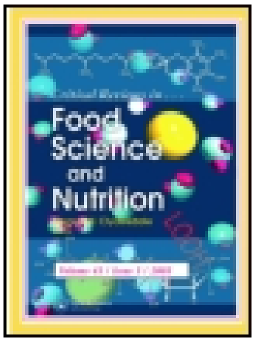

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REVIEW

Wheat bran, as the resource of dietary fiber: a review

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ABSTRACT
Wheat bran is a major by-product of white flour milling and had been produced in large quantities around the world; it is rich in dietary fiber and had already been used in many products such as whole grain baking or high dietary fiber addition. It has been confirmed that a sufficient intake of dietary fiber in wheat bran with appropriate physiological functions is beneficial to human health. Wheat bran had been considered as the addition with a large potential for improving the nutritional condition of the human body based on the dietary fiber supplement. The present review summarized the available information on wheat bran related to its dietary fiber functions, which may be helpful for further development of wheat bran as dietary fiber resource.

KEYWORDS
Wheat bran; dietary fiber; supplement; physiological functions

Introduction

Wheat (*Triticum* spp.), as one of the important staple grains in many parts of the world, is a member of the Grass family *Gramineae* (Poaceae), tribe *Triticeae* (Curtis, Rajaram, and Macpherson 2002; Diekmann 2009). It has been manufactured in five continents, including more than 100 countries. Europe, China, and India are the major wheat-producing regions. Table 1 shows the wheat production and growth rate of wheat production areas in the world in recent years (FAO 2019). Wheat production has steadily increased worldwide, which increased by 4% compared to 2018. Table 2 (USDA 2019) shows the supply and demand of wheat in China in the past 10 years. Wheat production and consumption of China have generally increased steadily. It has been an integral component of people's lives and diets. In terms of botany, there are more than 30,000 varieties of wheat which are mainly divided into six major classes based on hardness, color, shape, and planting season. The classes are hard red spring, hard red winter, soft red winter, hard white wheat, soft white wheat, and durum (Di Lena, Vivanti, and Quaglia 1997; Manickavasagan et al. 2010).

Wheat bran is the principal by-product of the wheat milling industry. It is the outermost part of wheat grains and accounts for a large portion of wheat grains (usually 15–20% of the weight of the grain). Wheat bran is a sustainable source. The annual output of the world and China is 187 tons and 32 million tons, respectively (Zhang, Li, et al. 2019). The principal ingredients of wheat bran include cellulose (32.1%), hemicellulose (29.2%), lignin (16.4%), and extracts (22.3%) (Xiao et al. 2019). From Table 3, the chemical composition such as protein and minerals in bran is more concentrated. There are 18 amino acids, including all amino acids necessary for the human body, contained in wheat bran. Studies have revealed that a variety of amino acids in wheat bran protein have better physiological and nutritional values than wheat protein. Meanwhile, wheat bran is rich in B vitamins, vitamin E, carotene, as well as minerals such as potassium, phosphorus, calcium, magnesium, etc. (Balandran-Quintana, Mercado-Ruiz, and Mendoza-Wilson 2015; Di Lena, Vivanti, and Quaglia 1997; USDA 2020).

From a botanical perspective, bran is defined as the outer skin and the aleurone layer in the structure of wheat kernels. However, because of the influence of processing conditions, bran in the actual milling process is usually divided from the inside to the outside: aleurone layer, transparent layer (nucleus epidermis), seed coat, inner peel (hybrid and tubular cells), and outer peel. The outer skin has high cellulose and lignin content. The aleurone layer is the most abundant part. It contains most of β-glucan, protein, and minerals in the wheat kernels, and is equally rich in vitamins and phenolic compounds. All these layers constitute the bran fraction together, which mainly plays a protective role in the internal structure (Anson et al. 2012).

The guideline for fiber food issued by the Food and Agriculture Organization of the United Nations states that healthy people should have 30–50 g/d (dry weight) of cellulose in their daily diet. In many countries, consumers' fiber intake is seriously inadequate. In China, the actual daily dietary fiber intake per capita is only about 14 g while the recommended intake is about 30 g. The intake is gradually decreasing with the improvement of the level of food processing (Kosik et al. 2017). Wheat bran is a good dietary fiber supplement, and the fiber has an excellent performance in many aspects of the human body's physiological functions.

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Table 1. Wheat production: leading producers (million tonnes) (FAO 2019).

	Average 5 yrs	2017	2018 estimate	2019 forecast	Change: 2019 over 2018 (%)
European Union	150.3	152	137.5	149.0	8.4
China (Mainland)	129.2	133.0	128.0	129.0	0.8
India	94.6	98.5	99.7	99.0	−0.7
Russian Federation	70.5	85.9	72.1	79.0	9.6
United States of America	54.6	47.4	51.3	52.0	1.4
Canada	30.2	30.0	31.8	33.0	3.9
Pakistan	25.8	26.7	25.5	24.5	−3.9
Ukraine	25.5	26.2	24.6	26.5	7.8
Australia	23.3	21.2	17.3	24.0	38.7
Turkey	20.7	21.5	20.0	21.0	5.0
Argentina	16.3	18.5	19.5	19.0	−2.4
Kazakhstan	14.1	14.8	13.9	14.5	4.0
Iran Islamic Rep. of	11.8	12.5	13.4	13.4	0.0
Egypt	9.2	8.8	8.8	9.0	2.3
Uzbekistan	6.6	6.1	6.0	6.5	8.3
Other countries	59.6	56.4	59.0	58.0	−1.7
World	742.3	759.4	728.3	757.4	4.0

Table 2. Wheat and coarse grains millions of metric tons/hectare (USDA 2019).

	Area harvested	Yield	Production	Imports	Exports	Feed dom. consumption	Domestic consumption	Ending stocks
2008/09	23.7	4.8	112.9	0.5	0.7	8.0	105.5	46.5
2009/10	24.4	4.7	115.8	1.4	0.9	11.0	108.0	54.8
2010/11	24.5	4.7	116.1	0.9	0.9	14.0	111.5	59.5
2011/12	24.5	4.8	118.6	2.9	1.0	25.0	123.5	56.5
2012/13	24.6	5.0	122.5	3.0	1.0	26.0	126.0	55.1
2013/14	24.5	5.1	123.7	6.8	0.9	17.0	117.5	67.2
2014/15	24.5	5.2	128.3	1.9	0.8	17.0	117.5	79.1
2015/16	24.6	5.4	132.6	3.5	0.7	16.0	117.5	97.0
2016/17	24.7	5.4	133.3	4.4	0.7	17.0	119.0	114.9
2017/18	24.5	5.5	134.3	3.9	1.0	17.5	121.0	131.2
2018/19	24.3	5.4	131.4	3.1	1.0	20.0	125.0	139.8
2019/20	24.1	5.5	132.0	3.2	1.3	21.0	128.0	145.7

Table 3. Chemical composition of the wheat bran (per 100 g) (Balandran-Quintana, Mercado-Ruiz, and Mendoza-Wilson 2015).

Total carbohydrates	64.51 g	Water	9.89 g
Dietary fiber	42.8 g	Energy	216 kcal
Sugars	0.41 g	Ash	5.8 g
Total fat	4.25 g	Fatty acids	0.63 g
Saturated	0.6 g		
Monoinsaturated	0.6 g	Vitamins	
Polyinsaturated	2.2 g	E	1.49 mg
		K	1.9 μg
Protein	15.5 g		
		Thiamin	0.523 mg
Minerals		Riboflavin	0.577 mg
Ca	73 mg	Niacin	13.578 mg
Fe	10.57 mg	B6	1.303 mg
Mg	611 mg	Folate	79 μg
P	1013 mg	Panthotenic acid	2.2 mg
K	1182 mg	Choline	74.4 mg
Na	2 mg		
Zn	7.27 mg		
Cu	0.998 mg		
Mn	11.5 mg		
Se	77.6 μg		

It is primarily focused on preventing cardiovascular diseases, gastrointestinal health, and regulating glucose and lipid metabolism.

For a long time, wheat bran was used in animal feed primarily and the utilization was not high. With the emphasis on a healthy diet and lifestyle in recent years, wheat bran has gradually been recognized as the fiber supplement with great potential to improve the nutritional status of inadequate dietary fiber intake. Wheat bran has been gradually applied to the processing of a variety of food, especially cereals with the highest proportion, such as baked products and cereal breakfast. Numerous studies have been conducted on the changes in texture, nutritional components of products, and the measures to reduce or avoid negative effects after supplementing wheat bran.

The article summarizes the physiological effects of dietary fiber in wheat bran. Meanwhile, we epitomize the effects of the addition of wheat bran or whole grain flour on various cereal foods, and the measures to improve the adverse impact. The review contributes to the further application of bran as a dietary fiber supplement in the food industry.

Dietary fiber in wheat bran

The definition of dietary fiber is as follows:

> Dietary fiber is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. (Committee 2001)

These are carbohydrate polymers with 10 or more monomer units that cannot be hydrolyzed or absorbed in the small intestine. However, dietary fiber will be fermented in the colon to generate short-chain fatty acids (Jones 2014). Wheat bran has a high content of total dietary fiber (TDF, usually reported as more than 50% of the total weight of wheat bran), more than 90% of which is insoluble dietary

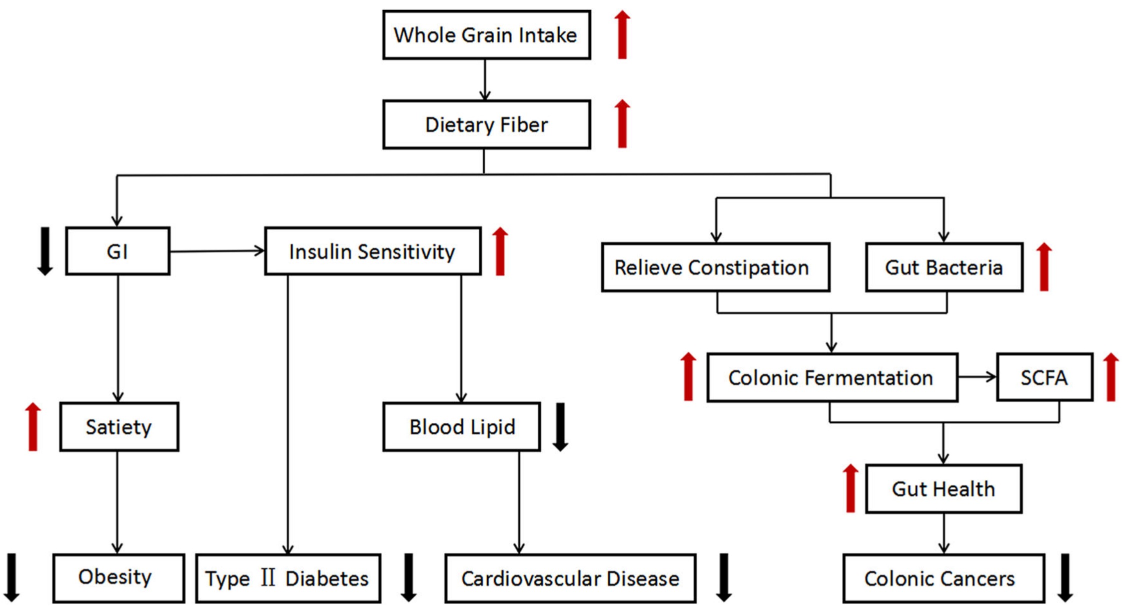

Figure 1. How dietary fiber in whole grain protects against major chronic diseases.

fiber (IDF). This article summarizes the main categories in bran fiber which is closely related to the health benefits.

Cellulose and lignin

Cellulose forms the cell wall of most plant materials as IDF. Cellulose is the major component of IDF and the most abundant natural polymer in nature. As a linear polymer of β-D-glucose molecules linked to the 1,4-position, it is not easily digested in the human system (Lu and Zhang 2007). Cellulose is the most abundant component and one of the keys to comprehensive utilization in wheat bran yet it is difficult to degrade. Cellulose is insoluble in cold and hot water, dilute acid and dilute alkali. The insolubility makes it not fully utilized in the food industry. Processing the cellulose in wheat bran to improve its comprehensive utilization efficiency and create higher economic value is of great significance to the food industry. To this end, there have been many studies about saccharifying cellulose by physical, chemical, and enzymatic methods to produce small molecular sugars such as xylose, arabinose, and glucose (Guo et al. 2012). It is worth noting that the products obtained by decomposing this natural source are often bio-friendly, safe, and harmless. Based on the enzymatic treatment of cellulose, the production of bioethanol from cellulose has been considered as a feasible way of energy utilization (Sharaf and El-Naggar 2018; Shokrkar, Ebrahimi, and Zamani 2018). On the other hand, the production of degradable, high-performance composite membranes and nanofibers are the current research hotpots (Silveira et al. 2015).

Lignin is an important part of TDF, which makes the fiber hydrophobic to resist enzymatic decomposition and bacterial decomposition in the small intestine and large intestine. It could almost completely recover in the feces. However, lignin may provide an undesired effect on taste when eating wheat bran. The main component of lignin is the polymerization of polyfunctional phenols with ether and ester bonds, which tightly binds with the cellulose in the cell wall and penetrates into the cell wall, forming a hard matrix (Argyropoulos and Menachem 1997).

Arabinoxylan (AX)

Arabinoxylan is the principal non-starch polysaccharide located in the cell wall of wheat, which can be divided into two groups according to the solubility: water-soluble arabinoxylan (WEAX), and water-insoluble arabinoxylan (WUAX) (Wang et al. 2020). The difference may be related to the degree of substitution of the polysaccharide chain, and the distribution of AX in wheat bran (Izydorczyk and Biliaderis 1995). AX is generally composed of a linear skeleton of β-(1,4) linked xylosylglycosyl units. Arabinofuranose is linked at the C (O) 3 and C (O) 2 positions via α-(13) and/or α-(12) linkages and uronic acid at the C (O) 2 position (Ring and Selvendran 1980). Some of these residues were replaced by α-L-arabinofuranosyl residues (arabinose). Ferulic acid was ester-linked at the C (O) −5 position of arabinose (Sun et al. 2019).

The structure of AX usually determines their physicochemical effects, fermentation process, and regulation of intestinal flora. Due to different wheat varieties, there are differences in composition and the structure of AX. The differences containing molecular weight, arabinose/xylose (A/X) ratio, and ferulic acid content were mainly observed. Structural characteristics of AX determine its physical and chemical properties, such as viscosity, shear thinning behavior, and gelation ability. Then these characteristics affect the rheology of the dough and the quality of the final product, especially baking products (Revanappa, Nandini, and Salimath 2015; Rosicka-Kaczmarek et al. 2016).

Beta-glucan

Beta-glucan is a soluble dietary fiber as a functional factor that regulates human health. The content in wheat usually accounts for 0.5–1.5%, which is lower than barley and oats. The content of β-D-glucan in white wheat bran is higher than that of red wheat bran (Wood 2007). Beta-glucan is mainly present in the aleurone layer and sub-dextrin layer of wheat. After a series of operations such as milling, it is collected in the bran (2.5–3%). Cereal mixed bonds (1-3) (1-4)-β-D-glucan (β-glucan) has many functions, making it unique as a plant cell wall component and dietary fiber (Miller and Fulcher 1994).

There is increasing interest in β-D-glucan in cereals, mainly because of their beneficial physiological effects on human health and potential importance as an ingredient in the functional food industry. β-glucan has been proven to have anti-oxidant, anti-cancer, and cardiovascular disease prevention effects. In addition, after extracting SDF from wheat bran, it can be invoked as a thickener and binder in food, which can keep the gel and emulsion stable (Gani and Benjakul 2019).

The physiological function of wheat bran dietary fiber

In the previous section, we outlined the basics of wheat bran and its dietary fiber. The reason why wheat bran has excellent physiological effects on the human body is two types of physiologically active substances: active polysaccharides (dietary fiber contained in wheat bran, other than starch) and phenolic compounds (phenolic acids, flavones, lignans, etc.). Dietary fiber is mainly related to human digestive and gastrointestinal functions. Phenolic compounds mainly have antioxidant and anti-cancer effects. This article will focus on the positive effects of dietary fiber in wheat bran on human physiological functions. According to the articles (Fardet 2010), the relationship between dietary fiber and human health is shown in Figure 1. It is important to note that dietary fiber could only prevent diseases most effectively when combined with other whole grain ingredients (Jacobs, Slavin, and Marquart 1995).

Modern nutrition and food science researches have shown many beneficial effects of wheat bran on human health. Multiple studies showed that dietary fiber could reduce intestinal transit time, lower blood cholesterol levels, lower blood glucose response, and insulin levels (Cho et al. 2013; Jensen et al. 2004; Liu et al. 2017). Besides, dietary fiber intake has a positive effect on human intestinal health, which can regulate the intestinal flora and has excellent effects on cancers such as colon cancer (Grasten et al. 2002). The wheat bran supplemented products we consumed need to be processed. Generally speaking, bran modification will not negatively affect the health effects (Deroover et al. 2020).

Helping reduce blood lipids and anti-obesity

Overweight and obesity have become increasingly serious problems in human society. Excessive blood lipids or cholesterol in the blood will bring a series of complications such as atherosclerosis, cardiovascular disease, and even chronic kidney disease (Gai et al. 2019). Numerous studies have been conducted on the effect of wheat bran intake on human blood lipid levels and weight.

There is an inverse relationship between dietary fiber intake and obesity, which is associated with an increase in satiety, a decrease in energy intake, and possibly an increase in energy loss from feces (Astrup et al. 2010; Freeland, Anderson, and Wolever 2009). However, the conclusions about the relationship between wheat bran intake and blood lipid levels are mixed. The large discrepancy may be due to various experimental protocols. There are different perceptions about whether wheat bran intake has a positive effect on blood lipid levels and cholesterol levels (Ahmad and Takruri 2015; Junejo et al. 2019; Maziyadixon and Klopfenstein 1994).

What has been agreed is that β-glucan in wheat bran is an essential part of cereal products in regulating blood lipids (Wolever et al. 2010). As a soluble dietary fiber, the viscosity provided by-glucan in the intestine is considered to be the major factor. β-glucan regulates body lipids mainly for the following reasons: β-glucan inhibits the body's absorption of bile acids and combines with bile acids in the small intestine to affect cholesterol synthesis. By eating β-glucan, the excretion of bile acids and cholesterol would increase (Bashir and Choi 2017). In addition, β-glucan can reduce the body's insulin concentration and improve insulin resistance (IR), in turn decrease the synthesis of cholesterol (Choi et al. 2010). However, it is worth noting that the content in wheat bran is not advantageous among all grains. Hui et al. (2019) analyzed the regulation of blood lipids by different cereals in network meta-analysis. The result showed that wheat bran had no observable effect on the regulation of blood lipids compared with oat and oat bran which are rich in β-glucan.

Moreover, AX in wheat fiber, the polyunsaturated fatty acids (PUFAs) and phytosterols in wheat bran oil also have an inhibitory effect on the body's cholesterol synthesis and blood lipid level. These are linked to the metabolism of bile acids and the excretion of bile acids and cholesterol (Lei et al. 2018; Tong et al. 2014).

Glycemic regulation and treatment of type 2 diabetes

Studies have revealed that in the process of regulating blood glucose, it is often accompanied by blood lipid regulation in the organism. Glucose and lipid metabolism generally usually occurs together. They are all manifestations of metabolic syndrome (MS) in the human body and have similar pathogenesis. These effects may be linked to the physicochemical properties of dietary fiber. Intake of dietary fiber will slow down the gastric emptying and absorption of glucose while improving the sense of fullness.

Numerous studies have demonstrated the physiological effect of wheat bran and its arabinoxylan and β-glucan on blood glucose regulation. The effect of β-glucan on blood glucose is closely related to gastric emptying time and insulin levels (Yu et al. 2014). The hypoglycemic activity of β-glucan is related to liver insulin resistance (IR) and intestinal flora. Regarding further mechanisms showed that the

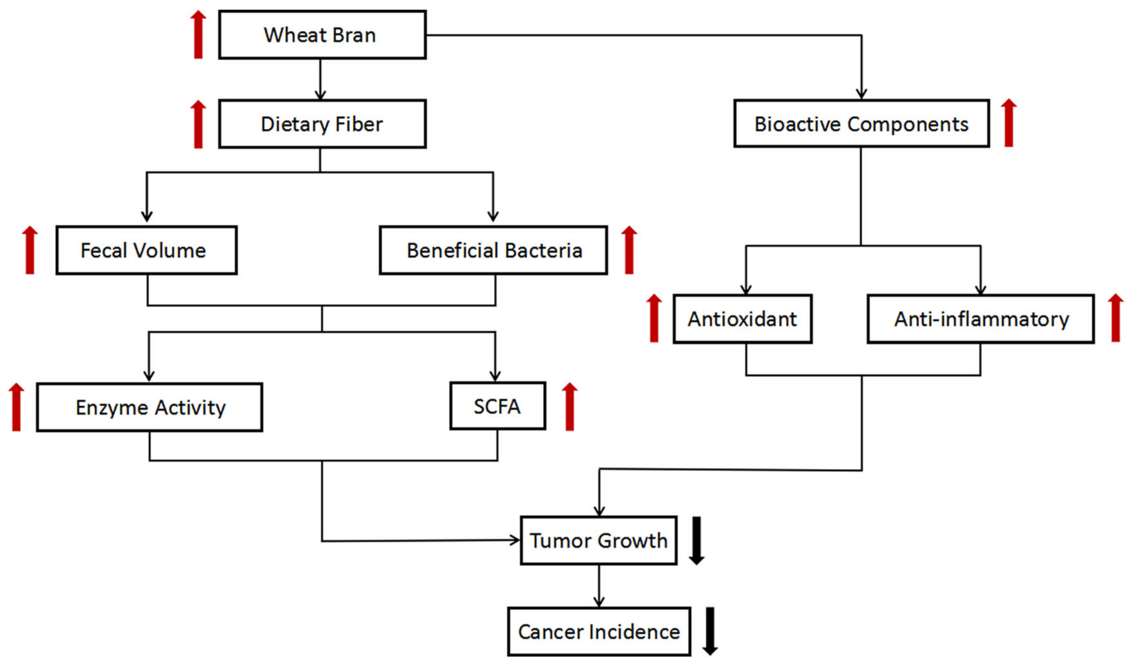

Figure 2. Relationship between intake of dietary fiber & bioactive substances and tumor.

sodium glucose transporter 1, the expression of PEPCK in the liver, and the JNK signaling are vital factors. All factors work together in order to maintain the body's glucose homeostasis (Cao et al. 2016).

Similarly, AX can regulate the postprandial blood glucose level of the human body. It has been proven that AX-rich fibers can significantly improve blood glucose control in patients with type II diabetes. Lu et al. (2004) reported that the supplement of 15 g/day of AX-rich fiber could significantly improve glycemic control in people with Type II diabetes. The postprandial blood glucose, insulin, triglycerides, and total ghrelin response are all improved (Garcia et al. 2007). AX can improve the body's glucose tolerance, which is related to the improvement of insulin sensitivity and intestinal flora fermentation (Boll et al. 2016). Regarding the mechanism of action of AX on type 2 diabetes, Nie et al. (2018) analyzed 21 metabolites related to it through metabolomics analysis revealing the role of AX in relieving type 2 diabetes. The physiological metabolic process such as the TCA cycle, tryp-tophan metabolism, lipid and ketone body metabolism, and so on were significantly improved by arabinoxylan treatment.

Cardiovascular disease and coronary heart disease

With the continuous improvement of people's living standards, the incidence of cardiovascular disease worldwide has gradually increased with a trend of youth. Overweight, smoking, lack of exercise, and high blood pressure are major risk factors for cardiovascular disease (CVD). Coronary heart disease (CHD) is the leading cause of death in most developed countries, and the incidence of coronary heart disease is rapidly increasing in developing countries (Anderson et al. 2000). There is epidemiological evidence of a strong correlation between high-density lipoprotein cholesterol (HDLC), triglyceride (TG) levels, and coronary heart disease (CHD). Because dietary fiber has a positive effect on regulating blood lipids and serum cholesterol, intake of wheat bran can reduce the risk of CVD and reduce the incidence of CHD (Jenkins, Kendall, and Ransom 1998).

Studies have demonstrated that long-term intake of cereal fiber can reduce the risk of CVD and CHD. Numerous researchers have carried out a large number of related studies targeting different age groups and different genders. Jensen et al. (2004) conducted a 7-year recording experiment on healthy men aged 40–75 years. The beneficial relationship between the whole grain diet and coronary heart disease was demonstrated by analyzing the incidence of CHD. Wheat bran probably a key factor. There were studies to conduct CHD monitoring experiments in healthy women and the elder through recording experiments. These studies verified that higher fiber intake decreased the risk of CHD (Mozaffarian et al. 2003; Wolk et al. 1999).

Gut bacteria and gut health

In modern society, various problems such as irregular diets, irrational nutritional structures, and unhealthy lifestyles have caused gastrointestinal diseases to be more common. The most serious intestinal problem is constipation. Consumption of dietary fiber to promote gastrointestinal motility and relieve constipation has become a consensus (Sulaberidze et al. 2017). Intake of dietary fiber can promote the production and health of feces. And the fermentation of dietary fiber in the colon has a positive effect on affecting microbial composition and reproduction and maintaining intestinal homeostasis. In addition, fermentation metabolites, especially SCFAs, play an important role in regulating metabolism (Carlson et al. 2017; Chambers et al. 2015).

Feces are metabolic waste produced by the body. Whether the feces are normal is one of the important indicators to measure the health of the intestines. It has been proven that wheat dietary fiber, mainly wheat bran dietary fiber, improved intestinal function. The improvement in fecal bulking after dietary fiber supplementation is related to gut health and disease prevention (Stevenson et al. 2012). The size of wheat bran needs to be considered. It had been confirmed that coarse wheat bran increased stool water content, a stool-softening effect, while fine bran had the opposite effect (McRorie et al. 2020).

Gut health is closely related to the gut flora. The intestinal flora is composed of approximately 2,000 different bacteria, numbering in the millions, and they are found in the gastrointestinal tract and play a fundamental role in regulating the host's physiological processes (Requena, Martinez-Cuesta, and Pelaez 2018). It is reported that the dietary fiber in bran could help the proliferation and fermentation of the bacterial flora and then promote intestinal health. Bran fibers could increase β-glucosidase activity, urease activity, and SCFA concentrations in colon stool (Grasten et al. 2002). The fermentation of dietary fiber in the intestine promoted the proliferation of beneficial colonies in the colon, maintained the intestinal ecological environment, and greatly promoted the health of the host. We can indicate that reasonable nutritional ratios and dietary diversity are equally important for intestinal health.

SCFA is a key substance protecting from colon cancer. In addition to enhance the feces, increased production of SCFA (especially butyrate) is another reason for the prevention of colon cancer. After feeding dietary fiber, the concentration of secondary bile acids in feces and the mutagenic activity of feces were significantly reduced, while the concentration of short chain fatty acids (SCFA) increased. Importantly, fiber supplementation showed a protective effect on reducing tumor incidence and tumor mass index (TMI) (Qu et al. 2005; Reddy et al. 1989). It is notable to note that the chemical active in wheat bran is also important for colon cancer prevention and treatment (Zhao et al. 2019). Figure 2 shows the association between fiber, bioactive components in wheat bran and colon cancer cell apoptosis. Owing to the peculiarity of tumor diseases, the researches on cancers were focused on animal experiments primarily. But these studies are reasonable that can provide a reliable suggestion and basis for people's healthy lifestyle.

Application and improvement of wheat bran in human food

As a by-product in wheat production, wheat bran has good potential for fiber utilization as food ingredients in food product formulations. The wheat by-products would convert into food supplements with high commercial value. The use of wheat bran in the food and feed industry has grown significantly over the last years as a great way to achieve resource reuse. How to modify bran to increase consumer acceptance is the focus in the application of bran (Hemdane et al. 2016).

Wheat bran is employed as an ingredient in different food products widely. Different amounts of wheat bran added in different cereal products have a huge impact on product quality (Onipe, Jideani, and Beswa 2015). The market demand for high-fiber food would continue to increase as more supporting data becomes available on health function and disease prevention ability.

Although the use of wheat bran in the production of food will modify the nutritional characteristics of the food, the sensory characteristics of the final product will decrease with increasing the content of dietary fiber. This change may affect consumer acceptance. Therefore, ensuring that its sensory quality does not change substantially is the principal challenge in the application process (Fischer 2018). In order to address this problem, many researchers have made various attempts. For example: Control the content of wheat bran in it and seek formulas that satisfy both sensory and nutritional need. Numerous treatments to improve wheat bran product quality, including physical, chemical, and enzymatic treatment. And additions to ensure satisfactory texture.

The application and improvement of wheat bran in various cereal food will be outlined below.

Effect of dough and gluten structure

The dough is a semi-processed product of most cereal products. After cutting, fermentation, baking, cooking, and drying, the dough can be utilized to obtain a wide variety of cereals. Such as baked products, noodles, pasta, steamed bread, etc. The texture of the dough to some extent establishes the quality of the products. The supplementation of wheat bran would change the structure of the dough and gluten. The ductility, water retention, and viscosity of the dough would be worse together with the gluten structure destroyed.

Numerous studies have analyzed the rheological properties of dough made with wheat bran or whole wheat flour. The amount of wheat bran added to the dough is the most important factor. The mechanical strength of the dough increases while the viscosity, ductility, and strength of the dough are reduced. The water absorption and water holding capacity would be improved meanwhile. The interaction of the fibrin in wheat bran prevents protein hydration in the dough and causes the gluten to be replaced or diluted, so the gluten structure would be loose and destroyed. Dough formation and kneading properties were affected. The dough formation and kneading characteristics are affected (Gómez et al. 2011; Liu et al. 2019; Ma et al. 2020). It is reported that the particle size of wheat bran has a significant effect on the change of dough rheological properties. Compared with coarse wheat bran, fine grain wheat bran reduce the dough's mixing tolerance and shortens the mixing time (Lapčíková et al. 2019; Rezaei, Najafi, and Haddadi 2019). This is due to the lower disruption of the gluten network by smaller grain wheat bran.

In order to improve the adverse effects of wheat bran on dough and gluten, various processing methods which would

Table 4. Some studies on the effect of wheat bran treatments on bread quality (compared with untreated bran product).

Processing methods	Effect of wheat bran on product	Reference
Fermentation	The specific volume and the acidity of bread increased. No significant change in bitterness and bran aftertaste	(Prückler et al. 2015)
	The flavor and breadcrumb softness are optimized, and peeled wheat bran has better results. Soluble AX content increased	(Katina et al. 2012)
	Improved the biochemical, functional, nutritional, textural, and sensory features of wheat bread	(Pontonio et al. 2017)
Prehydration	Improved bread quality (the specific volume, volume and softness). Positive effect on bread storage characteristics	(Park, Fuerst, and Baik 2017)
Steam explosion	Specific volume decreased while hardness of bread improved	(Aktas-Akyildiz et al. 2017)
Steam explosion + enzyme	Improved the specific volume, softness, and SDF content of bread	
Enzyme (cellulase, xylanase)	Optimized storage characteristics and loaf volume. Increased SDF content. The firmness of bread decreased	(Park, Fuerst, and Baik 2018)
Enzyme (dextransucrase)	Bread is more bulky and firmer and the acidity of bread rises	(Kajala et al. 2015)

increase the proportion of soluble dietary fiber and improve the taste of wheat bran could be used. Common treatment methods include fermentation, enzyme treatment, acid hydrolysis treatment, etc. The functional principles are same to break down the macromolecular substances or IDF in the dough into small hydrolyzed substances. Changes in gluten water holding capacity are important factors together. The ratio of SDF/IDF would be increased and the damage of the gluten network would be reduced after treatments (Zhang et al. 2018).

Baking products

During the manufacturing process, baked products produce special and attractive aromas through Maillard reactions, which have been widely received by consumers. The main baking products include bread, cake, cookie, biscuit, and so on. Adding wheat bran to the production of baked products is the most common application method. On the one hand, it can increase the fiber content in baked products to improve their health, and on the other hand, it may reduce the quality of baked products.

Bread

Adding wheat bran to bread making or using whole wheat flour to ensure that bread is very common now. The quantity and quality of gluten in bran-related tissues, as well as their effectiveness and vitality, significantly affect the properties of dough and bread (Jacobs et al. 2018). The direct addition has a terrible effect on the softness and specific volume of bread with the amount of cellulose supplement increased. Optimizing the texture and taste of bread by treating bran has been extensively studied.

The type of wheat bran, milling technology, supplement ratio, and particle size could significantly change the texture of the bread. Compared with larger particle size (783 μm), smaller bran (463 μm) will make the bread loaf volume larger, darker in color, smoother in appearance, tougher, and softer in taste (Navrotskyi et al. 2019; Zhang and Moore 1997). The suitable amount of wheat bran has a positive effect on the volume of bread, but an excessive amount has the opposite effect (Al-Saqer, Sidhu, and Al-Hooti 2007). Onipe, Jideani, and Beswa (2015) summarized the influence of the amount of bran on the quality of bread. The addition amount of bran in bread is generally 5%–30% to ensure the acceptable sensory characteristics. The elasticity and hardness of the bread increase, while the specific volume decreases in the range above.

In order to balance the negative impact of adding bran on bread quality, optimizing the texture and taste of bread by treating bran has been extensively studied. The methods commonly such as pre-water treatment, fermentation, and enzyme treatment currently. The effect of these processing methods is to increase the gluten network structure of the dough and thereby improve the quality of the baked product. After the bran was subjected to wet heat treatment (hydration, wet oxidation treatments), the quality of the bread increased significantly. Table 4 shows some related studies about the effect of wheat bran treatments on bread quality.

Biscuits and cookies

Compared to bread, biscuits, or cookies are smaller with different tastes. Thus the negative effect of wheat bran would be more obvious. Because of the negative effect on the dough, wheat bran may reduce the hardness, crispness, dryness, and chewability of the cookies. Increased wheat bran content makes cookies less acceptable. But cookies can have a unique wheat flavor and aftertaste at the same time (Gujral et al. 2003; Sudha, Vetrimani, and Leelavathi 2007). To avoid the acceptability of cookies being too low, bran cannot have a higher amount of biscuits (Laukova et al. 2016). Meanwhile, wheat bran would provoke a significant reduction in the in vitro GI of cookies which is helpful to human health (Kahraman et al. 2019).

Cake

Because of the delicate texture of the cake, wheat bran is not of high value in cake making. As the amount of wheat bran or particle size of bran increases, the quality of the cake (the specific volume, humidity, softness, brightness, etc.) decreases and the overall sensory score also decreases (Gómez et al. 2010; Lebesi and Tzia 2011). But there are researches showed that when adding bran with suitable particle size and amount of addition, the cake can be highly acceptable (Singh, Liu, and Vaughn 2012). Similar to other bakery products, the treatment of bran by enzymes (such as xylanase) can significantly improve the texture and nutritional characteristics of the product (Lebesi and Tzia 2011).

In addition to baked goods, wheat bran is also widely used in breakfast cereals, Chinese steamed bread, noodles, pasta, and so on with regional characteristics.

Ready-to-eat cereals

The whole grain breakfast is rich in dietary fiber. The nutritional components in ready-to-eat are kept intact and it is convenient and fast to eat. It is a great choice suitable for the pace of modern life and people's health requirements. The cereal breakfast would be a healthy product suitable for human consumption with excellent nutritional properties and unique tastes which is usually processed by extruding and compressing whole grains. Some products are mixed with other fruits to ensure comprehensive and balanced nutrition (Kamran, Saleem, and Umer 2008; Talens et al. 2012). Breakfast cereals ensure adequate fiber intake while supplementing important vitamins and minerals. The current optimization of cereal breakfast has a broad market prospect.

Cereal breakfast is a healthy food rich in dietary fiber. Owing to the high content of wheat bran in cereal breakfast and less damage, the physiological effects of wheat bran functional factors can be well expressed. The digestibility and hydrolysis of carbohydrate are decreased with the increase of wheat bran, which proved the hypoglycemic potential effect of wheat bran. In addition, ready-to-eat cereals are considered as a new source of complex polysaccharides with better antioxidant properties due to the nutritional properties of wheat bran (Baublis et al. 2000; Brennan et al. 2008; Holguín-Acuña et al. 2008). Maki et al. (2012) found that the ferulic acid content of volunteers and the nitrobacteria in feces selectively increased after eating breakfast cereals, due to the rich arabinylxylose in breakfast cereals.

Pasta

Pasta is one of the most popular cereals originated in Italy with the characteristics of easy to store and convenient to cook. It has been universal to utilize wheat bran or whole wheat flour as the addition to improve the nutritional or quality characteristics of the pasta. The addition of wheat bran to pasta could not only increase the dietary fiber content, but also contribute better antioxidant properties to the food which related to bran oleoresin strongly (Pasqualone et al. 2015; Vignola, Bustos, and Pérez 2018).

The quality of pasta made from whole wheat flour will decrease when excessive bran is added or the bran particle size is too large. The production of pasta with high bran substitution level (15–40%) and the influence of wheat bran on the quality were studied. Chillo et al. (2008) found that the pasta adding 15% or 20% durum wheat bran showed satisfactory performances both at dry state and in cooking. Sobota et al. (2015) considered that pasta with 30% common wheat bran could have the advantages of rich in dietary fiber, satisfactory sensory properties, and cooking properties meanwhile. The quality of pasta would decrease when mixed with excessive content of wheat bran, such as the change of microstructure of the food and the negative attractiveness to consumers. The use of finer bran can reduce this negative effect under the same high addition amount of wheat bran (Alzuwaid et al. 2020; Steglich et al. 2015).

Similar to the other cereal products, the addition or combination of polysaccharides (CMC, xanthan gum, locust bean gum, etc.) shows a positive effect on the quality of pasta (Martín-Esparza et al. 2018). Wheat bran with various treatments usually results in higher quality products than untreated bran. The bran with enzyme treatment such as cellulase can make the pasta with a more balanced ratio of IDF/SDF and a lower predicted glycemic index (Nguyen et al. 2020). The application of wheat bran after various pretreatments (wet heat treatment, dry heat treatment, squeeze cooking treatment, etc.) makes better cooking characteristics, nutritional characteristics, and more attractive quality in pasta (Wójtowicz et al. 2020; Sudha, Ramasarma, and Venkateswara Rao 2011). Besides, there have been some researches to optimize the production process of high-fiber pasta. la Gatta et al. (2017) proved that the sensory attributes and cooking quality parameters of the samples obtained by separate hydration were significantly improved compared to samples with simultaneous hydration. Ciccoritti et al. (2019) proposed a novel pasta-making process based on micronization and air separation technology. The products produced by this technology not only satisfied the palatability, but also showed an increase up to 113% in dietary fiber.

Noodles

Noodles originated in China with a history of more than 4,000 years. Like steamed bread, the researches on adding wheat bran to noodles has mainly focused on the effects of the amount of wheat bran, as well as its particle size on dough rheological properties and noodle processing quality (Niu et al. 2014). Owing to the presence of IDF in wheat bran, gluten structure, and protein network structure will be destroyed after adding wheat bran and sensory evaluation will decrease. Coarser wheat bran adversely affects the texture of noodles, the smoothness and appearance of the product are inadequate, ultra-fine bran with smaller particle size is used for supplementation generally (Zhang, Li, et al. 2019).

To ensure product quality, the amount of wheat bran added needs to be controlled. Song et al. (2013) reported that the water absorption and firmness of cooked noodles increased while the cooking loss decreased as the amount of bran added increased. When the bran content increased, the viscosity, decomposition rate, hardness, gum, and chewability of noodles decreased. These changes result in a decrease in sensory scores (Chen et al. 2011).

Chinese steamed bread (CSB)

Steamed buns are traditional fermented foods in China. The main ingredients include wheat flour, yeast, and water, which are treated with steam cooking. There is a great difference between CSB and Western-style toast. For example, the flavor of CSB is formed during the fermentation process while the taste of Western-style bread is derived from the Maillard reaction during the baking process (Lin et al. 2012).

Steamed bread with the higher quality should contain the following characteristics: uniform color and pores, delicate structure, and smooth surface. Similar to bakery products, the particle size of wheat bran has a greater effect on steamed bread. Wang, Hou, and Dubat (2017) found that the gluten network structure was strengthened and the grain cells were reduced by changing the particle size of the whole wheat flour. Similarly, various pretreatment methods on wheat bran could enhance the quality of whole wheat bread. After hydration, high pressure, or fermentation treatment on bran, the stability of the dough and the quality of the product are improved (Li et al. 2018).

Some distinctive food applications of wheat bran

In addition to the cereal foods mentioned above, there are still various wheat bran applications with distinctively regional or innovative characteristics in the food industry.

During the production of chapatti with whole wheat flour or wheat bran as raw materials, whole wheat flour with a higher specific gravity of arabinose and xylose had a better effect on the quality of chapatti (Gujral, Sharma, and Khatri 2018; Revanappa, Nandini, and Salimath 2015). Cao et al. (2017) proved the possibility of using wheat bran in instant noodles which resulted in the dietary fiber and crude protein content increased, the fat content reduced. Besides, the instant porridge prepared with wheat bran as the source of dietary fiber tends to have better viscosity and satiety (Oladiran, Emmambux, and de Kock 2018).

In addition, wheat bran after a variety of intensive processing (acid hydrolysis, alkaline hydrolysis, enzyme treatment, fermentation treatment, etc.) has been used as main material for different products frequently. Apart from the relatively broad studies about the production of clean energy such as ethanol, wheat bran had also been proven to be able to produce the bran sirup used in bread (Favaro, Basaglia, and Casella 2012; Okamoto et al. 2011; Pihlajaniemi et al. 2020). Moreover, the traditional Romanian beverage Borş would be obtained by fermenting mixing wheat bran and corn flour (Pasqualone et al. 2018).

Not only is wheat bran used as the main material of the products but also as an auxiliary in processing. The applications of wheat bran as a cell fixation carrier for probiotics in the fermentation of yogurt were considered to have a positive effect on the nutritional and quality characteristics of yogurt (Terpou et al. 2017). Universally, wheat bran would be directly added to processed meat products such as patties and sausages as a fiber supplement (Hjelm et al. 2019; Sarıçoban, Yılmaz, and Karakaya 2009).

Conclusion

This review summarizes the application of wheat bran in the cereal food industry and the composition and physiological effects of dietary fiber in wheat bran. As a dietary fiber supplement included in food, wheat bran has excellent performance on the cardiovascular and intestinal health of the body. However, such supplements have a negative impact on the senses and texture of food, reducing consumer acceptance to a certain extent. Pretreatment and processing of wheat bran can make it better employed in food production and processing to a certain extent. We can foresee that controlling the physical properties of added wheat bran and combining with some new innovative processing technologies, such as enzyme technology and microbial technology, can ensure the nutritional value of food while increasing customer acceptance. The application of wheat bran in the food industry will have broader application prospects.

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