grain. Purple and blue wheat grains, therefore, can be processed into innovative whole wheat (wholemeal) products that are rich in both dietary fiber and antioxidants. Combining the genetic components that produce purple pericarp and blue aleurone traits significantly increases the total concentration of anthocyanins and, as a result, the total antioxidant activity.

Anthocyanins are the most abundant and widely occurring flavonoid pigments and are responsible for most of the blue to blue-black and red to purple colors found in a wide variety of fruits, vegetables, flowers, leaves, roots, and other plant storage organs (9). The first anthocyanin was identified from the blue cornflower (*Centaurea cyanus* L.) in the early 20th century (39). Today, several hundred different anthocyanins have been identified and defined structurally. Interest in anthocyanins has increased recently because they represent natural alternatives to artificial food colorants, and research suggests they have potential health benefits due to their antioxidant properties (11,16, 21,34). In wheat (*Triticum* spp.), pigmentation by anthocyanins can appear in almost all plant parts (Fig. 1)

Purple Pericarp and Blue Aleurone Traits

Purple wheat grains were first introduced to the scientific community by Wittmack in the late 1800s (40). The grains were originally collected in Abyssinia (northern Ethiopia) in 1872 and 1873 (40,41). In his compendium on cereal varieties, Körnicke (19) described two tetraploid, purple-grained Ethiopian wheat varieties, *T. aethiopicum* var. *arraseita* and *T. aethiopicum* var. *schimperi*. In 1905, a German expedition to Abyssinia collected seeds from purple-colored wheat, which were further distributed to researchers in Europe by Wittmack (42). At the same time, two samples of purple wheat from Abyssinia designated as "*frumento eloboni*" were displayed at an agricultural exhibition in Italy (42). It is clear from these publications that purple wheat from Abyssinia was brought to Europe at the end of the 19th century and was widely distributed across Europe by the beginning of the 20th century, either through further distribution by botanists or repeated introduction from East Africa (47).

At the same time, plant scientists also carried out interspecific crosses between wheat and wheat relatives and wheat and rye to transfer genes for disease resistance, winter hardiness, perennial habit, forage traits, and yield components into wheat. Breeding activities in Central Europe gave rise to various European 'Blaukorn' germplasm (17,33,37,46). The source of the blue aleurone trait in this material originates from einkorn wheat (46). Simultaneously, hybridization with *Agropyron* spp. (wheatgrass) in North America resulted in various blue-aleurone genetic wheat stocks (30,31,38,47,48).

From Genetic Studies to Breeding

Purple and blue wheat strains were widely used during the first half of the 20th century to elucidate the inheritance of grain pigmentation (7,17,47). Finally, the purple grain color was transferred into advanced bread wheat material (8). In the 1960s and 1970s, purple wheat germplasm was developed worldwide for purposes such as the demarcation of feed wheat quality (15), development of hybrid wheat systems (5), and determination of outcrossing rates in the self-pollinating wheat crop (10). In the early 1980s, the first commercial purple wheat variety was released in New Zealand, and novel, eye-catching kibbled and whole grain products appeared on the market (44). Since then, commercial purple wheat varieties have also been released in Australia, Canada, China, and many European countries. In contrast, to the best of our best knowledge, no commercial varieties of blue wheat have been released to date except in Austria (29) and China (14).

Black-grained wheat germplasm has been reported by Chinese researchers (26,35,45). The dark or "black" grain color found in wheat is not due to melanin-like pigments, as is the case in barley (43), but results from a combination of purple pericarp and blue aleurone traits (6,35,36). The abundance of wheat with dark colored grains in China is most likely due to the frequent implementation of wide crosses with wild relatives in Chinese wheat breeding programs.

Anthocyanin Profile, Antioxidant Activity, and Health

Separation of grain anthocyanins by different chromatographic methods revealed distinct anthocyanin profiles for blue and purple wheats. In blue wheat, delphinidin was identified as the predominant anthocyanin aglycon, whereas cyanidin is the main aglycon in purple wheat. Generally, the anthocyanin profile is more complex in purple wheat (2,4,6,13,18,20,28,36). The results with regard to profile and total anthocyanin content are somewhat contradictory and point to interactions between genotypes and environments.

Various studies have demonstrated higher antioxidant properties for purple and blue wheat varieties compared with red or white varieties. The composition of anthocyanins, such as type

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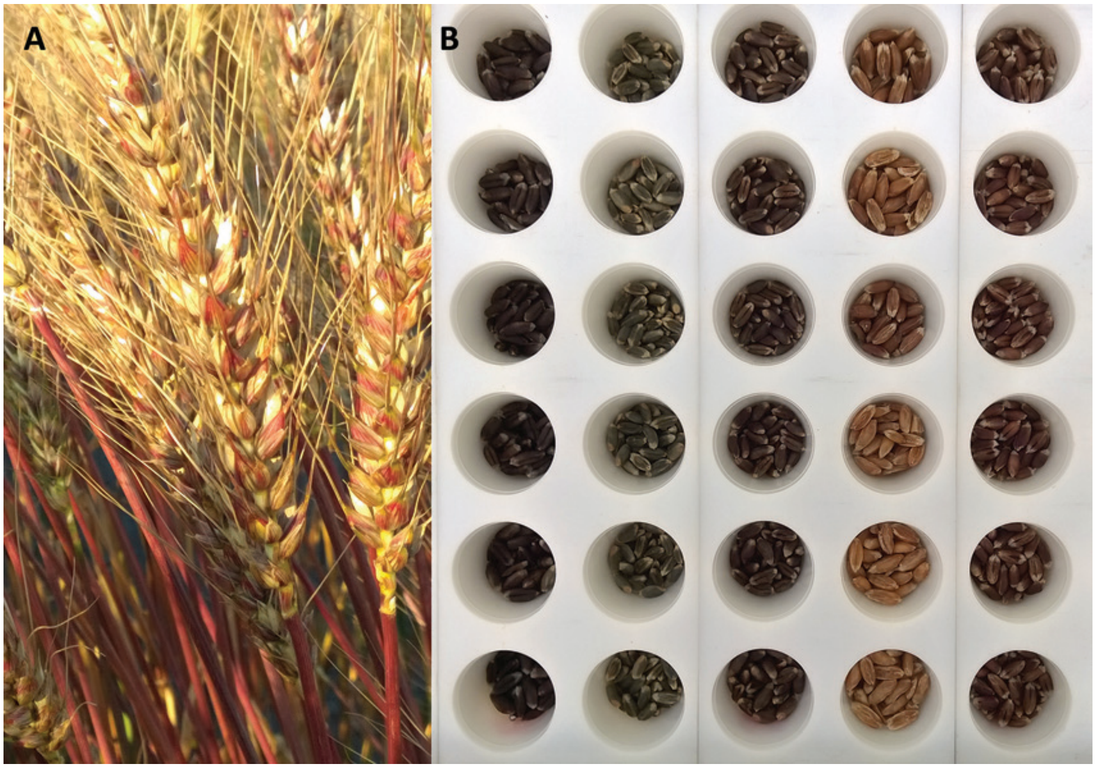

Fig. 1. A, Anthocyanin pigmentation of wheat (purple culm and glume) during ripening. **B,** Pigmented grains of selected single spikes from offspring of purple pericarp × blue aleurone wheat variety crosses prepared for sowing. Left to right: black, blue, deep purple, red, and purple grains. Due to the differences in inheritance of blue aleurone and purple pericarp traits, red or white grain types with no anthocyanin pigmentation can segregate as well as "black" grain types.

of aglycon and sugar moiety, seems to have a significant impact on antioxidant properties (1,16). The highest radical-scavenging activity was reported for a black grain genotype (25) and can be confirmed in our breeding material (Fig. 2). Although other compounds, such as phenolic acids, influence antioxidant capacity, anthocyanins play a major role in the overall free radical-scavenging capacity of colored wheat varieties (14). Therefore, breeding for high anthocyanin content by combining the genetic components of purple pericarp and blue aleurone traits is a promising approach to achieve wheat germplasm with high antioxidant content.

Products and Effects of Processing

A wide range of innovative products incorporating anthocyanin-pigmented wheat varieties has been experimentally and commercially developed (22). In addition to New Zealand, where specialty bread types made from purple wheat were first marketed (27,44), purple wheat products, especially whole grain breads (Fig. 3) and breakfast cereals, have found a niche market in Central Europe and Canada, where they are marketed under trademarked brands (e.g., PurPur® [backaldrin International The Kornspitz Company GmbH] or AnthoGrain™ [InfraReady Products Ltd.]). In China, many food manufacturing enterprises have developed products made with black wheat, such as soy sauce, cakes, and (instant) noodles (22).

Foods made with anthocyanin-rich wheat grains may offer health benefits due to the antioxidant activity of the pigments (12,22); however, processing does have a significant impact on anthocyanins and their antioxidant properties. Fractionation can significantly increase the concentration of anthocyanins (1,32), whereas heat and light can degrade anthocyanins during drying, processing, and storage (23,24). In addition to the use of purple and blue wheat grains for food, extraction of anthocyanins from the bran (3) may also enable their use in nonfood industries. With respect to health benefits, further research on the bioavailability and degradation of anthocyanins after and during processing is needed. However, purple and blue wheat grains definitely increase the diversity of potential cereal products, and by consuming whole grain purple wheat products, consumers can also benefit from a fiber-rich diet.

Conflicts of Interest

The authors declare no conflict of interest with respect to the mentioned companies.

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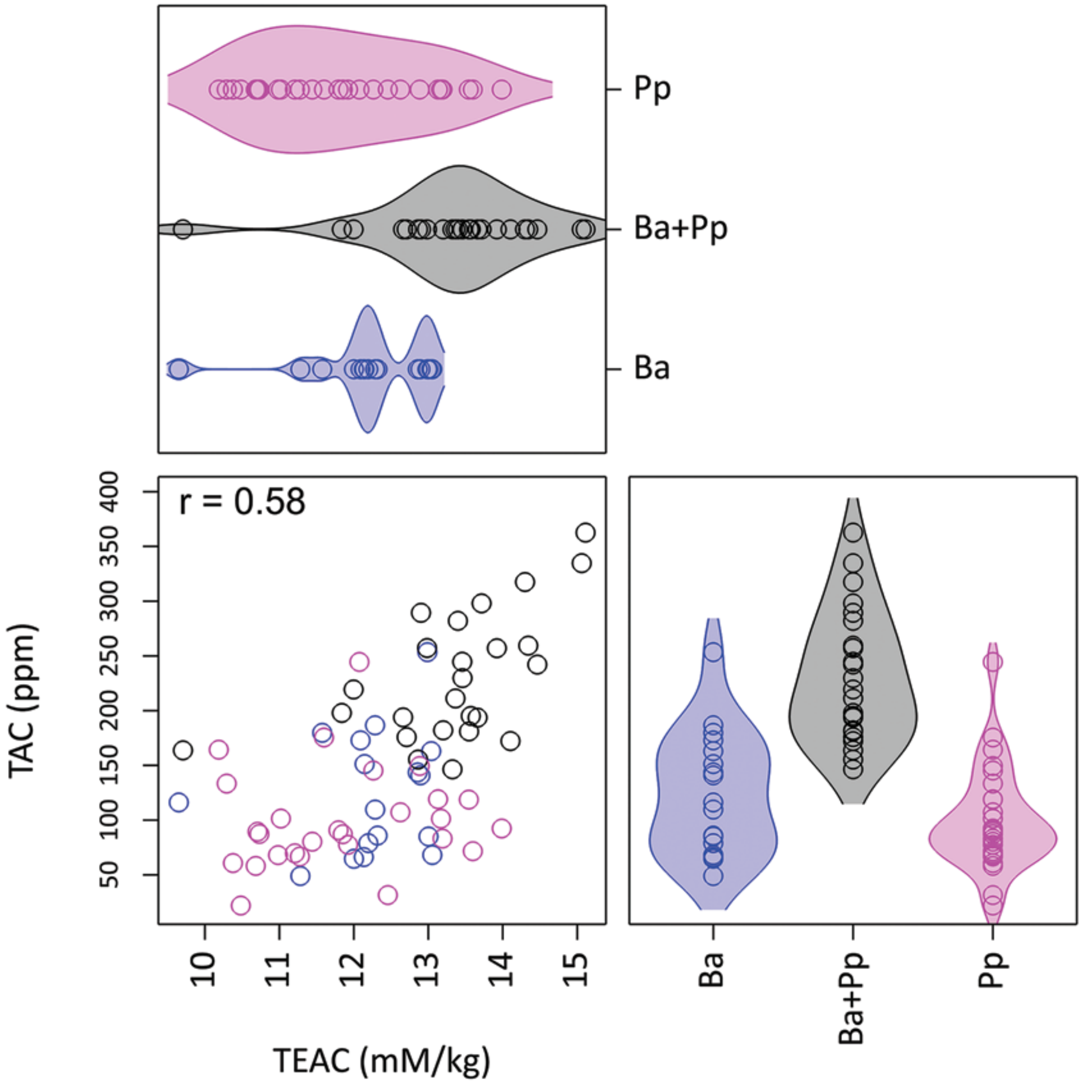

Fig. 2. Relationship between total anthocyanin content (TAC) and Trolox equivalent antioxidant capacity (TEAC) and density plots of purple (Pp), blue (Ba), and "black" (Ba+Pp) breeding lines derived from purple pericarp × blue aleurone wheat crosses.

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Fig. 3. Bread made from whole grain purple wheat. (Photo courtesy of backaldrin International The Kornspitz Company, Asten, Austria)

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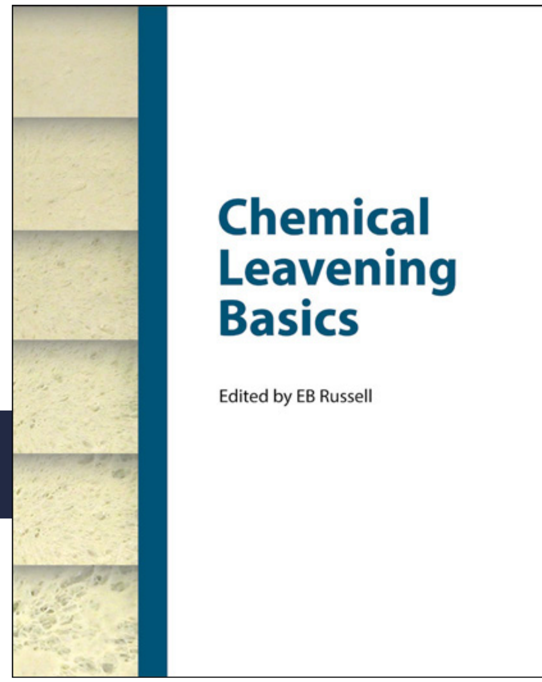

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