Русавська Валентина Андріївна, канд. іст. наук, проф., завідуюча кафедрою готельно-ресторанного та туристичного бізнесу, Київський національний університет культури і мистецтв. Адреса: вул. Євгенія Коновальця, 36, м. Київ, Україна, 01601. Тел.: +380978777640; e-mail: rusavska18@gmail.com, https://orcid.org/ 0000-0002-2741-6597.

Rusavska Valentyna, PhD in History, Profeesor, Head of Department of Hotel, Restaurant and Tourism Business, Kyiv National University of Culture and Arts. Address: Evgenia Konovaltsa Str., 36, Kyiv, Ukraine, 01601. Tel.: +380978777640; e-mail: rusavska18@gmail.com, https://orcid.org/0000-0002-2741-6597/

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THE PHYSIOLOGICAL FUNCTION AND APPLICATION OF CEREAL Β-GLUCAN IN THE FERMENTED DAIRY PRODUCTS

Qu Xiaoqing, Ju. Nazarenko, Li Bo

β-glucan is an important dietary fiber, it has many excellent physiological functions,and alsois one of the important raw materials for preventing many chronic diseases. Cereal β-glucan is a functional ingredient with easily obtain, and has a high market share. Firstly, the structural characteristics, sources and physiological functions of β-glucan were introduced in this paper; following, the physical and chemical properties of β-glucan were introduced; finally, the current situation of cereal β-glucan as a functional food ingredient in fermented dairy products was discussed. Overall, cereal β-glucan has a good affect in the fermented dairy products.

Keywords: *cereal, β-glucan, physiological function, application, fermented dairy products.*

ФІЗІОЛОГІЧНА ФУНКЦІЯ ТА ЗАСТОСУВАННЯ ЗЕРНОВИХ β-ГЛЮКАНУ У ФЕРМЕНТОВАНИХ МОЛОЧНИХ ПРОДУКТАХ: ОГЛЯД

Цю Сяодзинь, Ю. Назаренко, Лі Бо

β-глюкан – це полісахарид із довгим молекулярним ланцюгом, ланки якого представлені глюкозою. Він відноситься до біологічно активних речовин, сприятливо впливає на всі внутрішні органи і системи людини. Є *різновидом клітковини, а значить, сприяє очищенню кишечника і нормалізації його мікрофлори. Він має багато корисних фізіологічних функцій, є одним із важливих сировинних матеріалів для профілактики багатьох хронічних захворювань. Цей інгредієнт є ефективним імуномодулюючим агентом, широко використовується в медичній практиці та профілактичному харчуванні в усьому світі. Відкриття групи натуральних активних речовин β-глюканів із мінімумом побічних ефектів із точки зору сучасної медицини дуже важливе. Ефективність β-глюканів для лікування і профілактики багатьох захворювань заснована на корегуванні нестійкості імунної системи і неодноразово підтверджена багатьма експериментами і клінічними дослідженнями. Зерновий β-глюкан є функціональним інгредієнтом, який легко отримувати, зберігати й використовувати. Він є дуже поширеним продуктом. У цій роботі представлені структурні характеристики, джерела отримання та фізіологічні функції β-глюкану, фізичні та хімічні властивості β-глюкану, обґрунтовано сучасну ситуацію з використання злаків β-глюкану як функціонального харчового інгредієнта у ферментованих молочних продуктах. Числеуні сучасні дослідження в галузі технології кисломолочних напоїв довели, що у відповідному діапазоні β-глюкан зернових може покращити структурні характеристики продуктів. Наприклад, впливаючи на структуру мережі білка під час ферментації, він зменшує відділення сироватки, покращує здатність утримувати воду та в'язкість у кисломолочних продуктах. При цьому може бути використаний для виробництва переважно низькожирних ферментованих молочних продуктів, оскільки має органолептичні властивості жирних продуктів, покращує смак і консистенцію. β-глюкан має багатокомпонентний хімічний склад, пребіотичну дію, у разі використання в кисломолочних продуктах може чинити виражений біфідогенний вплив. Зазначене відповідає вимогам нутриціології до харчування сучасної людини.*

Ключові слова: *злаки, β-глюкан, фізіологічна функція, застосування, кисломолочні продукти.*

Statement of the problem. With the rapid development of modern food industry, the proportion of health food in people's diet is increasing sharply. Meanwhile, due to the accelerated pace of life, and people's physical exercise is reduced, which increases the risk of people suffering from chronic diseases, such as hypertension, diabetes, dyslipidemia and overweight/obesity. Nutrition intervention can prevent and control these chronic diseases. For example, adding dietary fiber with multiple health functions is an important method.

The incidence rate of lifestyle diseases is increasing rapidly. The incidence rate of diseases caused by unhealthy lifestyles is increasing all over the world. It was reported that the global proportion of overweight adults has reached 1.8 billion, of which more than 600 million adults were affected by obesity (WHO: profile, 2016). Many diseases, such as coronary heart disease (CHD), stroke, insulin resistance, type II diabetes, hypertension and metabolic syndrome, are associated with overweight [1]. From 1980 to 2014, the number of diabetes cases were increased fourfold in the world (from 108 million to 422 million). It is estimated that by 2045, there will be as many as 700 million adults with diabetes, and 90% of them will be patients with type II diabetes [2].

Nutrition therapy combined with physical exercise plays an extremely key role in the prevention and treatment of lifestyle diseases. Among them, the intake of food rich in fiber is one of the important nutritional therapies. Cereal β-glucan has a variety of physiological effects, which can effectively prevent metabolic syndrome, type II diabetes and other chronic diseases [3], and has attracted more and more attention of researchers in various countries.

Structural characteristics and sources of β-glucan. Glucan is a type of carbohydrate polymerized from D-glucopyranose monomer. According to the different glycosidic bond, it can be divided into α-glucan and β-glucan, which is an important part of cereal organisms. β-glucan is a kind of water-soluble/water-insoluble non starch homopolysaccharide, which can be linked by β-1,3, β-1,4, β-1,6 glycosidic bonds, and its structure is branched or circular. β-glucan widely exists in plants, fungi and bacteria, especially in cereals and fungi [4].

The cereal sources of β-glucan are barley [4], wheat, oat, etc., and with different contents, such as barley 2.5% – 11.3%, 2.2% – 7.8%, wheat 0.2% – 1.2% [5]. The structure of cereal β-glucan is generally composed of β-1,3 and β-1,4 glycosidic bonds without branched chain structure, as shown in Fig. 1 [4].

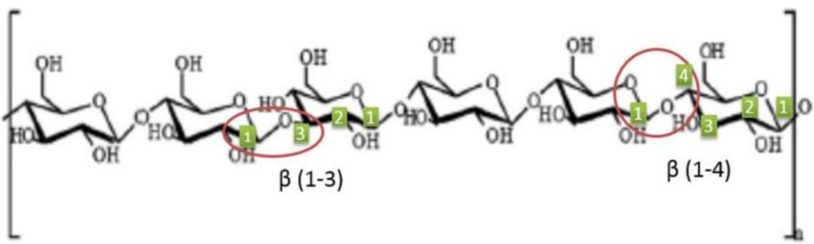

Fig. 1. Chemical structure of b-glucan from cereals
(Source: Adapted from Zhu, Du, & Xu, (2016) [4])

Barley, oat and wheat have similar structure of β-glucan, they are composed of β-1,3 and β-1,4 glycosidic bonds, but the chain length and proportion of β-1,4 and β-1,3 glycosidic bonds are different. In addition, the ratio of cellotriose (DP3) andcellotriose (DP4) determine the diversity of cereal β-glucan, and they molar ratio is known as the structural fingerprint of cereal β-glucan, which is an important structural feature of cereal β-glucan).

β-glucan is an important component of cell wall in the edible fungi, yeast and bacteria. It is mainly composed of β-1,3 and β-1,6 glycosidic bonds alone or/and mixed, and most of them have branched chain structure. At present, the main sources of edible fungi studied are *Pleurotusostreatus*, *Coprinuscomatus* and *Agaricusbisporus* [6], the main source of fungi is yeast, and the bacteria is *Lactobacillus brevis* in beer [7].

3. Physiological functions of β-glucan

3.1. Regulating blood sugar

Because its strong hydration ability and high viscosity, β-glucan can delay intestinal absorption of carbohydrate and reduce exogenous blood glucose. β-glucan can also protect and improve the functional characteristics of islet β cells, and let the insulin maintains stable secretion and, achieves the purpose of regulating blood glucose.

Oat β-glucan can significantly reduce glycemic index (GI). Previous studies found that oat β-glucan can significantly reduce the GI value of food [8]. Kim et al. (2013) reported that increasing the oat β-glucan content, the GI value of food showed a downward trend, and the GI value of starch showed a downward trend with the increase of β-glucan molecular weight and viscosity [9]. Oat β-glucan can effectively reduce the body's fasting blood glucose [10], improve the body's postprandial blood glucose. Rami, Zidek and Schober (2001) showed that the bedtime snacks containing 1.8 g oat β-glucan can significantly reduce postprandial blood glucose in children with type II diabetes [11]. The other, dietary supplementation of 6% oat β-glucan reduced postprandial blood glucose of experimental pigs [12].

3.2. Regulating cholesterol

It is well known that intake β-glucan can reduce the levels of total cholesterol and low-density lipoprotein cholesterol in blood, increase the level of free fatty acids in blood, regulate lipid metabolism disorder, and restore the level of triglyceride in blood to normal. Wolever et al. (2010) found that the oat β-glucan with high, medium and low molecular weight have different ability to reduce serum low-density lipoprotein cholesterol, but the treatment effect was not affected by the age and gender [13]. Some researches showed that β-glucan from different sources can reduce cholesterol and blood glucose [14].

3.3. Regulating immunity

β-glucan has the function of regulating immunity, and can stimulate the antibacterial activity. β-glucan regulates the expression levels of genes related to immune cells, and has the effect of anti-cancer and anti-tumor [15].

3.4. Other physiological functions

β-glucan can reduce the fat obesity [16], enhance gastrointestinal peristalsis [17], maintain the intestinal health [18], anti-inflammatory [19], and effectively prevent the metabolic syndrome and other chronic diseases [20].

β-glucan has been certified as a type of health food by the Food and Drug Administration (FDA), and European Food Safety Authority (EFSA). It is recommended to ingest at least 0.75g β-glucan per day, and 3 g β-glucan can achieve health function (EFSA).

4. Physicochemical properties of β-glucan and its application in food industry

4.1. Physicochemical properties of β-glucan

The physicochemical properties of β-glucan mainly includes the hydration (water holding and swelling), rheological properties, foaming properties and emulsifying properties. Rheological properties include the viscosity, gelation, shear thinning, viscoelasticity and so on. The differences of their properties are mainly related to the structure and concentration of β-glucan.

Compared with the cereal derived β-glucan, microbial derived β-glucan has a stronger swelling ability, and a lower hydration ability, foaming ability, foaming stability and fat binding ability. For example, the high viscosity and poor water solubility of β-glucan in yeast limits its application in industry [14].

By dissolving in water, the cereal β-glucan can form a highly viscous solution in the gastrointestinal tract [9]. Oat β-glucan has a good hydration capacity, with swelling capacity of 12.1~15.1 g/g [21]. It has been reported that the cereal β-glucan has a higher bioactivity due to it's better water solubility [22].

The viscosity of β-glucan solution is affected by the source, molecular weight, temperature, concentration and solvent. The structure of β-glucan is the most important factor. Mikkelsen et al. (2010) found that the viscosity of oat β-glucan was 100 times higher than that of barley β-glucan at the same concentration [23]. This is mainly because its molecular chain contains a high proportion of β-1,4/β-1,3 and DP4/DP3. Agbenorhevi et al. (2011) studied the rheological properties and microstructure of oat β-glucan with the different molecular weight, who considered that the rheological behavior was highly depended on the molecular weight and the concentration of β-glucan [24]. The higher the molecular weight of oat β-glucan was, the higher the viscosity of oat β-glucan was. The concentration is also an important factor toaffecte the viscosity of oat β-glucan solution. Oat β-glucan solution can produce higher viscosity at lower concentration. When the concentration is above 2g/L, the apparent viscosity decreases with the increase of shear rate, which shows the typical characteristics of pseudoplastic fluid [25]. According to the research of Autio, Myllymaki et al. (1987), the oat β-glucan showed better rheological properties when the concentration was lower than 1% [26].

The gelation of cereal β-glucan is one of the important processing characteristics [27]. It plays a decisive role in the texture of food. It's texture characteristics can be controlled by molecular weight fraction or concentration. In practical application, it is necessary to select the appropriate molecular weight and concentration of β-glucan to meet the industrial requirements.

4.2. Application of β-glucan in food industry

β-glucan products on the markets of various countries are mainly extracted from cereal, yeast and other raw materials. In the actual industrial processing and application, considering the availability of β-glucan sources and the differences in its processing characteristics and physiological functions, the cereal β-glucan, especially oat β-glucan, has an important application value, which has attracted the close attention of researchers all over the world . According to the survey data of FMRI, the global market value of β-glucan was US $307.8 million in 2016. The other, according to the market and market forecast, the global β-glucan market will reach 476.5 million US dollars until 2022, showing a great development potential [28].

β-glucan has become a hot spot in food science and life science, due to its availability of raw materials, processing characteristics and various physiological functions. As an important functional food ingredient, it is widely used in biscuits, bread, cake, meat, dairy and other foods. Beside affecting the sensory properties of food, the cereal β-glucan can interact with fat, protein, starch and other substances in food, through its water holding, oil holding and emulsifying properties.

5. Research progress on application of cereal β-glucan in yogurt

Fermented dairy products are an important part of the global human diet. Yogurt is a high protein healthy food, its consumption is a sign of healthy diet and lifestyle. Many researchers tried to add oat and barley β-glucan to the fermented dairy products. Oat and barley β-glucan are mainly used as polysaccharide/dietary fiber to influence the texture of yogurt, and have the prebiotic properties.

5.1. Effect of cereal β-glucan on texture and structure of yogurt

Current studies have proved that in an appropriate range, cereal β-glucan can improve the texture characteristics of yogurt, such as affecting the network structure of protein in yogurt, reducing the separation of whey, improving the water holding capacity and viscosity value of yogurt, etc. The specific addition amount and application methods are shown in Table 1.
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Table 1

Application of cereal β-glucan in fermented dairy products

Source	Brand/ Concentration	Amount used	Application Method	Technological function	Main results	References
1	2	3	4	5	6	7
Barley β-glucan	Differing in molecular size 40× 10^3 Da-250× 10^3 Da	0.5–2.0%	Different concentrations of fresh β - glucan solution were prepared, and different levels of skimmed milk were added. After sterilization, the dispersion was acidified at 42 ^{o}C for 18 h.	High concentration of β-glucan reduces serum separation of milk gel	Using high β-glucan concentration (1.5% and 2.0%, w/w) in milk gels containing low skim milk levels (up to 12%, w/w) or β-glucans having structural features that promote high viscosity or a secondary gel network formation by the polysaccharide	[29]
Cereal β-glucan	β-glucan composite /fat replacer	0.25–1%	Milk was mixed with β-glucan complex and skimmed milk powder at 5% (w / w) level, homogenized, cooled, added with starter, fermented and refrigerated	The use of β-glucan hydrocolloidal composite in non-fat yogurt affects the whey separation and viscosity of fat free yogurt	The best results were obtained by addition of the composite at a level of 0.25% or 0.50% for the manufacture of non-fat yogurt	[30]
Oat β-glucan	β-glucans were extracted from oats (non-	1–2%	0, 1 and 2% levels of β-glucan were added to milk, homogenized, sterilized,	β-glucan had significantly (P<0.05) increasing effects on	Results showed that the optimum conditions to obtain the synbiotic yogurt made by camel milk were defined as: adding 2% β-glucan	[31]

Continuation of Table 1

1	2	3	4	5	6	7
	enzymatic method)		probiotics added, filling, fermented and storage	viscosity, WHC and the viability of probiotic bacteria	(prebiotic agent) to milk with 1.9% fat content inoculated to 0.5% probiotic bacteria with a storage time of 7 d.	
Barley β-glucan	Commercial food grade β-glucan，75%	0.25–1.0%	Weighed amount of β-glucan (0.25–1%) was added gradually in buffalo skim- med milk at 45 °C sterilized, probiotics added, filling, sealing and storage	Enhance the functional properties, provide functionality of missing fat and to improve physical, rheological and textural properties of the final product	Syneresis and viscosity was positively affected with the addition of β-glucan till 0.5% level and higher concentration caused destabilization of the product	[32]
Barley β-glucan	91.52%	0.5–2%	Milk containing 4.5% fat and 2% skimmed milk powder were homogenized, heated for 5 min, β-glucan was dispersed into 100 mL of hot milk at 60 °C, stirred continuously for 10 minutes, and then introduced into the rest of the milk used for yogurt preparation, stirred for 2 min. Add sugar (12%) to the milk, mix for 5 min,	Improved the rheological, physiochemical and sensory properties of the yogurt improved the nutritional values by acting as prebiotic in probiotic yogurt	Addition of β-glucan significantly ($p < 0.05$) improved whey separation (syneresis), viscosity, texture profile and sensory characteristics during storage	[33]

Continuation of Table 1

1	2	3	4	5	6	7
			then pasteurize at 80 °C for 5 minutes, cool to 45 °C for 5 min, add starter, ferment and storage			
Oat β-glucan	86%	0.10%, 0.15%, 0.20%	The β-glucan powder was added into the milk matrix at the levels of 0.10%, 0.15% and 0.20%, heated at 95 °C for 10 min for pasteurization, distributed into the pre sterilized glass container and cooled to 4 °C for 1 d. Add the starter and culture at 40 °C until the final pH value is (4.9 ± 0.1)	Better sensory evaluation results, lower syneresis, and better WHC	Low-fat yogurt enriched with β-glucan at 0.10% level demonstrated superior quality, less whey separation, good textural properties and lower syneresis	[34]
Oat β-glucan	86%	0.15%	The milk was heated to 30 °C, standard β-glucan was added gradually, heated to 60 °C, the mixture was stirred continuously at 600 rpm for 20 min in a magnetic stirrer, then cooled to the fermentation temperature of 40…42 °C, the starter was added, fermented and storage	Improve the texture of yogurt, shorten the fermentation time and improve the function of probiotics	After adding β-glucan, the dehydration rate and WHC of yogurt increased from 23.6% and 44.1% to 17.06% and 49.6%, the viscosity of yogurt increased by 2.3 mPa·s, the fermentation time shortened by 30 min, and the total number of probiotics increased by $2\cdot10^7$ CFU/g	[35]

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5.2. Prebiotic properties

In addition to improve the texture of yogurt, the cereal β-glucan has been shown to have a prebiotic properties. In the gastrointestinal tract, cereal β-glucan is act as a substrate for microbial fermentation, it selectively stimulating the growth and activity of a small number of beneficial bacteria. Shen et al. (2012) adopted the way of gavage the mice with oat β-glucan and barley β-glucan for 6 weeks and analyzed the intestinal health indicators, who found that the number of Lactobacillus and Bifidobacterium in the intestinal tract of mice were increased during the administration of cereal β-glucan, and the intestinal health promotion effect of oat β-glucan was better than that of barley β-glucan [36]. Gee et al. (2007) studied the effect of barley β-glucan on the growth of two yoghurt starter cultures (SCS) composed of Streptococcus thermophilus, Lactobacillus delbrueckii and subsp. Bulgaricus, and through monitoring the fermentation efficiency of SCS with pH value, who found that barley β-glucan had not adverse effect on the growth of SCS [37]. Ibrahim et al. (2009) studied the effects of adding oat β-glucan and/or Bifidobacterium producing exopolysaccharides (EPS) on the physical properties, fermentation time and sensory standard of low-fat yogurt (fat content 1.5%), the results showed that adding oat β-glucan and EPS producing Bifidobacterium to low-fat yogurt could improve the physical and sensory properties of yogurt and increased the activity of probiotics [38]. Rosburg et al. (2010) found that 0.44% β-glucan (concentrated or freeze-dried) had protective effect of the Bifidobacteriumunder cold storage [39].

Some scholars have conducted in vitro digestion experiments and medical nutrition experiments on the application of cereal β-glucan in yogurt. Rinaldi et al. (2015) studied the bioavailability of peptides and amino acids (AA) in acidic milk gel (or yogurt) containing denatured corn starch, pectin and 75.6% pure barley β-glucan, the results showed that the different polysaccharides added at the end of digestion had not effect on the bioavailability of protein [40].

Liutkevičius et al. (2015) studied that the addition of 0.6% oat β-glucan had not effected on the fermentation time of fermented products (yogurt, Kefir and fermented milk drinks), and significantly increased the viscosity of the products. The medical nutrition experiment showed that after 21 days of consumption of fermented products containing β-glucan, the total cholesterol and low density lipoprotein in the blood were significantly decreased, while the high density lipoprotein (HDL) was significantly increased, and eating fermented milk beverage based on buttermilk skimmed milk and rich in oat β-glucan was beneficial to human health [41].

In a word, cereal β-glucan has a good solubility, high viscosity, thickening and other processing characteristics, which can improve the texture structure of yogurt, also have a prebiotic characteristics. Therefore, it has a good application prospect in the production of functional yogurt.

Conclusion. The number of chronic patients with hypertension, diabetes, dyslipidemia and overweight/obesity caused by unhealthy lifestyle is increasing in the world. In recent years, how to improve the health of the people is the research direction of food scientists. Due to the excellent properties of cereal β-glucan , food scientists have begun to pay more and more attention to the application in fermented dairy products. The application of cereal β-glucan in fermented dairy products can provide functional dairy products for consumers, promote the sustainable and healthy development of β-glucan industry, also expand the diversification of global dairy processing industry. However, there are still many problems in the current research. The research on the application of cereal β-glucan in fermented dairy industry is not deep enough, and there is no perfect research system. Further study on the effect of cereal β-glucan on the structure and function of dairy products is an important direction of the future research.

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Qu Xiaoqing, PhD student of food technology, Sumy National Agrarian University. Address: Herasyma Kondratjeva str., 160, Sumy, Ukraine, 40021. Tel.: +380632232975; e-mail: qingyang2719@163.com.

Цю Сяодзинь, асп. харчових технологій, Сумський національний аграрний університет. Адреса: вул. Герасима Кондратьєва, 160, м. Суми, Україна, 40021. Тел.: +380632232975; e-mail: qingyang2719@163.com.

Nazarenko Yulia, PhD in Tech. Science, Associate Professor, The Technology and Safety of Food products Department, Sumy National Agrarian University. Adress: Herasyma Kondratjeva str., 160, Sumy, Ukraine, 40021. Tel.: +380507677919; e-mail: nazarenko.sumy@gmail.com.

Назаренко Юлія, канд. техн. наук, доц., кафедра технологій та безпечності харчових продуктів, Сумський національний аграрний університет. Адреса: вул. Герасима Кондратьєва, 160, м. Суми, Україна, 40021. Тел.: +380507677919; e-mail: nazarenko. sumy@gmail.com.

Li Bo, Doctor of Food Science, Professor, School of Food Science, Henan Institute of Science and Technology. Adress: Xinxiang, PR China, 453000. Tel.: +8613782509320; e-mail: libohnxx@163.com.

Лі Бо, д-р харчових наук, проф. Школи харчових наук, Інститут науки і техніки Хенаня. Адреса: Сіньсян, КНР, 453000. Тел.: +8613782509320; e-mail: libohnxx@163.com.

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ДОСЛІДЖЕННЯ ТА ПОРІВНЯЛЬНИЙ АНАЛІЗ ВЛАСТИВОСТЕЙ РІЗНИХ ВИДІВ М'ЯСНОЇ СИРОВИНИ

Г.В. Запаренко, В.В. Дорожко, О.Г. Дьяков,
А.О. Борисова, І.В. Галясний

Досліджено функціонально-технологічні властивості м'яса страуса порівняно з властивостями курятини, яловичини та свинини. Виявлено, що страусятина характеризується підвищеною вологопоглинальною та вологоутримуючою здатністю порівняно з іншими видами м'ясної сировини, має кращі емульгуючі властивості й менше втрачає масу під час термічної обробки.

Ключові слова: *м'ясо страуса, курятина, яловичина, свинина, функціонально-технологічні властивості.*