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Beyond Bread and Beer: Value-Added Products from Wheat

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Abstract

Although wheat (*Triticum aestivum*) and related cereals [Barley (*Hordeum vulgare*), Rye (*Secale cereale*)] are primarily used for producing baked goods and beverages, cereal crops can be used to create many value-added goods beyond these traditional products. Fractionation of cereal grains and extraction of valuable phytochemicals allows greater access to materials for use in food additives and nutritional supplements. Fermentation for beverage and fuel bioethanol production results in not only renewable fuel, but also a range of other coproducts, including nootropics. In addition to traditional grain fermentation, straw fermentation is also discussed, which further utilizes the whole plant. The main by-product of cereal grain fermentation, wheat stillage, can undergo a range of processes to enhance its value as animal feeds, as well as extraction of useful compounds. These methods provide a glimpse of the many sequential and divergent processes that may bring us closer to realizing the full potential of wheat and related cereal grains.

Keywords: added-value products, wheat, fermentation, bioactive compounds, phytochemicals bioethanol, fractionation, protein

1. Introduction

Wheat is the world's second most produced grain [1], with global production forecasted to reach a new record of 780 million tonnes for 2021–2022 [2]. Wheat end-uses include food products (e.g., bread, pasta) [1], other consumer goods (e.g., hair products, skin care, cleaning agents) [1], and industrial applications (e.g., renewable fuels) [3]. In Canada, wheat varieties are often grouped by their functional properties and are categorized as Western Canadian or Eastern Canadian varieties, depending on the regions where they are grown [4]. These varieties are often used for the food and feed industry, although those with high starch and lower protein content are typically used as animal feed or for biofuel production [4, 5].

Opportunities to increase the value of wheat start while it is still growing, as limited grazing can allow the wheat to serve as both fresh feed for cattle and produce a harvestable crop at the end of the season [6]. Under suitable climatic conditions (i.e., low early-season rainfall) grazing by domestic animals can even improve crop yields by reducing lodging and improving the crops' response to late-season rain [7]. After harvest, the most common processes for adding value to wheat are food related.

In areas with high wheat production, flour mills can use the largest portion of available wheat by far, with most of the remaining wheat going towards production of breakfast food, pet food, and feed for livestock [8, 9].

In addition to traditional uses of wheat, fractionation of whole wheat grains can add considerable value. It is predicted that by 2024 the wheat starch market will exceed \$4 Billion (USD) owing to significant use of wheat in agriculture-based industries [10]. The extraction of starch from wheat is an involved process requiring steeping and degermination [10]. After fractionation, bioactive compounds can be extracted and concentrated from individual wheat fractions, such as vitamin E from the germ and bran layers [11].

In North America, wheat is one of the predominant feedstocks for starch-based bioethanol production, especially where this cereal crop is locally available and abundant [12]. Wheat bioethanol is a renewable source of fuel, and its use can reduce greenhouse gas emissions when used to displace petroleum-based gasoline. Several valuable co-products can also arise from ethanol fermentation, including nootropic compounds, organic acids, glycerol, and a variety of fusel alcohols [13].

The recovery of grain by-products also holds crucial opportunities for wheat valorization, as waste products such as wheat straw also have value. Historically, wheat straw is incorporated into soil after harvest to improve soil quality, or removed and used as a component of animal feed or building material [14, 15]. Straw has also been investigated as a resource for liquid biofuel production (e.g., ethanol, butanol) [16, 17].

After alcoholic fermentation, additional processing can increase the total added value by utilizing the leftover stillage. Although fermentation consumes most available starches and sugars, proteins from both the wheat and yeast are left in the stillage after the ethanol is evaporated from the mash [18]. This protein-rich mixture can be integrated in animal feeds, as well as have valuable components removed to produce industrial chemicals [19].

In this chapter, we review value-added processes and products that go beyond the use of wheat for flours and beverages. These processes include fractionating whole wheat grain, extracting bioactive phytochemicals, fermenting both milled wheat and wheat straw for biofuel production, as well as the use of the resulting byproducts from wheat fermentation. Together, these processes provide a multitude of paths towards enhancing the total value of wheat.

2. Wheat fractionation

Mature cereal grain like those from wheat, rye, and barley are primarily composed of starch, protein, and cell wall polysaccharide (**Figure 1**). Typically, these materials account for 90% of grain dry weight [20]. Many bioactive components of wheat grains (e.g., polyphenols, phytic acid, phenolics, and minerals) are concentrated in the bran [21–23], specifically the aleurone layer [24]. The aleurone layer contains the highest amounts of bioactive compounds with antioxidant activity [25–28]. Additionally, wheat germ is also a source of value-added compounds including vitamin E (e.g., tocopherols) and oil.

Wheat bran obtained by milling constitutes about 15% of the mass of milled grain, and is composed primarily of the outer pericarp, inner pericarp, testa, hyaline layer, embryo, aleurone layer, and residual starchy endosperm (**Figure 1**) [20–22].

Starch accounts for ~60–70% of the mass of wheat grain [29] and is primarily composed of amylose and amylopectin [30], making it suitable for a wide variety of industrial applications, food products, and other consumer goods.

Figure 1.
Anatomy of wheat grain.

After milling, the endosperm is the primary product that makes up white flour (refined flour), while whole wheat flour (whole-grain flour) consists of the bran, germ, and endosperm [31]. Compared to white flour, whole wheat flour is richer in vitamins, phenolic acids, and minerals, as the whole kernel is included [31]. Meanwhile, due to the absence of bran, germ, and the aleurone components, white flour is more suited for use in baked food products that require leavening [31]. Further fractionation and milling processes can be used to isolate valuable bioactive phytochemicals.

Protein fractionation and extraction is another method of wheat valorization. Protein content can be influenced by the application of nitrogen fertilizer, which can result in an increased proportion of gliadin proteins, thus affording wheat that produces dough with increased extensibility [32]. Proteins make up to 7–22% of wheat grain dry weight [33], although it is unevenly distributed in the grain. For example, 5.1% of protein has been reported for the pericarp, 5.7% for the testa, 22.8% for the aleurone, and 34.1% for the germ [34].

Solvent fractionation can produce several protein concentrates with unique properties. Wheat protein fractions, like all proteins, are classified based on differences in their solubility: albumins are water soluble, globulins are soluble in dilute salt solutions, prolamins are soluble in 70% aqueous ethanol, and glutenin is soluble in dilute acids/bases [11]. Each protein fraction imparts different functionality to wheat products and when isolated can be used in specific applications. For example, wheat albumin can be used as a nutraceutical that controls blood sugar [35]. Wheat globulin has been found to increase dough stiffness and can be used in noodle products to improve both extensibility and hardness [36].

The other two fractions of wheat protein, gliadin and glutenin, are together known as gluten. Gluten is commonly marketed in two forms; vital wheat gluten, which can be hydrated using water to recover its elastic properties, and nonvital wheat gluten, which is irreversibly denatured [37]. Although nonvital wheat gluten is typically used as an ingredient for protein enrichment, vital wheat gluten can also be used for its structural properties [38]. Vital wheat gluten can be used to fortify flour and increase the elastic properties required for bread-making or can be used to produce textured protein products used to imitate or extend meat. Wheat gluten can also be used as a stabilizing agent for foods, particularly, commercially produced sauces. Vital wheat gluten has recently been gaining attention for its use as a biodegradable polymer suited for the manufacture of packaging materials.

Natural antimicrobials are more readily incorporated into wheat bioplastics than traditional plastics. Protein-based plastics are prepared at lower temperatures

using conditions that are less likely to volatilize and/or degrade antimicrobials [39]. Additionally, wheat gluten has been proposed as a sensing material to monitor carbon dioxide accumulation within food packaging [40]. In the future, gluten-based foods might be available in biodegradable gluten-based packaging that acts as a matrix for antimicrobials such as essential oils, and provides feedback on whether the food inside is spoiling!

3. Bioactive phytochemicals in wheat

Whole wheat is a rich source of bioactive phytochemicals including, flavonoids, phytic acid, phenolic acids, carotenoids, tocopherols, alkylresorcinols, benzoxazinoids, phytosterols, γ -oryzanol, β -glucan, and lignans (**Table 1**) [75, 76]. Methods for extraction of these phytochemicals (**Table 1**) are further detailed in Luthria et al., [76]. Most of the phenolic acids (e.g., ferulic acid) exist in the form of bound insoluble complexes and are primarily aggregated in the cell wall matrix of whole grain [77]. These compounds have anti-inflammatory properties that promote gastrointestinal health [23]. They can also act as antioxidants to prevent heart disease and lower the incidence of colon cancer [23]. Consequently, wheat phenolic acids can have great value when formulating functional food products. Destruction of the cell wall matrix is necessary to increase the accessibility of these bioactive compounds. This can be accomplished using a variety of processes including the use of enzymes, fermentation [78], steam explosion, and ultra-fine grinding [79].

Other antioxidant compounds include pigments (e.g., carotenoids). These are typically found in the germ, aleurone, and endosperm fractions [80], although the distribution of these compounds can vary depending on the type of wheat (e.g., einkorn, durum, and common wheat) [81–83]. Carotenoid content in wheat grain can range between 1.8 and 5.8 mg/g [84]. These pigments (e.g., lutein, zeaxanthin, β -carotene) can have provitamin A activity and provide protection against cardiovascular disease and UV-inducing skin damage, as well as yielding products that impart improved antioxidant capacity and can mitigate oxidative stress [11, 80].

Wheat is also a moderate source for vitamin E (e.g., α -tocopherol) [11], providing approximately 5–17 mg of α -tocopherol equivalent per 100 g [85, 86]. The sum of all tocopherols and tocotrienols (a.k.a. tocols) in wheat is in the range of 49–58 mg/g [87–89]. Wheat germ tocols are primarily α - and β -tocopherols, whereas tocols of the pericarp, testa, and aleurone are enriched in tocotrienols [11]. α -Tocopherol is a fat-soluble antioxidant that protects cell membranes with high contents of polyunsaturated fatty acids against oxidative damage [90, 91]. When consumed, these tocols mitigate the production of reactive oxygen/nitrogen species and modulating signal transduction [90] thereby boosting immune response [91].

Wheat β -glucans, lignans, and phytosterols have been investigated as treatments for hypercholesterolemia and cardiovascular disease [92–94]. Importantly, a major lignan in wheat bran was identified to be secoisolariciresinol diglucoside (SDG), which is known to be converted into the mammalian lignans enterodiols and enterolactone by intestinal microflora [95, 96]. Wheat also contains lariciresinol diglucoside. These lignan metabolites function as antioxidants and free radical scavengers, leading to decreased risk of cancer development [95, 97] and hypocholesterolemic properties [98]. These compounds are predominantly concentrated in the outer layers of the grain (e.g., seed coat and pericarp), and in the aleurone layer; however, small concentrations can be found in the inner endosperm [99]. Compared to other cereal grains, wheat

Compound	Location in grain	Use	Extraction method	Market size (US dollars)
Alkylresorcinols	Outer membrane of wheat grain	Biochemical markers of whole grain diet	CSE, SFE, UAE [41–46]	—
Benzoxazinoids	Roots and leaves	Antiallergenic, anti-inflammatory, anticancer, and appetite-suppressing effects	ASE [47]	—
β-Glucan	Aleurone cell walls of wheat bran	Hypocholesterolemic properties	A/BH [48]	\$0.73B by 2025 [49]
Carotenoids	Germ, aleurone, and endosperm fractions	Antioxidant	CSE, SFE [50–53]	\$1.74B by 2025 [54]
Flavonoids	Germ	Anti-inflammatory	UAE, MAE, PLE, SFE [55]	\$1.06B by 2025 [56]
γ-Oryzanol	Wheat bran	Hypocholesterolemic properties	UAE, CSE [57]	\$2.0B by 2022 [58]
Lignans	Wheat bran	Antioxidant	A/BH, ED [59]	\$0.59B by 2027 [60]
Phenolic acids	Outer membrane of wheat grain	Anti-inflammatory	CSE, MAE, PLE, SPE, ED [61–66]	\$2.1B by 2025 [67]
Phytic acids	Outer membrane of wheat grain	Antioxidant	A/BH [68]	\$0.83B by 2028 [69] [*]
Phytosterols	Wheat bran and germ	Production of therapeutic steroids, nutrition, and cosmetics	ASE, A/BH [70, 71]	\$1.3B by 2027 [72]
Tocopherols/toocotrienols	Germ, pericarp, testa, and aleurone	Antioxidant	CSE, SFE [51–53, 73]	\$11.94B by 2025 [74]

Abbreviations: Conventional solvent extraction (CSE); microwave-assisted extraction (MAE); pressurized liquid extraction (PLE); solid-phase extraction (SPE); supercritical fluid extraction (SFE); ultrasonic-assisted extraction (UAE); enzymatic digest (ED); acid/base hydrolysis (A/BH).
^{*}Denotes market size for nutraceuticals.

Table 1.
Use, market size, and extraction methods for bioactive phytochemicals derived from wheat.

is not rich in lignans [100], although they can be a source of SDG. Approximately, 2 mg/g of secoisolariciresinol can be found in the common wheat germ, refined flour, and whole grain flour [99]. Overall, total lignan content in common wheat can range from 2 to 52 mg/g in the germ, refined flour, or whole grain flour [99].

Other value-added components include oil content in wheat bran (3–4%) and germ (7–9%) [101]. Due to the presence of antioxidant bioactive phytochemicals the health benefits of these oils have been investigated [101]. For example, wheat germ oil and wheat bran oil were found to contain high amounts of polyunsaturated fatty acids, as well as bioactive compounds tocopherols, carotenoids, and oryzanol like compounds (e.g., steryl ferulates) [101]. Wheat germ oil can be obtained via

mechanical pressing of separated wheat germ, whereas supercritical CO₂ extraction [102, 103], or solvent extraction [104] can be used to recover oil from both wheat germ and wheat bran. The content of bioactive compounds in these oils could be of sufficient quantity to mitigate cardiovascular disease, diabetes, cancer, and other diseases [101]. They have also been utilized in a range of medicinal (e.g., fish oil production), cosmetic (e.g., shampoo), insect control, vitamin, feed, and food products [104]. More recently, the utilization of wheat germ oil and wheat bran fiber have successfully been applied as a fat replacer in developing low-fat beef patties, resulting in better quality, stability, and reduced cholesterol content [105]. Since wheat germ is a by-product of wheat milling and contains extractable oil, isolation and purification of these oils can add significant value as a source of bioactive phytochemicals.

In general, the stability of wheat bioactive phytochemicals can be influenced by processing (milling, fermentative proofing, baking, enzymatic hydrolysis, extrusion, cooking, steaming, malting, etc.) [106] and storage conditions (temperature, light, pressure, time, etc.) [107]. For example, cooking of wheat grain can result in a 55% loss of tocopherol content [108], and increased temperatures and pressures can result the degradation of antioxidant pigments [109]. Therefore, depending on the wheat variety, food processing and milling methods can greatly affect the concentration and activity of wheat bioactive compounds [76, 110].

4. Wheat grain in biofuel production

Bioethanol can be produced using any sugar or starch-rich crop, and is an increasingly attractive fuel type as it reduces reliance on the limited supply of fossil fuels. Biofuels generated from renewable feedstocks can contribute to the reduction of greenhouse gases when compared to crude oil. Globally, the total production of ethanol is over 26 billion gallons in 2020 [111]. In Canada, wheat is the second most common feedstock used for bioethanol, and wheat fermentation is of interest for developing local and renewable energy supplies across many parts of Asia, Europe, and North America.

Ethanol production for biofuels is typically accomplished with a simplified process. Wheat entering the process is typically coarsely milled then rapidly heated with steam to destroy any microbial contamination and produce a thick mash. Sugars are released from the starch by an enzymatic process called saccharification. Initially, starch is treated with heat tolerant alpha-amylase that can function at temperatures as high as 95°C. Subsequently, glucoamylase is added to release more sugars. Other enzymes are optionally added to decompose pectins and hemicellulose. After saccharification, nutrients are added to accelerate the fermentation [112]. Fermentation using yeast (typically *Saccharomyces cerevisiae*) converts the sugar to ethanol, with many factors affecting the final ethanol yield [113]. After fermentation, the mixture, called beer, is transferred to a distillation system where ethanol is distilled from the beer [13]. Finally, the ethanol mixture is further purified through rectification and dehydration, resulting in a final ethanol concentration of 95% or higher [114].

A relatively recent improvement to the fermentation process, referred to as very high gravity (VHG) fermentation, involves the use of the highest possible concentration of sugar in the mash. Select yeasts strains have been identified that can tolerate both the high initial sugar concentration and high ethanol concentrations (>15%) [114, 115]. By fermenting high concentration solutions, considerable amounts of water can be saved, allowing plants to operate at higher capacity without the need

for additional space and equipment [116]. The yield of ethanol from wheat can be improved through selection of high starch and low protein cultivars [117].

During fermentation of wheat grain, additional value-added compounds are also produced including glycerol, succinic acid, acetic acid, lactic acid, and α -glycerylphosphorylcholine (e.g., a nootropic compound) [13, 118]. The nootropic compound α -GPC has been investigated as a treatment for Alzheimer's disease and strokes [119]. Production of α -GPC varies significantly with cultivar, and several cultivars have produced promising amounts of this substance when fermented [118, 120].

5. Wheat straw/waste in biofuel production

Despite the potential positives of bioethanol as a replacement for fossil fuels, there have been many criticisms of the use of food sources for bioethanol production. A major concern is that using crops in large-scale production of bioethanol will divert food to the energy sector. It is feared that this competition will increase food prices and contribute to the scarcity of available products as the world population grows [121, 122]. As production of biofuel expands, the materials used must be based on non-food sources such as byproducts, waste, or agricultural losses to remain economically viable and sustainable. Most wheat produced is used for human consumption; it is grown in over 120 countries, and accounts for approximately 1/5 the world's caloric needs [123]. To avoid competing with food crops for agricultural land, bioethanol can instead be produced using less nutrient-rich parts of the crop, such as the straw.

Wheat straw is one of the most abundant agricultural byproducts and is of low commercial value. Straw is primarily used for cattle feed, disposed of, or even burned as waste. On average, 1 kg of straw is collected for every 1.3 kg of grain [124], and this straw can be used as a feedstock for producing bioethanol. Pre-treatment of lignocellulosic products such as wheat straw is required prior to fermentation and is performed using hydrolysis to make cellulose more conducive to enzyme action [125]. Commonly, steam explosion is used as a pre-treatment method and combined with an acid catalyst in wheat straw bioethanol production [124, 126–128]. Other studies have demonstrated success in using H_2SO_4 prior to steam treatment to improve sugar, and therefore ethanol, yields [129]. Production of biofuels from cellulose-rich materials is generally more complex and requires new technologies, but the prices of raw materials such as wheat straw are significantly less and act as an incentive for the biofuel industry to pursue lignocellulosic resources. Currently, the overall production of bioethanol from grain is less costly than from wheat straw [130], however, as the technology develops and government restrictions on greenhouse emissions increase, the use of cellulose-rich materials in bioethanol production is likely to grow significantly.

Biofuel production also provides an opportunity to reclaim damaged and spoiled crops [131]. Damaged grains (e.g., discoloration, breakage, cracking, fungi infection, insect damage, chalky grain) used for ethanol production can reduce feedstock costs by a factor of 10 when compared to grains of higher quality [131]. Alcoholic fermentations of wheat damaged from some of these materials, such as *Fusarium* fungal infections, can produce stillage/wet grains that are unsuitable to use as feed for cattle due to the presence of mycotoxins [132], however, these byproducts need not go to waste. Fermented *Fusarium* infected wheat can be fed to black soldier fly larvae which are able to degrade the toxins, allowing the wheat's nutrients to be recovered [133, 134]. The larvae can then be dried and sold as a highly nutritional and protein-rich feed ingredient.

6. Adding value to fermented wheat byproducts

Alcoholic fermentation of wheat depletes available simple sugars and starches, as these are used for the yeast to grow and produce ethanol. However, after the ethanol is distilled from the beer, the remaining stillage contains protein, oils, fiber, and non-starch carbohydrates. These residual nutrients can also add significant value to fermented wheat through a variety of different processing options. Most commonly, whole stillage is separated into thin stillage (liquid containing suspended solids) and distillers' wet grains (wet solid portions) using physical processing techniques such as screening and centrifugation [135]. The thin stillage can then be dewatered and heated, resulting in a condensed syrup known as distillers' soluble. By mixing the syrup with wet grains as they dry, a nutritional cattle feed referred to as distillers' dry grains with soluble (DDGS) is produced [136].

Compared to unprocessed stillage/wet grains, DDGS has a much greater shelf life and is more readily transported [137]. The DDGS also contains a higher concentration of protein (~38%) than unfermented wheat [19], and the sale of cattle feed typically provides 10–20% of an ethanol producer's revenue [137]. Fermented wheat can also be further enhanced as a feed product through various protein concentration methods [18], including secondary fermentation using lactic acid bacteria. Secondary fermentation can result in an increase in higher value compounds such as 1,3-propanediol, and a feed with up to 60% protein [138] and greater probiotic content [139].

Alternatively, protein from DDGS can be solubilized and extracted to allow amino acids to be removed individually [19]. By leaving essential amino acids in the DDGS, the product can retain value as an animal feed, while allowing valuable non-essential amino acids to be extracted. The extracted amino acids can include aspartic acid, glutamine, glycine, L-arginine, L-lysine, L-phenylalanine, proline, and serine [19]. These non-essential amino acids can have further value added through various chemical transformations, such as aspartic acid into acrylamide [140].

Protein can also be concentrated by the removal of other substances, such as fiber, from the fermented wheat products. Fiber can be removed via aspiration of DDGS coming from dry-grind ethanol facilities [141]. This can allow the fiber-rich fraction to be valorized through the extraction of phytosterols, which are concentrated in the fraction. The reduced fiber content of the remaining fraction results in higher protein and fat content, improving its value as a feed [142]. DDGS can also be fractionated into high protein and high fiber fractions through sieving [143]. By using a combination of both air classification (winnowing) and sieving, a fiber fraction of around 50% reduced protein, and a fraction with an additional 30% protein can be produced, compared to the whole DDGS [117]. Oil is another component of wheat that is still present after fermentation. Although there are patented techniques for extracting oil from corn DDGS and thin stillage [144, 145], the lower oil content of wheat and other grains has resulted in oil extraction techniques remaining largely undeveloped for fermented wheat products.

7. Conclusion

Wheat is one of the largest grain crops produced in the world, second only to corn, with United States and Canada being the two largest exporters of wheat globally.

Typically, the end products of wheat are used as food sources for either human or animal consumption, however, the production of biofuel using feedstocks such as wheat is steadily expanding. The fractionation and appropriate selection of harvested wheat crops is crucial to increase economic value; wheat varieties can be tailored for specific applications, such as biofuel production, or the extraction of bio-active phytochemicals. Furthermore, the stability, quality, and concentration of bioactive compounds can be affected by the processing and storage conditions of wheat, which contribute to the value of these products in cosmetics or antioxidant and anti-inflammatory supplements. Typically, biofuel production uses wheat grain with high starch content to create efficient and productive fermentations. This type of biofuel production is under increasing criticism for the diversion valuable food sources and agriculturally productive land. By using grain production by-products such as wheat straw, or damaged grained crops, ethanol production can be accomplished with reduced greenhouse gas emissions and less expensive, renewable feedstocks. Lignocellulosic by-products can add significant value to wheat through fermentation and will be of growing interest with increasing societal and economic pressures to reduce dependency on petroleum. Even after fermentation, the remaining stillage can be used as high protein feed, and have valuable products diverted to industrial streams. Overall, these processes can substantially enhance the value of wheat and reduce agricultural waste. The future will likely lead to new techniques and further improvements in wheat processing.

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Conflict of interest

Dr. Martin J.T. Reaney is the founder of, and has an equity interest in, Prairie Tide Diversified Inc. (PTD, Saskatoon, SK, Canada: previous company name is Prairie Tide Chemicals Inc.).

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References

- [1] Statista. Worldwide Production of Grain in 2020/21, by Type [Internet]. 2021. Available from: <https://www.statista.com/statistics/263977/world-grain-production-by-type/> [Accessed: December 21, 2021]
- [2] Sosland Publishing. USDA Forecasts Records for World Wheat Production, Use and Trade [Internet]. 2021. Available from: <https://www.world-grain.com/articles/15837-usda-forecasts-records-for-world-wheat-production-use-and-trade> [Accessed: October 15, 2021]
- [3] Talebnia F, Karakashev D, Angelidaki T. Production of bioethanol from wheat straw: An overview on pretreatment, hydrolysis and fermentation. *Bioresource Technology*. 2010;**101**:4744–4753. DOI: 10.1016/j.biortech.2009.11.080
- [4] Canada Grain Commission. Canadian Wheat Classes [Internet]. 2019. Available from: <https://grainscanada.gc.ca/en/grain-quality/grain-grading/wheat-classes.html> [Accessed: October 17, 2021]
- [5] Bradford H, Hayes P. Canada Biofuels Annual 2019: GAIN Report Number: CA19017. 2019. USDA Foreign Agricultural Service. 2019
- [6] Kilcher MR. Effect of cattle grazing on subsequent grain yield of fall rye (*Secale cereale* L.) in southwestern Saskatchewan. *Canadian Journal of Plant Science*. 1982;**62**:795–796
- [7] Virgona JM, Gummer FAJ, Angus JF. Effects of grazing on wheat growth, yield, development, water use, and nitrogen use. *Australian Journal of Agricultural Research*. 2006;**57**(12). DOI: 10.1071/AR06085
- [8] Bureau of the Census. Census of Manufacturers: Grain Mill Products. Washington, DC: U.S. Department of Commerce; 1992
- [9] Lou J, Wilson W. Value-Added Wheat Products: Analysis of Markets and Competition. Agricultural Economics Report No. 386. Fargo, ND: North Dakota State University; 1998
- [10] Wood L. Global Wheat Starch Market Report 2018-2024: Key Growth Drivers, Market Trends and Key Players—Market to Exceed \$4 Billion—ResearchAndMarkets.com [Internet]. 2018. Available from: <https://www.businesswire.com/news/home/20180321005489/en/Global-Wheat-Starch-Market-Report-2018-2024-Key-Growth-Drivers-Market-Trends-and-Key-Players--Market-to-Exceed-4-Billion---ResearchAndMarkets.com> [Accessed: December 02, 2021]
- [11] Uthayakumaran S, Wrigley C. Chapter 5 - Wheat: Grain-quality characteristics and management of quality requirements. In: Wrigley C, Batey I, Miskelly D, editors. *Cereal Grains*. 2nd ed. Cambridge, MA, USA: Woodhead Publishing; 2017. pp. 91-134. DOI: 10.1016/b978-0-08-100719-8.00005-x
- [12] Saunders J, Izydorczyk M, Levin DB. Limitations and challenges for wheat-based bioethanol production. In: *Economic Effects of Biofuel Production*. 1st ed. London, UK: IntechOpen; 2011. pp. 429-452. DOI: 10.5772/20258
- [13] Tse TJ, Wiens DJ, Chicilo F, Purdy SK, Reaney MJT. Value-added compounds from ethanol fermentations—A review. *Fermentation*. 2021;**7**:267. DOI: 10.3390/fermentation7040267

- [14] Elbashiry EMA, Chen J, Tuo W, Ren Y, Guo Z. Review of the pretreatment methods for wheat straw building materials. *Journal of Reinforced Plastics & Composites*. 2018;37(1):35-48. DOI: 10.1177/0731684417730442
- [15] Moir J, Letts, J. Thatch: Thatching in England 1790-1940. *English Heritage Research Transactions* 5; Earthscan Publications Ltd.; 1999. p. 228
- [16] Glithero NJ, Wilson P, Ramsden SJ. Straw use and availability for second generation biofuels in England. *Biomass Bioenergy*. 2013;55:311-321. DOI: 10.1016/j.biombioe.2013.02.033
- [17] Qureshi N, Saha BC, Cotta MA, Singh V. An economic evaluation of biological conversion of wheat straw to butanol: A biofuel. *Energy Conversion and Management*. 2013;65:456-462. DOI: 10.1016/j.enconman.2012.0.015
- [18] Ratanapariyanuch K, Shim YY, Wiens DJ, Reaney MJT. Grain thin stillage protein utilization: A review. *Journal of the American Oil Chemists' Society*. 2018;95:933-942. DOI: 10.1002/aocs.12056
- [19] Villegas-Torres MF, Ward JM, Lye GJ. The protein fraction from wheat-based dried distiller's grain with solubles (DDGS): Extraction and valorization. *New Biotechnology*. 2015;32(6):606-611
- [20] Shewry PR, Hawkesford MJ, Piironen V, Lampi A-M, Gebruers K, Boros D, et al. Natural variation in grain composition of wheat and related cereals. *Journal of Agricultural and Food Chemistry*. 2013;61:8295-8303. DOI: 10.1021/jf3054092
- [21] Health Canada. Novel food Information—Wheat Bran Extract as a Novel Food Ingredient. [Internet]. 2015. Available from: <https://www.canada.ca/en/health-canada/services/food-nutrition/genetically-modified-foods-other-novel-foods/approved-products/wheat-bran-extract-food-ingredient.html> [Accessed: November 24, 2021]
- [22] Hemery Y, Chaurand M, Holopainen U, Lampi A-M, Lehtinen P, Piironen V, et al. Potential of dry fractionation of wheat bran for the development of food ingredients, part I: Influence of ultra-fine grinding. *Journal of Cereal Science*. 2011;53:1-8
- [23] Laddomada B, Caretto S, Mita G. Wheat bran phenolic acids: Bioavailability and stability in whole wheat-based foods. *Molecules*. 2015;20:15666-15685. DOI: 10.3390/molecules200915666
- [24] Ciudad-Mulero M, Barros L, Fernandes Â, Ferreira ICFR, Callejo MJ, Matallana-González MC, et al. Potential health claims of durum and bread wheat flours as functional ingredients. *Nutrients*. 2020;12:504. DOI: 10.3390/nu12020504
- [25] Delcour JA, Rouau X, Courtin CM, Poutanen K, Ranieri R. Technologies for enhanced exploitation of the health-promoting potential of cereals. *Trends in Food Science & Technology*. 2012;25:78-86. DOI: 10.1016/j.tifs.2012.01.007
- [26] Esposito F, Arlotti G, Bonifati AM, Napolitano A, Vitale D, Fogliano V. Antioxidant activity and dietary fibre in durum wheat bran by-products. *Food Research International*. 2005;38:1167-1173. DOI: 10.1016/j.foodres.2005.05.002
- [27] Mareo Anson NM, van der Berg R, Havenaar R, Bast A, Haenen G. Ferulic acid from aleurone determines the antioxidant potency of wheat grain (*Triticum aestivum* L.). *Journal of Agricultural and Food Chemistry*. 2008;56:5589-5594. DOI: 10.1021/jf800445k

- [28] Zhou K, Su L, Yu L. Phytochemicals and antioxidant properties in wheat bran. *Journal of Agricultural and Food Chemistry*. 2004;**52**:6108-6114. DOI: 10.1021/jf049214g
- [29] Toepfer EW, Polansky MM, Eheart JF, Slover HT, Hepburn FN, Quackenbush FW. Nutrient composition of selected wheats and wheat products XI Summary. *Cereal Chemistry*. 1972;**49**:173-186
- [30] Shewry PR, Hey SJ. The contribution of wheat to human diet and health. *Food and Energy Security*. 2015;**4**:178-202. DOI: 10.1002/fes3.64
- [31] Taccari M, Aquilanti L, Polverigiani S, Osimani A, Garofalo C, Milanovic V, et al. Microbial diversity of type I sourdoughs prepared and Back-slopped with Wholemeal and refined soft (*Triticum aestivum*) wheat flours. *Journal of Food Science*. 2016;**81**:1996-2005. DOI: 10.1111/1750-3841.13372
- [32] Godfrey D, Hawkesford MJ, Powers SJ, Millar S, Shewry PR. Effects of crop nutrition on wheat grain composition and end use quality. *Journal of Agricultural and Food Chemistry*. 2010;**58**:3012-3021. DOI: 10.1021/jf9040645
- [33] Vogel KP, Johnson VA, Mattern PJ. Protein and lysine content of grain, endosperm, and brand of wheats from USDA world wheat collection. *Crop Science*. 1976;**16**:655-660. DOI: 10.2135/cropsci1976.0011183X001600050014x
- [34] Jensen SA, Martens H. The botanical constituents of wheat and wheat milling fractions. II. Quantification by amino acids. *Cereal Chemistry*. 1983;**60**:170-177
- [35] Saito S, Oishi S, Shudo A, Sugiura Y, Yasunaga K. Glucose response during the night is suppressed by wheat albumin in healthy participants: A randomized controlled trial. *Nutrients*. 2019;**11**(187):1-9. DOI: 10.3390/nu11010187
- [36] Zhang LL, Guan EQ, Yang YL, Liu YX, Zhang TJ, Bian K. Impact of wheat globulin addition on dough rheological properties and quality of cooked noodles. *Food Chemistry* 2021;**362**:130-170. DOI: 10.1016/j.foodchem.2021.130170
- [37] Tedrus G de AS, Ormenese R de CSC, Speranza SM, Chang YK, Bustos FM. Estudo da adição de vital gluten à farinha de arroz, farinha de aveia e amido de trigo na qualidade de pães. *Ciência e Tecnologia de Alimentos*. 2001;**21**:20-25. DOI: 10.1590/s0101-20612001000100006
- [38] Ortolan F, Steel CJ. Protein characteristics that affect the quality of vital wheat gluten to be used in baking: A review. *Comprehensive Reviews in Food Science and Food Safety*. 2017;**16**(3):369-381. DOI: 10.1111/1541-4337.12259
- [39] Gómez-Heincke D, Martínez I, Partal P, Guerrero A, Gallegos C. Development of antimicrobial active packaging materials based on gluten proteins. *Journal of the Science of Food and Agriculture*. 2016;**96**(10):3432-3438. DOI: 10.1002/jsfa.7525
- [40] Bibi F, Guillaume C, Gontard N, Sorli B. Wheat gluten, a bio-polymer to monitor carbon dioxide in food packaging: Electric and dielectric characterization. *Sensors & Actuators, B: Chemical*. 2017;**250**:76-84. DOI: 10.1016/j.snb.2017.03.164
- [41] Christian HG, Anna EM, Reinhold C, Ralf MS. Development and validation of an HPLC method for the determination of alk(en)ylresorcinols using rapid ultrasound-assisted extraction of mango peels and rye grains. *Food Chemistry*.

2015;**169**:261-269. DOI: 10.1002/9781119207917.ch21

[42] Gunenc A, Hadinezhad M, Tamburic-Ilincic L, Mayer PM, Hossenian F. Effects of region and cultivar on alkylresorcinols content and composition in wheat bran and their antioxidant activity. *Journal of Cereal Science*. 2013;**57**:405-410. DOI: 10.1016/j.jcs.2013.01.003

[43] Holt MD, Moreau RA, DerMarderosian A, McKeown N, Jacques PF. Accelerated solvent extraction of alkylresorcinols in food products containing uncooked and cooked wheat. *Journal of Agricultural and Food Chemistry*. 2012;**60**:4799-4802. DOI: 10.1021/jf3001422

[44] Landberg R, Dey ES, Francisco JDC, Aman P, Kamal-Eldin A. Comparison of supercritical carbon dioxide and ethyl acetate extraction of alkylresorcinols from wheat and rye. *Journal of Food Composition and Analysis*. 2007;**20**:534-538. DOI: 10.1016/j.jfca.2007.02.009

[45] Rebolleda S, Beltrán S, Sanz MT, González-Sanjosé ML, Solaesa ÁG. Extraction of alkylresorcinols from wheat bran with supercritical CO₂. *Journal of Food Engineering*. 2013;**119**:814-821. DOI: 10.1016/j.jfoodeng.2013.07.008

[46] Sampietro DA, Jimenez CM, Belizán MM, Vattuone MA, Catalán CA. Development and validation of a micromethod for fast quantification of 5-n-alkylresorcinols in grains and whole grain products. *Food Chemistry*. 2013;**141**:3546-3551. DOI: 10.1016/j.foodchem.2013.06.069

[47] Pedersen H, Laursen B, Mortensen A, Fomsgaard I. Bread from common cereal cultivars contains an important array

of neglected bioactive benzoxazinoids. *Food Chemistry*. 2011;**127**:1814-1820. DOI: 10.1016/j.foodchem.2011.02.070

[48] Maheshwari G, Sowrirajan S, Joseph B. Extraction and isolation of β -glucan from grain sources—A review. *Journal of Food Science*. 2017;**82**:1535-1545. DOI: 10.1111/1750-3841.13765

[49] Grand View Research. Beta-glucan Market Size, Share & Trends Analysis Report by Source (Cereal, Mushroom, Yeasts, Seaweed), by Application (F&B, Personal Care, Pharmaceuticals, Animal Feed), By Type, By Region, and Segment Forecasts, 2018-2025. San Francisco, CA, USA: Grand View Research; 2017

[50] Durante M, Lenucci MS, Laddomada B, Mita G, Caretto S. Effects of sodium alginate bead encapsulation on the storage of durum wheat (*Triticum durum* Desf.) bran oil extracted by supercritical CO₂. *Journal of Agricultural and Food Chemistry*. 2012;**60**:10689-10695. DOI: 10.1021/jf303162m

[51] Ge Y, Ni Y, Yan H, Chen Y, Cai T. Optimization of the supercritical fluid extraction of natural vitamin E from wheat germ using response surface methodology. *Journal of Food Science*. 2002;**67**:239-243. DOI: 10.1111/j.1365-2621.2002.tb11391.x

[52] Gelmez N, Kincal NS, Yener ME. Optimization of supercritical carbon dioxide extraction of antioxidants from roasted wheat germ based on yield, phenolic and tocopherol contents, and antioxidant activities of the extracts. *Journal of Supercritical Fluids*. 2009;**48**:217-224. DOI: 10.1016/j.supflu.2008.11.002

[53] Hidalgo A, Brandolini C, Pompei C, Piscozzi R. Carotenoids and tocopherols of einkorn wheat (*Triticum monococcum* ssp. *monococcum* L.). *Journal of Cereal*

Science. 2006;**44**:182-193. DOI: 10.1016/j.jcs.2006.06.002

[54] Grand View Research. Carotenoids Market Size, Share & Trends Analysis Report by Source (Natural, Synthetic), by Product (Beta-Carotene, Lutein, Lycopene, Astaxanthin, Zeaxanthin, Canthaxanthin), by Application, and Segment Forecasts, 2018-2025. San Francisco, CA, USA: Grand View Research; 2016

[55] Chaves JA, de Souza MC, da Silva LC, Lachos-Perez D, Torres-Mayanga PC, da Fonseca Machado AP, et al. Extraction of flavonoids from natural sources using modern techniques. *Frontiers in Chemistry*. 2020;**8**:507887. DOI: 10.3389/fchem.2020.507887

[56] Grand View Research. Flavonoids Market Size, Share & Trends Analysis Report by Product (Anthocyanins, Flavones, Anthoxanthins), by Application, By Region, and Segment Forecasts, 2018-2025. San Francisco, CA, USA: Grand View Research; 2016

[57] Loypimai P, Moongngarm A, Sittisuanjik A, Khamanan S. Optimization of tocots and γ -oryzanol extraction from rice bran using ultrasound and soybean oil as a green solvent. *Food Research*. 2020;**4**:2322-2332. DOI: 10.26656/fr.2017.4(6).360

[58] Grand View Research. Gamma Oryzanol Market Size, Share & Trends Analysis Report by Application (Sports Supplement, Cosmetics, Pharmaceuticals, Animal Feed), and Segment Forecasts to 2022. San Francisco, CA, USA: Grand View Research; 2016

[59] Cukelj N, Jakasa I, Sarajlija H, Novotni D, Curic D. Identification and quantification of lignans in wheat bran by gas chromatography-electron capture detection. *Talanta*. 2011;**84**:127-132. DOI: 10.1016/j.talanta.2010.12.025

[60] Grand View Research. Lignans Market Size, Share & Trends Analysis Report by Source (Plant Resins, Cereals & Grains), by Application (Food & Beverages, Animal Nutrition), By Region (APAC, North America) and Segment Forecasts, 2020-2027. San Francisco, CA, USA: Grand View Research; 2020

[61] Angioloni A, Collar C. Effects of pressure treatment of hydrated oat finger millet and sorghum flours on the quality and nutritional properties of composite wheat breads. *Journal of Cereal Science*. 2012;**56**:713-719. DOI: 10.1016/j.jcs.2012.08.001

[62] Buranov A, Mazza G. Extraction and purification of ferulic acid from flax shives, wheat and corn bran by alkaline hydrolysis and pressurized solvents. *Food Chemistry*. 2009;**115**:1542-1548. DOI: 10.1016/j.foodchem.2009.01.059

[63] Hromadkova Z, Kostalova Z, Ebringerova A. Comparison of conventional and ultrasound-assisted extraction of phenolics-rich heteroxylans from wheat bran. *Ultrasonics Sonochemistry*. 2008;**15**:1062-1068. DOI: 10.1016/j.ultsonch.2008.04.008

[64] Inglett GE, Rose D, Stevenson DG, Chen D, Biswas A. Total phenolics and antioxidant activity of water and ethanolic extracts from distillers dried grains with soluble with or without microwave irradiation. *Cereal Chemistry*. 2009;**86**:661-664. DOI: 10.1094/CCHEM-86-6-0661

[65] Irakli MN, Samanidou VF, Biliaderis CG, Papadoyannis IN. Development and validation of an HPLC-method for determination of free and bound phenolic acids in cereals after solid-phase extraction. *Food Chemistry*. 2012;**134**:1624-1632. DOI: 10.1016/j.foodchem.2012.03.046

- [66] Meneses N, Martins S, Teixeira JA, Mussatto SI. Influence of extraction solvents on the recovery of antioxidant phenolic compounds from brewer's spent grains. *Separation and Purification Technology*. 2013;**108**:152-158. DOI: 10.1016/j.seppur.2013.02.015
- [67] Grand View Research. Polyphenols Market Size, Share & Trends Analysis Report by Product (Grape Seed, Green Tea, Cocoa), by Application (Beverages, Food, Feed, Dietary Supplements, Cosmetics), and Segment Forecasts, 2019-2025. San Francisco, CA, USA: Grand View Research; 2019
- [68] Ebrahimian M, Motamedi H. Utilization of wheat bran as a source for phytic acid production. *International Food Research Journal*. 2016; **23**:2436-2439
- [69] Grand View Research. Nutraceuticals Market Size, Share & Trends Analysis Report by Product (Dietary Supplements, Functional Food, Functional Beverages), by Region, and Segment Forecasts, 2020-2028. San Francisco, CA, USA: Grand View Research; 2021
- [70] Dunford NT, Irmak S, Jonnala R. Effect of the solvent type and temperature on phytosterol contents and compositions of wheat straw, bran, and germ extracts. *Journal of Agricultural and Food Chemistry*. 2009;**57**:10608-10611. DOI: 10.1021/jf9022383
- [71] Nurmi T, Nyström L, Edelman M, Lampi AM, Pirronen V. Phytosterols in wheat genotypes in the HEALTHGRAIN diversity screen. *Journal of Agricultural and Food Chemistry*. 2008;**56**:9710-9715. DOI: 10.1021/jf8010678
- [72] Grand View Research. Phytosterols Market Size, Share & Trends Analysis Report by Product (Beta-sitosterol, Campesterol, Stigmasterol), by Application (Pharmaceuticals, Cosmetics, Food Ingredients), By Region, and Segment Forecasts, 2020-2027. San Francisco, CA, USA: Grand View Research; 2020
- [73] Ge Y, Yan H, Hui B, Ni Y, Wang S, Cai T. Extraction of natural vitamin E from wheat germ by supercritical carbon dioxide. *Journal of Agricultural and Food Chemistry*. 2002;**50**:685-689. DOI: 10.1021/jf010615v
- [74] Grand View Research. Mixed Tocopherols Market Size, Share & Trends Analysis Report by Product (Alpha Rich, Gamma Rich, Gamma-Delta Rich), by Application (Dietary Supplements, Cosmetics, Pharmaceuticals), and Segment Forecasts, 2018-2025. San Francisco, CA, USA: Grand View Research; 2017
- [75] Gani A, Wani SM, Masoodi FA, Hameed G. Whole-grain cereal bioactive compounds and their health benefits: A review. *Journal of Food Processing & Technology*. 2012;**3**:146. DOI: 10.4172/2157-7110.1000146
- [76] Luthria DL, Lu Y, Maria John KM. Bioactive phytochemicals in wheat: Extraction, analysis, processing, and functional properties. *Journal of Functional Foods*. 2015;**18**:910-925. DOI: 10.1016/j.jff.2015.01.001
- [77] Lu Y, Fuerst PE, Lv J, Morris CF, Yu L, Fletcher A, et al. Phytochemical profile and antiproliferative activity of dough and bread fractions made from refined and whole wheat flours. *Cereal Chemistry*. 2015;**92**:271-277. DOI: 10.1094/cchem-10-14-0214-R
- [78] Yin ZN, Wu WJ, Sun CZ, Liu HF, Chen WB, Zhan QP, et al. Antioxidant and anti-inflammatory capacity of ferulic acid released from wheat bran by

- solid-state fermentation of *Aspergillus niger*. Biomedical and Environmental Sciences. 2019;32:11-21. DOI: 10.3967/bes2019.002
- [79] Rosa NN, Barron C, Gaiani C, DuFour C, Micard V. Ultra-fine grinding increases the antioxidant capacity of wheat bran. Journal of Cereal Science. 2013;57:84-90. DOI: 10.1016/j.jcs.2012.10.002
- [80] Masisi K, Diehl-Jones WL, Gordon J, Chapman D, Moghadasian MH, Beta T. Carotenoids of aleurone, germ, and endosperm fractions of barley, corn and wheat differentially inhibit oxidative stress. Journal of Agricultural and Food Chemistry. 2015;63:2715-2724. DOI: 10.1021/jf5058606
- [81] Abdel-Aal E-SM, Young JC, Rabalski I, Hucl P, Fregeau-Reid J. Identification and quantification of seed carotenoids in selected wheat species. Journal of Agricultural and Food Chemistry. 2007;55:787-794. DOI: 10.1021/jf062764p
- [82] Giordano D, Locatelli M, Travaglia F, Bordiga M, Reyneri A, Coisson JD, et al. Bioactive compound and antioxidant activity distribution in roller-milled and pearled fractions of conventional and pigmented wheat varieties. Food Chemistry. 2017;233:483-491. DOI: 10.1016/j.foodchem.2017.04.065
- [83] Siebenhandl S, Grausgruber H, Pellegrini N, Del Rio D, Fogliano V, Pernice R, et al. Phytochemical profile of main antioxidants in different fractions of purple and blue wheat, and black barley. Journal of Agricultural and Food Chemistry. 2007;55:8541-8547. DOI: 10.1021/jf072021j
- [84] Kruger JE, Reed G. Enzymes and color. In: Pomeranz Y editor. Wheat: Chemistry and Technology. 3rd ed. St. Paul, MN: AACC International; 1988. pp. 411-500
- [85] Beta T, Duodu K. Bioactives: Antioxidants. In: Wrigley C, Corke H, Seetharaman K, Faubion J. editors. Encyclopedia of Food Grains. Vol. 2. Oxford, UK: Elsevier; 2016. pp. 277-282
- [86] Bramley PM, Elmadfa I, Kafatos A, Kelly FJ, Manios Y, Roxborough HE, et al. Vitamin E. Journal of the Science of Food and Agriculture. 2000;80:913-938. DOI: 10.1002/(SICI)1097-0010(20000515)80:7<913::AID-JSFA600>3.0.CO;2-3
- [87] Bock MA. Minor constituents of cereals. In: Kulp K, Ponte JGJ. editors. Handbook of Cereal Science and Technology. 2nd ed. New York: Marcel Dekker; 2000. pp. 479-504
- [88] Chung OK, Ohm J. Cereal lipids. In: Kulp K, Ponte JGJ. editors. Handbook of Cereal Science and Technology. 2nd ed. New York: Marcel Dekker; 2000. pp. 417-477
- [89] Chung OK, Ohm J, Ram MS, Park S-H, Howitt C. Wheat Lipids. In: Khan K, Shewry PR, editors. Wheat: Chemistry and Technology. 4th Ed. Saint Paul, MN, USA: American Association of Cereal Chemists Inc.; 2009. pp. 363-399
- [90] Lee GA, Han SN. The role of vitamin E in immunity. Nutrients. 2018;11:1614. DOI: 10.3390/nu10111614
- [91] Lewis ED, Meydani SN, Wu D. Regulatory role of vitamin E in the immune system and inflammation. IUBMB Life. 2019;71:487-494. DOI: 10.1002/iub.1976
- [92] Higuchi M. Antioxidant properties of wheat bran against oxidative stress. In: Preedy VR, Zibadi S, editors. Wheat and Rice in Disease Prevention and Health. San Diego, USA: Academic Press; 2014. pp. 181-199

- [93] Quílez J, García-Lorda P, Salas-Salvadó J. Potential uses and benefits of phytosterols in diet: Present situation and future directions. *Clinical Nutrition*. 2003;**22**:343-351. DOI: 10.1016/s0261-5614(03)00060-8
- [94] Sima P, Vannucci L, Vetvicka V. β -Glucans and cholesterol (review). *International Journal of Molecular Medicine*. 2018;**4**:1799-1808. DOI: 10.3892/ijmm.2018.3411
- [95] Qu H, Madl RL, Takemoto DJ, Baybutt RC, Wang W. Lignans are involved in the antitumor activity of wheat bran in colon cancer SW480 cells. *The Journal of Nutrition*. 2005;**135**:598-602. DOI: 10.1093/jn/135.3.598
- [96] Yang X, Guo Y, Tse TJ, Purdy SK, Mustafa R, Shen J, et al. Oral pharmacokinetics of enriched secoisolariciresinol diglucoside and its polymer in rats. *Journal of Natural Products*. 2021;**84**:1816-1822. DOI: 10.1021/acs.jnatprod.1c00335
- [97] Davies MJ, Bowey EA, Adlercreutz H, Rowland IR, Rumsby PC. Effects of soy or rye supplementation of high-fat diets on colon tumor development in azoxymethane-treated rats. *Carcinogenesis*. 1999;**20**:927-931. DOI: 10.1093/carcin/20.6.927
- [98] Guo Y, Yang X, Tse TJ, Purdy SK, Mustafa R, Shen J, et al. Hypocholesterolemic efficacy of secoisolariciresinol diglucoside and its polymer in rat. *Journal of Natural Products*. 2021;**84**:2845-2850. DOI: 10.1021/acs.jnatprod.1c00549
- [99] Rodríguez-García C, Sánchez-Quesada C, Toledo E, Delgado-Rodríguez M, Gaforio JJ. Naturally lignan-rich foods: A dietary tool for health promotion. *Molecules*. 2019;**24**:917. DOI: 10.3390/molecules24050917
- [100] Landette JM. Mammalian lignans: A review of source, intake, metabolism, intestinal bacteria, health. *Food Research International*. 2012;**46**:410-424. DOI: 10.1016/j.foodres.2011.12.023
- [101] Kumar GS, Krishna AGG. Studies on the nutraceuticals composition of wheat derived oils wheat bran oil and wheat germ oil. *Journal of Food Science and Technology*. 2015;**52**:1145-1151. DOI: 10.1007/s13197-013-1119-3
- [102] Piras A, Rosa A, Falconieri D, Procedda S, Dessi MA, Marongju B. Extraction of oil from wheat germ by supercritical CO₂. *Molecules*. 2009;**14**:2573-2581. DOI: 10.3390/molecules14072573
- [103] Zacchi P, Daghero J, Jaeger P, Eggers R. Extraction/fractionation and deacidification of wheat germ oil using supercritical carbon dioxide. *Brazilian Journal of Chemical Engineering*. 2006;**23**:105-110
- [104] Ghafoor K, Özcan MM, AL-Juhaimi F, Babiker EE, Sarker ZI, Ahmed IAM, Ahmed MA. Nutritional composition, extraction, and utilization of wheat germ oil: A review. *European Journal of Lipid Science and Technology*. 2017;**119**:1600160. DOI: 10.1002/ejlt.201600160
- [105] Khalid A, Sohaib M, Nadeem MT, Saeed F, Imran A, Imran M, et al. Utilization of wheat germ oil and wheat bran fiber as fat replacer for the development of low-fat beef patties. *Food Science & Nutrition*. 2021;**9**:1271-1281. DOI: 10.1002/fsn3.1988
- [106] Batifoulier F, Verny M-A, Chanliaud E, Remesy C, Demigne C. Effect of different breadmaking methods on thiamine, riboflavin and pyridoxine contents of wheat bread. *Journal of Cereal Science*. 2005;**42**:101-108

- [107] Reddy MB, Love M. The impact of food processing on the nutritional quality of vitamins and minerals. *Advances in Experimental Medicine and Biology*. 1999;**459**:99-106
- [108] Wyatt CJ, Perez Carballido S, Mendez RO. α - and γ - tocopherol content of selected foods in the Mexican diet: Effect of cooking losses. *Journal of Agricultural and Food Chemistry*. 1998;**46**:4657-4661. DOI: 10.1021/jf9800716
- [109] Hashemi SMB, Pourmohammadi K, Gholamhosseinpour A, Es I, Ferreira DS, Mousavi Khaneghah A. Fat-soluble vitamins. In: Barba FJ, Saraiva JMA, Cravotto G, Lorenzo JM, editors. *Innovative Thermal and Non-Thermal Processing, Bioaccessibility and Bioavailability of Nutrients and Bioactive Compounds*. Cambridge, MA, USA: Woodhead Publishing; 2019. pp. 267-289. DOI: 10.1016/b978-0-12-814174-8.00009-3
- [110] Li Y, Ma D, Sun D, Wang C, Zhang J, Xie Y, et al. Total phenolic, flavonoid content, and antioxidant activity of flour, noodles, and steamed bread made from different colored wheat grains by three milling methods. *Crop Journal*. 2015;**3**:328-334. DOI: 10.1016/j.cj.2015.04.004
- [111] Annual Ethanol Production: U.S. and World Ethanol Production. Renewable Fuels Association. Available from: <https://ethanolrfa.org/markets-and-statistics/annual-ethanol-production> [Accessed: November, 2021]
- [112] Patni N, Pillai S, Dwivedi A. Wheat as a promising substitute of corn for bioethanol production. *Procedia Engineering*. 2013;**51**:355-362
- [113] Tse TJ, Wiens DJ, Reaney MJT. Biofuel production—A review of factor affecting ethanol yield. *Fermentation*. 2021;**7**:268. DOI: 10.3390/fermentation7040268
- [114] Swain M, Mohanty S. Bioethanol production from corn and wheat: food, fuel, and future. In: Ramesh CR, Ramachandran S, editors. *Bioethanol Production from Food Crops*. San Diego, USA: Academic Press; 2019. pp. 45-49. DOI: 10.1016/C2017-0-00234-3
- [115] Puligundla P, Smogrovicova D, Obulam V, Ko S. Very high gravity (VHG) ethanolic brewing and fermentation: A research update. *Journal of Industrial Microbiology & Biotechnology*. 2011;**38**(9):1133-1144
- [116] Thomas K, Hynes S, Ingledew W. Practical and theoretical considerations in the production of high concentrations of alcohol by fermentation. *Process Biochemistry*. 1996;**31**:321-331
- [117] Saunders J, Izydorczyk M, Levin D. Limitations and challenges for wheat-based bioethanol production. In: Dos Santos-Bernades M, editors. *Economics Effects of Biofuel Production*. London, UK: InTech; 2011. pp. 429-452. DOI: 10.5772/20258
- [118] Oyeneye A, Shen J, Shim YY, Tse TJ, Reaney MJT. Production of α -glycerylphosphorylcholine and other compounds from wheat fermentation. *ACS Omega*. 2020;**5**:12486-12494. DOI: 10.1021/acsomea.0c01352
- [119] Moreno MDJM. Cognitive improvement in mild to moderate Alzheimer's dementia after treatment with the acetylcholine precursor choline alfoscerate: A multicenter, double-blind, randomized, placebo-controlled trial. *Clinical Therapeutics*. 2003;**25**:178-193. DOI: 10.1016/s0149-2918(03)90023-3

- [120] Tse TJ, Wiens DJ, Shen J, Beattie AD, Reaney MJT. *Saccharomyces cerevisiae* fermentation of 28 barley and 12 oat cultivars. *Fermentation*. 2021;7:59. DOI: 10.3390/fermentation7020059
- [121] Machado K, Seleme R, Maceno M, Zattar I. Carbon footprint in the ethanol feedstocks cultivation—Agricultural CO₂ emission assessment. *Agricultural Systems*. 2017;157:140-145
- [122] Malaca J, Freire F. Addressing land use change and uncertainty in the life-cycle assessment of wheat-based bioethanol. *Energy (Oxford)*. 2012;45(1):519-527
- [123] Enghiad A, Ufer D, Countryman A, Thilmany D. An overview of global wheat market fundamentals in an era of climate concerns. *International Journal of Agronomy*. 2017;2017:1-15
- [124] Ruiz H, Silva D, Ruzene D, Lima L, Vicente A, Teixeira J. Bioethanol production from hydrothermal pretreated wheat straw by a flocculating *Saccharomyces cerevisiae* strain—Effect of process conditions. *Fuel (Guildford)*. 2012;95:528-536
- [125] Erdei B, Barta Z, Sipos B, Réczey K, Galbe M, Zacchi G. Ethanol production from mixtures of wheat straw and wheat meal. *Biotechnology for Biofuels*. 2010;3(1):16
- [126] Ballesteros I, Negro MJ, Oliva JM, Cabanas A, Manzanares P, Ballesteros M. Ethanol production from steam-explosion pretreated wheat straw. *Applied Biochemistry and Biotechnology*. 2006;12:496-508
- [127] Hu G, Heitmann JA, Rojas OJ. Feedstock pretreatment strategies for producing ethanol from wood, bark, and forest residues. *BioResources*. 2008;1:270-294
- [128] Ingrao C, Matarazzo A, Gorjian S, Adamczyk J, Failla S, Primerano P, et al. Wheat-straw derived bioethanol production: A review of life cycle assessments. *The Science of the Total Environment*. 2021;781:146751
- [129] Linde M, Jakobsson EL, Galbe M, Zacchi G. Steam pretreatment of dilute H₂SO₄-impregnated wheat straw and SSF with low yeast and enzyme loadings for bioethanol production. *Biomass and Bioenergy*. 2008;4:326-332
- [130] Lantz M, Prade T, Ahlgren S, Björnsson L. Biogas and ethanol from wheat grain or straw: Is there a trade-off between climate impact, avoidance of iLUC and production cost? *Energies (Basel)*. 2018;11(10):2633
- [131] Razdan N, Kocher GS. Utilization of damaged and spoiled wheat grains for bioethanol production. *Bioscience Biotechnology Research Communications*. 2018;11:658-673. DOI: 10.21786/bbrc/11.4/17
- [132] Canadian Food Inspection Agency. RG-8 Regulatory Guidance: Contaminants in Feed (formerly RG-1, Chapter 7) [Internet]. 2017. Available from: <https://inspection.canada.ca/animal-health/livestock-feeds/regulatory-guidance/rg-8/eng/1347383943203/1347384015909?chap=0> [Accessed: December 05, 2021]
- [133] Gulsunoglu Z, Aravind S, Bai Y, Wang L, Kutcher HR, Tanaka T. Deoxynivalenol (DON) accumulation and nutrient recovery in black soldier fly larvae (*Hermetia illucens*) fed wheat infected with fusarium spp. *Fermentation*. 2019;5:83. DOI: 10.3390/fermentation503008
- [134] Wiens DJ, Tse TJ, Reaney MJT. Using black soldier fly larvae to reclaim and concentrate nutrients

from *Fusarium* head blight infected wheat. Conference Presentation. Entomological Society of Canada/ Entomological Society of Ontario 2021 Joint Annual Meeting, Niagara Falls, Ontario, Canada

[135] Wu YV, Sexson KR, Lagoda AA. Protein-rich residue from wheat alcohol distillation: Fractionation and characterization. *Cereal Chemistry*. 1984;**61**:423-427

[136] Bhadra R, Muthukumarappan K, Rosentrater KA, Kannadhasan S. Drying kinetics of distillers wet grains (DWG) under varying condensed distillers Solubles (CDS) and temperature levels. *Cereal Chemistry*. 2011;**88**(5):451-458

[137] Rosentrater KA, Ileleji K, Johnston DB. Manufacturing of fuel ethanol and distillers grains—Current and evolving processes. In: Liu KS, Rosentrater KA, editors. *Distillers Grains—Production, Properties, and Utilization*. 1st ed. Boca Raton: AOCS Publishing; 2012. pp. 73-102

[138] Ratanapariyanuch K, Shim YY, Emami S, Reaney MJT. Production of protein concentrate and 1,3-propanediol by wheat-based thin stillage fermentation. *Journal of Agricultural and Food Chemistry*. 2017;**65**:3858-3867

[139] Pedersen C, Jonsson H, Lindberg J, Roos S. Microbiological characterization of wet wheat distillers' grain, with focus on isolation of lactobacilli with potential as probiotics. *Applied and Environmental Microbiology*. 2004;**70**:1522-1527

[140] Scott E, Peter F, Sanders J. Biomass in the manufacture of industrial products—The use of proteins and amino acids. *Applied Microbiology and Biotechnology*. 2007;**75**:751-762. DOI: 10.1007/s00253-007-0932-x

[141] Singh V, Moreau RA, Hickes KB, Belyea RL, Staff CH. Removal of fiber from distillers dried grains with solubles (DDGS) to increase values. *Transactions of ASAE*. 2002;**45**:389-392

[142] Thacker P, Deep A, Beltranena E. Use of a post-production fractionation process improves the nutritional value of wheat distillers grains with solubles for young broiler chicks. *Journal of Animal Science and Biotechnology*. 2013;**4**(18):1-6. DOI: 10.1186/2049-1891-4-18

[143] Liu KS. Fractionation of distillers dried grains with solubles (DDGS) by sieving and winnowing. *Bioresource Technology*. 2009;**100**:6559-6569. DOI: 10.1016/j.biortech.2009.07.053

[144] Cantrell DF, Winsness DJ. Method of recovering oil from thin stillage. United States Patent # US 8,008,517 B2. 2011

[145] Haas M. Extraction and use of DDGS lipids for biodiesel production. In: Liu KS, Rosentrater KA, editors. *Distillers Grains—Production, Properties, and Utilization*. 1st ed. Boca Raton: AOCS Publishing; 2012. pp. 487-502