https://doi.org/10.17221/67/2023-CJFS

Review on nutritional benefits of triticale

*Svetlana Kamanova[1], Yernaz Yermekov[1], Kamran Shah[2], Aiziguli Mulati[3], Xuebo Liu[3], Berdibek Bulashev[1], Dana Toimbayeva[1], Gulnazym Ospankulova[1]**

[1]*Department of Food Technology and Processing Products, Technical Faculty, Saken Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan*
[2]*College of Horticulture, South China Agricultural University, Guangzhou, China*
[3]*Laboratory of Functional Chemistry and Nutrition of Food, College of Food Science and Engineering, Northwest Agriculture and Forestry University, Yangling, Shaanxi, China*

**Corresponding author: bulashevag@mail.ru*

Citation: Kamanova S., Yermekov Y., Shah K., Mulati A., Liu X., Bulashev B., Toimbayeva D., Ospankulova G. (2023): Review on nutritional benefits of triticale. Czech J. Food Sci., 41: 248–262.

Abstract: Triticale (× *Triticosecale* Wittmack) is a hybrid cereal prepared by crossing wheat and rye. Triticale grain contains substances that have a positive effect on reducing the risk of cardiovascular disease, obesity, cancer, and type 2 diabetes, as well as increasing body's immune response and intestinal function, which warrants a need for greater attention to research on triticale crop's nutritional composition. This review covers the most recent research on the nutritional composition of triticale grain in comparison to other cereals, its role in the food industry, and its usage as a food, providing a scientific foundation for triticale's further development as a sustainable crop. Due to the wide variety of chemical compounds revealed in triticale grain, it has the potential to be utilised as a substitute cereal for various food and beverages.

Keywords: cereals; carbohydrates; proteins; phenolics; polysaccharides

Triticale was first produced in the 19th century to acquire a high-yield, disease-tolerant crop with a unique nutritional composition (Ammar et al. 2004). Triticale (× *Triticosecale* Wittmack) is the product of the artificial crossing of tetraploid wheat's (*Triticum aestivum*) and ryes' (*Secale cereals*) genomes, resulting in a hexaploid (AABBRR) complete type or octoploid (AABBDDRR) substituted type of triticale. Triticale which has all the R chromosomes from rye is called complete triticale (AABBRR). This type of triticale retains most of the adaptive characteristics of rye for proper plant growth in those agricultural areas where soil and climatic conditions are unsuitable for wheat. Substituted type (AABBDR) refers to a hybrid, where ryes' chromosome 2R has been substituted with common wheat' chromosome 2D (Lukaszewski 2006), this type has a better baking quality of triticale flour (Zeller and Hsam 1983; Singh et al. 1990, Pérez et al. 2003). Triticale grain generally contains more vitamins and minerals than rye or wheat grains (Chopadeand et al. 2017).

Over the last 10 years, triticale production increased worldwide, mainly in Poland, Germany, France, Belarus, and Russia (FAOSTAT 2018). Myriads of triticale varieties are available on the global market, including Belcanto, Panaso, Corado, et cetera. Two triticale Dauren and Rossika varieties were created in Saken Seifullin Kazakh Agrotechnical University (Noncommercial Joint Stock Company).

Supported by the Ministry of Agriculture of the Republic of Kazakhstan (Project No. BR10764998, Development of technologies using new strains of beneficial microorganisms, enzymes, nutrients, and other kits in the production of special dietary foods).

https://doi.org/10.17221/67/2023-CJFS

Triticale, along with other cereals, is known for its excellent nutritional value, high protein content, and particularly for its higher amount of lysine (Kies and Fox 1970). Compared to wheat bread, Triticale bread is inferior in its sensory qualities but outperforms it in nutritional value (Heger and Eggum 1991). V. Zečević et al. studied the influence of nitrogen and environmental factors on the quality of winter triticale varieties and found that when applying 120 kg·N·ha^{-1}, the highest accumulations of wet gluten content were noted. However, the technological quality of triticale varieties is improving but remains at the level of the third class (Zečević et al. 2010).

Triticale plays a unique role in producing dietary bread for patients with metabolic diseases, which explains why global demand for triticale production has risen in recent years (FAOSTAT 2018). In general, triticale grain helps to control diabetes (Havensone et al. 2017), improves digestion, boosts circulation, increases cell production, and boosts bone growth. Some studies have shown that triticale flour is better suited to produce crackers (Leon et al. 1996; Pérez 2003; Serna-Saldívar et al. 2004) and other unleavened products (Skovmand et al. 1984) than for baking bread.

Triticale contains phenols and dietary fibres (soluble and insoluble) with antioxidant activity (alkylresorcinols, proanthocyanidin) (Straumīte et al. 2017), vitamins, macro- and microelements (Buchholz et al. 2012), and polysaccharides (arabinoxylans, fructan, β-glucan, and cellulose) (Hosseinian and Mazza 2009; Jonnala et al. 2010; Rakha et al. 2012; Knudsen 2014).

Despite all these triticale grains are cultivated and consumed much less than other grain crops, which may be explained by the lack of more detailed information on their nutritional value. The aim of this work is to research triticales components for their potential use in food production.

MATERIAL AND METHODS

Nutritional composition of triticale grain

The morphological parts of the triticale grain don't differ significantly from its parent species (Surget and Barron 2005; Sapirstein and Bushuk 2016). Triticale grain, like wheat and rye, consists of three core parts: bran, endosperm, and germ (Evers et al. 1999).

Figure 1 depicts a longitudinal segment of a triticale caryopsis and shows the relative positions of bran, en-

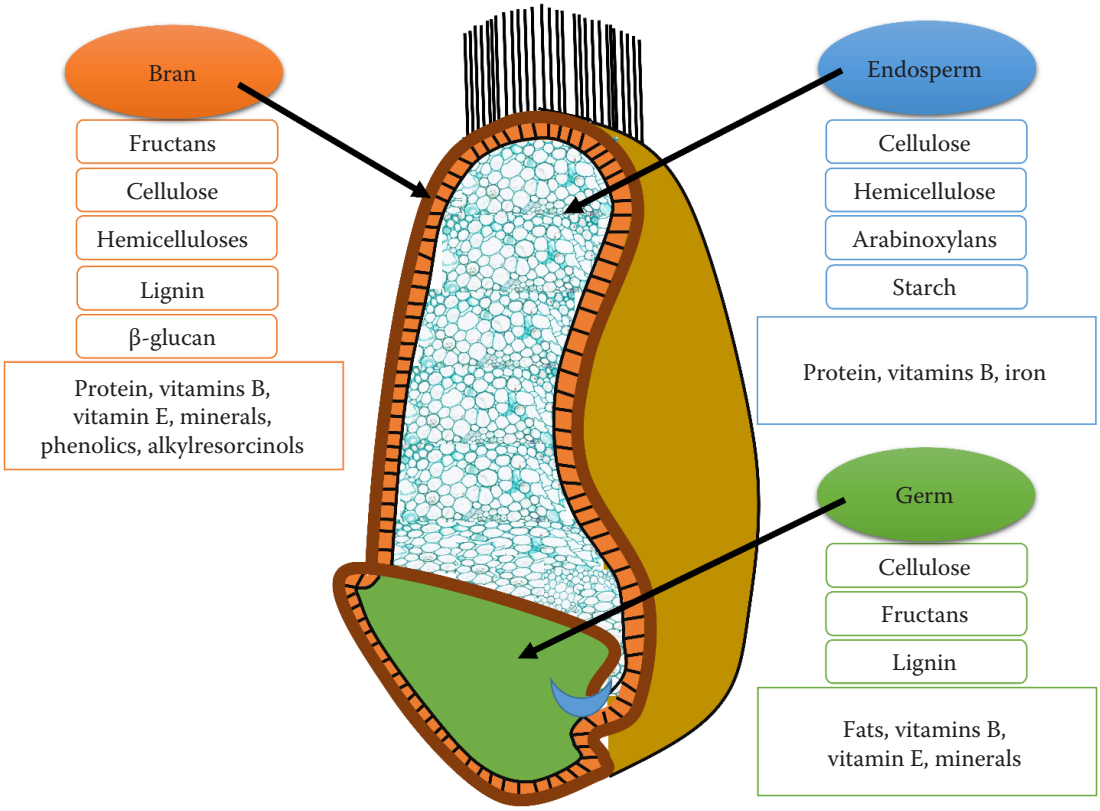

Figure 1. A schematic illustration of the composition of bran, endosperm, and germ in a longitudinal section of triticale grain

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dosperm, and germ. Bran is a rich source of fructans, cellulose, hemicellulose, lignin, β-glucan, protein, vitamin B and E, minerals, phenolics, and alkylresorcinols. The endosperm contains cellulose, hemicellulose, arabinoxylans, starch, protein, vitamin B, and iron (Joye 2020). The germ contains cellulose, fructans, lignin, fats, vitamins B and E, and minerals. This means triticale can be utilised as an alternative cereal in the manufacture of foods and beverages, moreover triticales' whole grain flour like whole grain flour from its parental species (wheat and rye) (Schmiele et al. 2012), due to the large variety of chemical compounds found in it, has a better nutritional value than its' flour, production process which includes removal of bran. Analogous benefits are also observed in whole grain flours of triticales parental species – wheat and rye (Schmiele et al. 2012).

Triticale mainly contains starch and non-starch polysaccharides, which are widely studied, as well as other chemical components, the composition of which depends on genetic and environmental factors, research on which is lacking (Hurkman et al. 2003; Liu et al. 2011).

Table 1 shows how triticale has beneficial benefits for the human body. However, the specific mechanisms are still unknown (Agil and Hosseinian 2014).

Baking qualities of triticale. Triticale is a good protein source on par with wheat and other cereals, also containing a high lysine content. Triticale bread is inferior to wheat bread in terms of sensory rating after baking, but it outperforms wheat bread regarding nutritional value (Heger and Eggum 1991).

Production of bakery goods and pasta products currently grows at a faster rate than other food categories, even though whole-grain flour benefits the human body due to its biologically active compounds, there are technological problems associated with the

Table 1. Selected components of triticale grain and their functions

Component	Feature	References
Carbohydrates	amylopectin and amylose affect gelatinisation, retrogradation, water absorption, and paste viscosity	Cornejo-Ramírez et al. 2015
Phenolic compounds	antimicrobial activity	Reiss 1989; Iwatsuki et al. 2003
	antimutagenic activity	Fardet 2010
	antioxidant activity	Hladyszowski et al. 1998
	inhibit the accumulation of triglycerides and protect against oxidation	Agil et al. 2016
	antioxidant, anti-inflammatory properties	Roca-Rodríguez et al. 2014
	antitumor properties	Prasad et al. 2012
	neuroprotective effect	Hucheng Chen et al. 2018
Polysaccharides	reduce postprandial responses to glucose and insulin	Juntunen et al. 2002; Sierra et al. 2002
	increases insulin sensitivity in both diabetics and non-diabetics	Alminger and Eklund-Jonsson 2008
	absorb free radicals, reduce oxidative stress	Malunga et al. 2017
	prebiotic action	Raschka and Daniel 2005
	increase the bioavailability of copper, iron, magnesium, and zinc	Coudray et al. 2006; Lobo et al. 2009
	chemoprophylaxis of colon carcinogenesis	De Moura et al. 2012
	increases the absorption of calcium	Cashman 2003
Minerals	functional part of various enzymatic processes in gluconeogenesis	Lee et al. 2000
	the main antioxidant component found in cereals	Rayman 2000
Protein	antioxidant action, anti-inflammatory and anti-tumour properties lower cholesterol	De Lumen 2005; Nakurte et al. 2012; García-Nebot et al. 2014

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deterioration of the real properties of the dough, and hence the poor quality of the final product (Cappelli and Cini 2021).

Salehi and Arzani (2013) investigated the effect of field salinity stress on grain quality traits in eighteen triticale lines.

Woś and Brzeziński (2015) described a process for making line triticale BOH 1512 (Panteon) with good baking quality and high yield. Triticale flour has a high amylase activity; therefore, the dough cannot be baked thoroughly.

Aprodu and Banu (2016) conducted a comparative analysis of the physicochemical and technological properties of triticale, rye, and wheat. Triticale, among the studied crops, had the lowest dough development time, dough stability and weakening. The dough had insufficient plasticity, however, the results showed that the triticale bread was superior compared to the rye samples. Tayyar (2014) studied some of the chemical and technological properties of Turkish triticale genotypes and found significant differences between triticale genotypes for the traits studied, including grain moisture, protein content, gluten content, gluten index, green precipitation, modified precipitation, shedding amount, and ash. The results showed that the triticale genotypes had the worst bread-baking quality and could be used in mixtures with baking wheat.

Some researchers have developed methods that allow goods to be made from triticale flour without adding wheat flour. In Australia and the United States, triticale grain flour is widely used for making bread, muffins, cakes, cookies, and other bakery products (Peña-Bautista 2004; Kurishbayev et al. 2020).

Carbohydrates

Carbohydrates are vital in diets that lower the risk of type 2 diabetes and heart disease. Whole grain products are high in fibre, and significantly contribute to total cholesterol reduction, and help with glycemic index management in patients with diabetes (Mann 2007). Carbohydrates make up most of triticale's dry weight, accounting for more than 70% [73.14 g·(100 g)$^{-1}$]. Cornejo-Ramírez et al. (2015) found that the complete type of triticale contains 8.8% more total carbohydrates and 13.8% more starch than the substituted type. The total content of carbohydrates of whole grain flours of rye (Malafronte et al. 2022) and wheat (Iqbal et al. 2022) averages around 76.3% and 61.3%, respectively.

Starch. The starch of cereals is synthesised depending on the environment (growing temperature 28–37 °C) and genotype (Hurkman et al. 2003; Liu et al. 2011). Triticales' average starch content ranges from 66.3% to 68.5%, and its amylose level ranges from 23.4% to 28.5%. Whereas the starch content in wheat grain is 73.2%, amylose 33.0%, in rye grain, the starch content is 72.1%, amylose 25.0% (Burešová et al. 2010). Due to the size of the starch granules, substituted triticale has less amylose than complete triticale (Ao and Jane 2007; Navarro-Contreras et al. 2014).

Triticale starch granules have bimodal distribution (Stoddard 1999; Wilson et al. 2006; Ao and Jane 2007), A-type granules have a lenticular or disc-shape with a diameter of 10–35 μm (Ao and Jane 2007; Li et al. 2011), whereas B-type granules have a spherical shape with a diameter of 2 μm (Ao and Jane 2007). The quantity of amylopectin and amylose in different types (A, B-type) of grain starches varies, affecting physical and chemical properties (Cornejo-Ramírez et al. 2015). The size and shape of type A and B granules of starch of barley, wheat, and triticale are important characteristics that determine the degree of starch decomposition, viscosity, and gelatinisation temperature (Stevnebø et al. 2006; Ao and Jane 2007). These characteristics are essential in starch and bakery industries (Shinde et al. 2003; Park et al. 2009).

Polysaccharides. Polysaccharides have been shown to reduce the risk of diet-related severe diseases such as colorectal cancer and diverticular disease (Topping 2007). Arabinoxylans and β-glucans are the most important polysaccharides of the cell wall that have high molecular weight and are partially soluble in aqueous media, so they form solutions with high viscosity (Collins et al. 2010). Thus, arabinoxylans and β-glucans contribute to the soluble fibre component in the human diet, positively affecting the human body (Collins et al. 2010). The content of water-soluble non-starch polysaccharides (WHPs) in wheat, rye, triticale, barley, and oats grain is 680, 719, 673, 651, and 641 mg·g^{-1}, respectively (Girhammar and Nair 1992).

Arabinoxylans. The primary polysaccharides of the cell wall arobynoxylans, a kind of pentosan, have a positive effect on human health, playing a key part in numerous physiological processes and disease prevention mechanisms (Agil and Hosseinian 2014; Straumīte et al. 2017). The content of arabinoxylans in rye grain is in the range 8–12%, wheat 4–8% (Korge et al. 2023), and 6–8% in triticale (Bona et al. 2014). The molecular weight and degree of substitution (the ratio of arabinose to xylose) of arabinoxylans significantly impact their physiological functions (Chen et al. 2019).

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Oxidation of glucose and proteins can result in the creation of free radicals (Wright et al. 2006), which may damage islet cells, resulting in insulin resistance and inflammation. Arabinoxylans can absorb free radicals, thereby lower oxidative stress (Malunga and Beta 2015a, 2015b; Malunga et al. 2017) and lowering the risk of cardiovascular disease and type 2 diabetes (Mendis et al. 2017; Chen et al. 2018). According to studies, the antioxidant function of arabinoxylans is negatively related to the degree of substitution (Malunga and Beta 2015a, 2015b), and arabinoxylan hydrolysates with a high degree of substitution may be helpful in reducing inflammation in colon cancer cells (Mendis et al. 2017).

β-glucan. Like other crops, Triticale grain has a type of dietary fibre known as β-glucan. Itis added to food because it has the potential to generate high-viscosity solutions in the human intestine, which benefits the human body (El Khoury et al. 2012). Furthermore, no adverse effects have been reported. while adhering to a β-glucan rich diet consisting of oat or barley and their derivatives (Hallfrisch and Behall 2003). Content of β-glucan in triticale, wheat, and rye grain averages around 0.3–1.2, 0.5–1, and 1.3–2.7 g, respectively (Bacic et al. 2009).

Plant β-glucan is a viscous dietary fibre that is used to treat a wide variety of metabolic syndromes. For example, obese individuals with hypercholesterolemia who consumed 15 g of yeast β-glucan for 8 weeks saw a rise in High-Density Lipoprotein (HDL) and a decrease in total cholesterol content 4 weeks after (Nicolosi et al. 1999). In addition, when β-glucan was introduced to a diet low in saturated fat and cholesterol, the concentration of low-density lipoprotein cholesterol dropped by 5–10% in individuals with hypercholesterolemia and diabetes mellitus (Sierra et al. 2002). The metabolic syndromes include insulin resistance (with or without hyperglycemia) and type 2 diabetes (El Khoury 2012). In both groups with and without diabetes, β-glucan has been demonstrated to lower postprandial insulin and glucose responses and increase insulin sensitivity (Juntunen et al. 2002; Alminger and Eklund-Jonsson 2008). Additionally, in comparison with a glucose control solution [25 g·(180 mL)$^{-1}$ test drink], a beverage containing 25 g·(180 mL)$^{-1}$ of β-glucan isolated from cereals may attenuate postprandial glycemic response and insulinemic reactions in healthy people (Kendall et al. 2008).

Fructan. Fructans are prebiotics that supports the immune system, have a chemoprophylactic effect on colon carcinogenesis (de Moura et al. 2012), stimulate the growth of gastrointestinal bacteria (Gibson et al. 2005), improve relaxation (Szajewska et al. 2006), increase calcium absorption (Cashman 2003), maintain a functional barrier of the intestinal mucosa (Kleessen and Blaut 2005), and reduce the risk of gastrointestinal infection (Gibson et al. 2004). Lowering blood glucose levels (Rumessen et al. 1990), serum cholesterol, triglycerides, and phospholipids are among the other advantages (Williams 1999).

Rakha et al. (2011) found the fructan content of triticale grain ranged from 1.6 to 2.9 g·(100 g)$^{-1}$. The fructan content in wheat grain has been determined to be 0.9–1.8 g·(100 g)$^{-1}$ (Fretzdorff and Welge 2003). Finnish rye grain contained 4.6–6.6 g·(100 g)$^{-1}$ (Karppinen et al. 2003).

Due to the effect on absorption rates in the human intestinal tract, Abrams et al. (2007) investigated the effect of inulin-type fructans on increasing calcium absorption and concluded that adolescents who consumed inulin-type fructans daily had better calcium absorption and higher bone mineral content. It has been found that inulin-type fructans promote calcium absorption primarily due to their influence on colon absorption. Inulin-type fructans have a physiological effect on the human body in addition to benefits to intestinal health. Inulin-type fructans have also been found to increase the bioavailability of iron, copper, zinc, and magnesium in mice (Raschka and Daniel 2005; Coudray et al. 2006; Lobo et al. 2009), but such effects have not been observed in humans (Coudray et al. 1997).

Proteins

Lack of protein in the human organism is associated with an increased risk of diseases such as poor lipid metabolism and heart disease (Appel et al. 2005; Tulchinsky 2010). The content of amino acids in winter triticale is a genetically determined trait. Still, it also depends on the production technology, the percentage of grain in the crop rotation, and weather conditions. (Jaśkiewicz and Szczepanek 2018).

Triticale, along with other cereals, is known for its great nutritional value, rich protein content, and particularly for its higher amount of lysine, which is the principal limiting amino acid in cereal grains (Kies and Fox 1970). Navarro-Contreras et al. (2014) found that triticale protein has a more considerable proportion of globulin 19.7–30.2%, albumin 38–45.4%, gliadin content 11.4–26.1%, and a smaller proportion of gluten (6.8–9.6%) and residual fractions compared to wheat and rye proteins. In addition to albumin, globulin, and gliadin, triticale grain contains lunasin, which has yet

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to be widely explored about its helpful qualities and effects on the human body.

Lunasin. Lunasin is a 43-amino-acid peptide in soybeans and cereal grains such as barley, rye, wheat, and triticale (Nakurte et al. 2012). Lunasin controls an epigenetic mechanism that can be beneficial in the initial stages of the carcinogenic process. Lunasin possesses anti-inflammatory and anti-tumour characteristics and the ability to lower cholesterol. Database searches of transcriptomes and DNA sequences encoding lunasin or protein precursors in wheat and other cereals have not shown the presence of peptide lunasin (Mitchell et al. 2013). Lunasin was found to be lacking in wheat varieties in follow-up research employing chemical liquid chromatography-electrospray ionisation mass spectrometry (LC-ESI-MS) and molecular polymerase chain reaction (PCR) (Dinelli et al. 2014). However, Nakurte et al. (2012) and Mitchell et al. (2013) found a higher content of peptide lunasin in triticale at 6.5 mg·g^{-1}, compared to wheat's 0.23 mg·g^{-1} and rye's 1.5 mg·g^{-1}.

According to Nakurte et al. (2012), triticale grain can play an essential role in functional nutrition. The antioxidant effect of lunasin on enterocytes exposed to oxidising chemicals was investigated by García-Nebot et al. (2014). These findings have biological significance because the intestinal concentration of lunasin can be much greater than the blood serum concentration, implying that this peptide may help protect the intestinal mucosa integrity against problems linked to oxidative damage (Blanca et al. 2009). These findings pave the way for more research into lunasin's antioxidant activity in other cell lines and its potential as a chemopreventive and cardioprotective drug. Although the lunasin peptide is sensitive to the action of digestive enzymes during its transit through the gastrointestinal tract, the shorter fragments released after its cleavage also exhibit biological activity, according to Indiano-Romacho et al. (2019) studies.

Mammalian cells were induced with chemical carcinogens and viral oncogenes, and the action of lunasin on them showed anticancer efficacy. This peptide has also been shown to prevent skin cancer in mouse models with chemical carcinogen-induced cancers (Blanca et al. 2009).

Vitamins, minerals

Whole grains contain elements necessary for the human body, the inner shell of bran contains phosphates and other mineral salts, and the embryonic axis includes vitamins B and E (Kumar et al. 2011).

Triticale grain contains vitamin E 0.47 mg%, vitamin P 4.5 mg%, and vitamin C 2.3 mg%, which differs from wheat (Bazhay-Zhezherun et al. 2016). Buchholz et al. (2012) found that triticale had a total thiamine level of 9.69 nmol·g^{-1} dry matter (DM), while wheat had a total thiamine content of 7.67 nmol·g^{-1} DM. Like triticale, wheat, rye, oats, and barley do not contain thiamine triphosphate or adenosine triphosphate (Zhu 2018). Wheat grain 0.34 mg% of vitamin E, 3.9 mg% of vitamin P, and 2.6 mg% of vitamin C (Bazhay-Zhezherun et al. 2016).

Vitamin E protects unsaturated fatty acids from free radicals, increases blood circulation, and reduces the risk of blood clots (Boshtam et al. 2002). Vitamin C is a component of redox systems; it stimulates cholesterol oxidation, participates in the creation of connective tissue structures, and contributes to the formation of a variety of hormones that have a beneficial influence on the organism's immune system. P-vitamin-containing substances thicken the walls of capillaries, lowering their permeability (Figueroa-Méndez and Rivas-Arancibia 2015). The phytic acid concentration in triticale grains can bind to minerals, reducing their bioavailability. The phytic acid content of triticale grain is 1.92 mg·g^{-1}, which is significantly higher than in wheat (0.26 mg·g^{-1}). The total phosphorus content of triticale is 3.48 mg·g^{-1}, comparable to rye and wheat phosphorus content. Phytase can increase mineral bioavailability and complete phytic acid hydrolysis (Mikulski and Kłosowski 2015).

Triticale's chemical composition differs from that of rye and wheat, and it falls somewhere amid these two cereals. Triticale grain has more magnesium (Mg), calcium (Ca), potassium (K), zinc (Zn), sodium (Na), and copper (Cu) than wheat grain (Figures 2, 3) (Rodehutscord et al. 2016). In terms of potassium (K) content (5.03 g·kg^{-1}), wheat in terms of iron (Fe) content (31.5 mg·kg^{-1}), and manganese (Mn) content (29.8 mg·kg^{-1}), triticale is inferior to rye and wheat.

The content of K and Ca in triticale grain is higher than in the wheat grain but lower than in the rye grain, whereas Mg content is higher than in the rye grain but lower than in the wheat grain (Figure 2).

Zhu (2018) investigated the concentration of macro- and micro-elements in various triticale grains and discovered that content of potassium (K) [466 mg·(100 g)$^{-1}$] was the highest, followed by phosphorus (P) [321 mg·(100 g)$^{-1}$], magnesium (Mg) [153 mg·(100 g)$^{-1}$], calcium (Ca) [35 mg·(100 g)$^{-1}$], and sodium (Na) [2 mg·(100 g)$^{-1}$], iron (Fe) [2.59 mg·(100 g)$^{-1}$] and zinc (Zn) [2.66 mg·(100 g)$^{-1}$] and manganese (Mn)

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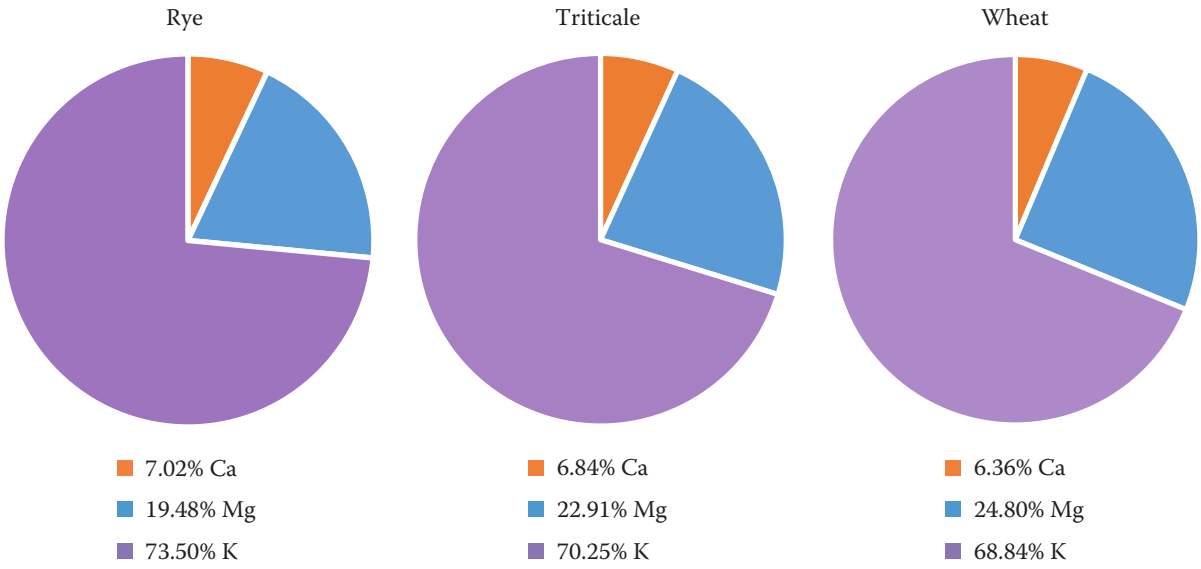

Figure 2. The concentration of major macro-minerals in different cereal grains

Ca – calcium; Mg – magnesium; K – potassium

[3.2 mg·(100 g)$^{-1}$] which also had the highest concentration of micro-elements. The high magnesium content of triticale grains provides excellent protection for insulin-dependent individuals. Magnesium has a role in gluconeogenesis through a variety of enzymatic pathways.

The main source of selenium in human nutrition is grain crops. On average, spring wheat contains 72 mg·kg^{-1}, while spring rye contains 85 mg·kg^{-1} Se. The selenium content in the spring triticale grain was 81 mg·kg^{-1}, which exceeds the value of spring wheat and is at the level of rye (Bóna et al. 2009). Selenium is found in plants as selenomethionine, which can be incorporated into the structure of proteins instead of methionine, linking to important amino acids, and is used to store selenium in plant organs and tissues. The grains' nuclei contain most of this amino acid (Ciappellano et al. 1990; Schrauzer 2001). Rodehutscord et al. (2016) studied the amino acid content

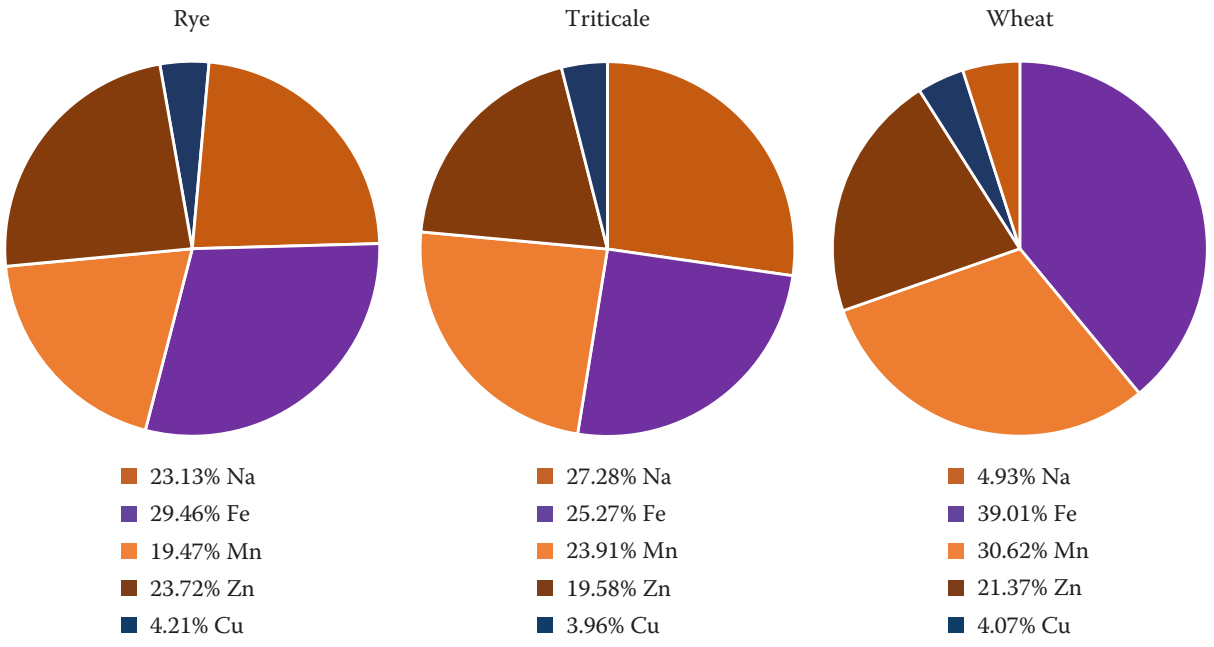

Figure 3. The concentration of major micro-minerals in different cereal grains

Na – sodium; Fe – iron; Mn – manganese; Zn – zinc; Cu – copper

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of cereals and discovered different variances between genotypes. Triticale grain has higher methionine content [1.57 g·(16 N)$^{-1}$] than wheat [1.47 g·(16 N)$^{-1}$] and rye [1.52 g·(16 N)$^{-1}$], the results of the studies presented in Figure 4.

Selenium is a key antioxidant in cereal crops that protects cells from oxidative damage by boosting glutathione peroxidase and thioredoxin reductase activity (Lee et al. 2000; Rayman 2000). Selenium has been shown to have anti-carcinogenic, causing cell death, inhibiting oxidation and modulating the immunological response properties (Combs and Gray 1998; Ganther 1999; Kim et al. 2011). Selenium protects against cardiovascular disease, viral infections, and ageing (Rayman 2000). Hwang et al. (2006) found that selenium is a crucial micro-element that can reduce the risk of several types of malignant tumours. Pathways involving cyclooxygenase-2 have been related to protecting against various malignant tumours, including colon cancer. They discovered that the COX-2/prostaglandin E (2) signaling pathway mediates the key anticancer effects of selenium through AMP-activated protein kinase (AMPK), which serves as a cellular energy sensor. Selenium-activated AMPK reduced COX-2 expression in tumour xenografts and colon cancer cell lines. Several investigations are underway into the concentration of selenium and Selenomethionine amino acids in triticale.

Phenolic compounds

Cereal bran is high in phenolic compounds that have anti-inflammatory characteristics along with beneficial effect on the gastrointestinal tract (Laddomada et al. 2015) and may lower the risk of colon cancer (McRae 2017; He et al. 2019). Proanthocyanidins, polymeric versions of catechins, are found in whole grains of various cereals (Holtekjølen et al. 2006), and the bioavailability of phenolic acids in whole grains determines their biological action. 75% to 80% of wheat phenolic acids are bound phenolic acids (Fernandez-Orozco et al. 2010). Whole-grain phenolic acids contain anticancer, antibacterial, antioxidant, and anti-inflammatory properties (Shahidi and Yeo 2018). Polyphenols are natural antioxidants with a wide range of biological functions (Scalbert et al. 2005). Studies have reported the content of various polyphenols (free and bound) in the composition of multiple genotypes of cereals that have different biological activities in human nutrition (Irakli et al. 2012; Kandil et al. 2012; Zhu 2018). Phenolic acids such as coumaric, ferulic, gallic, hydroxybenzoic, vanillic, syringic, and sinapic acids are found in both free and bound forms in triticale (Irakli et al. 2012). Ferulic acid accounts for 90% of the total amount of phenolic acids. Due to its high ferulic acid content, enzyme-treated bran can be employed as a functional food ingredient (Kim et al. 2006). According to Hosseinian and Mazza (2009), most phenol-

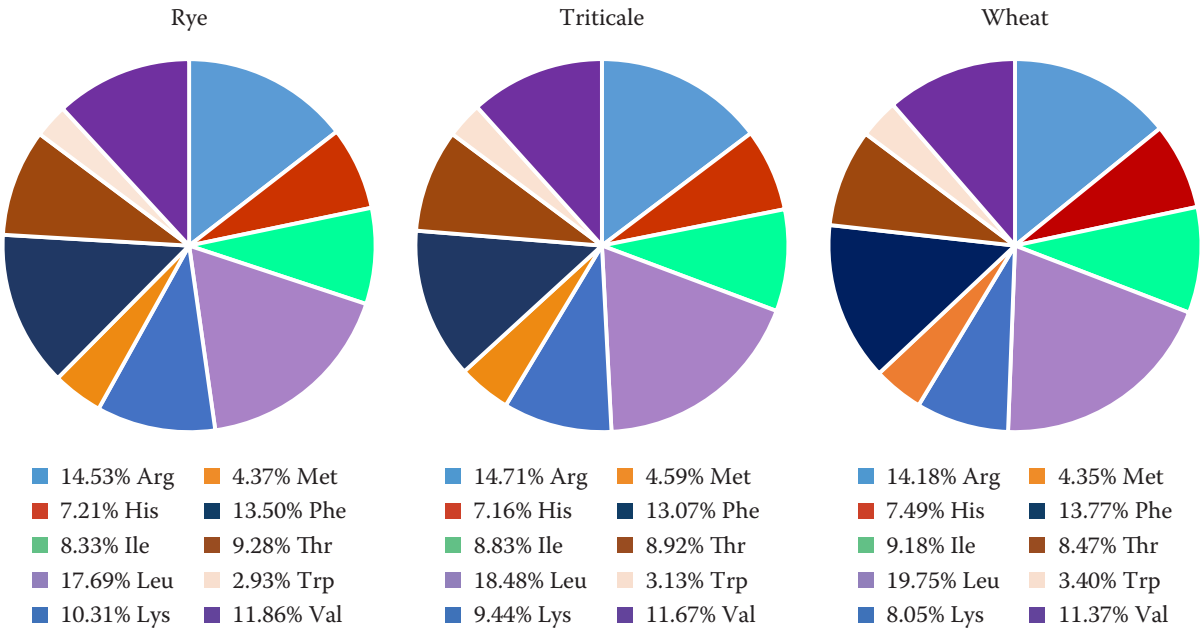

Figure 4. The concentration of essential amino acids (AA) in the crude protein of different cereal grains

Arg – arginine; His – histidine; Ile – isoleucine; Leu – leucine; Lys – lysine; Met – methionine; Phe – phenylalanine; Thr – threonine; Trp – tyrosine; Val – valine

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ic acids were present in bound form in wheat, rye, and oat bran. Triticale, wheat, rye, and oat bran contained 9.9, 13.7, 12.3, and 2.8 mg of free phenols per 100 g, and 270.7, 439.9, 253.4, and 85.1 mg of bound phenols per 100 g, respectively. Grain such as triticale has a lot of phytic acids (Reddy et al. 1982), and it is also known as an antioxidant, even though it is typically considered an antinutrient due to its capacity to bind minerals (Graf et al. 1987). Graf and Eaton (1993) proposed that phytic acid forms chelates with various metals that prevent iron from catalysing the damage of redox reactions, their findings showed that colon bacteria produce substantial amounts of oxygen radicals and that dietary phytic acid can protect the intestinal epithelium and adjacent cells from oxidative damage.

Liu et al. (2021) found that bound phenols from triticale before digestion inhibited 95% of α-glucosidase and 97% of α-amylase, indicating a good hypoglycemic ability. Kaszuba et al. (2021) studied the content of phenolic acids in the grain of Polish varieties of triticale and found that the grain contained 13 phenolic acids, of which 42–44% was represented by ferulic acid. The number of phenolic acids was significantly lower in triticale flour. than in grain. It has been established that a substantial proportion of phenolic acids are present in bran, so using bran in the bread recipe will increase the content of phenolic acids by 3.5 times.

Alkylresorcinols. In cereals, alkylresorcinols (AR) are phenolic lipids and triticale is a reliable source of AR, which is concentrated in the grain's husk. Scientists have found that the AR content in triticale bran ranges from 277.5 to 308.3 mg·(100 g)$^{-1}$ (Agil 2016) and wheat bran from 221 to 323 mg·(100 g)$^{-1}$. The content of alkylresorcinols ranges from 48.9–61.8 mg·(100 g)$^{-1}$ in wheat, 43.9–64.7 mg·(100 g)$^{-1}$ in triticale, 56.8–76.1 mg·(100 g)$^{-1}$ in the rye and 0.4–0.5 mg·(100 g)$^{-1}$ in barley on a dry weight basis (Ross et al. 2003; Mattila et al. 2005).

AR has been found to have antibacterial (Reiss 1989), antimutagenic (Iwatsuki et al. 2003), and antioxidant (Hladyszowski et al. 1998) effects due to the existence of water-insoluble hydrocarbon chains with polar water-soluble OH-groups linked to the benzene ring. Most of the current research on the biological importance of AR comes from *in vitro* investigations. Whole grains have three key benefits: antioxidant (because of AR and phenolic acids) (Stevenson et al. 2012), mechanical (due to fibre content), and nutritional aspect. Epidemiological data suggests that eating whole grain cereals products has health benefits, including lowering obesity and the risk of diabetes, cancer, and coronary heart disease (Hallmans et al. 2003; Shahidi and Chandrasekara 2013; Sang and Zhu 2014; Chanson-Rolle et al. 2015; Seo et al. 2015). The amount of AR or its metabolites found in the human body is related to the number of whole-grain foods consumed.

The human body absorbs AR absorption in its native form and can be found unchanged in blood plasma and as metabolites in urine samples (Ross et al. 2004; Aubertin-Leheudre et al. 2008; Landberg et al. 2011; Ross 2012; Andersson et al. 2014; Meija et al. 2015; Onipe et al. 2015; Biskup et al. 2016; Bordiga et al. 2016).

AR is at a maximal micromolar concentration in blood plasma after whole grain consumption and reaches minimal nanomolar concentration under fasting. AR has the potential to alter a variety of physiological and pathological processes related to the immune system's metabolism and function (Gąsiorowski et al. 1996; Stasiuk and Kozubek 2010). Agil et al. (2016) studied the effects of AR extracted from triticale bran, which was added to a high-fat diet, on the development of obesity and oxidative stress. This study discovered that AR extracted from triticale was a functional product that helped to avoid oxidative processes in obesity-related diets.

Proanthocyanidins. Proanthocyanidins are a type of flavonoid that is 20 times more potent than ascorbic acid and 50 times more effective than vitamin E and selenium as antioxidants. Due to their antioxidant, anti-inflammatory, and anticancer (Prasad et al. 2012) qualities, proanthocyanidins are gaining popularity in nutrition and medicine.

The total content of proanthocyanidin in the bran of triticale is 265.4 mg·(100 g)$^{-1}$, which is higher than in the bran of rye [212.0 mg·(100 g)$^{-1}$] but less than in the bran of wheat [509.4 mg·(100 g)$^{-1}$] (Hosseinian and Mazza 2009). Proanthocyanidins are present in the external layer of the membrane (McCallum and Walker 1990; Naczk and Shahidi 2006). Hucheng Chen et al. (2018) studied the neuroprotective effect of proanthocyanidins via reactive oxygen types/c-Jun N-terminal kinase (JNK) signaling in models of 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP) induced Parkinson disease *in vitro* and *in vivo*. The results showed that the neuroprotective activity of proanthocyanidins could be mediated by inhibiting the generation of reactive oxygen and by modulating the activation of JNK. Epidemiological studies by Gao et al. (2012) also showed that proanthocyanidins may reduce the risk of Parkinson's disease. These data have shown that proanthocyanidins may have neuroprotective effects in models of *in vitro* and *in vivo* of Parkinson's disease and have potential in its prevention or treatment.

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CONCLUSION

The world's triticale production has risen steadily in recent years. Triticale grain has a higher biological value than wheat and rye; in terms of exchange energy content, it outperforms wheat by 14% and rye by 23% on average. Triticale has a greater lunasin concentration than rye and wheat, indicating strong antioxidant and anti-inflammatory capabilities. Triticale flour, like wheat and rye flour, includes important minerals such as potassium, phosphorus, copper, manganese, and others, in addition to high-quality protein. Triticale is used to make various meals and beverages (including bread, cookies, pasta, and malt). Triticale bran can make yoghurt as a prebiotic and antioxidant source. Triticale has obvious potential as a complement to main cereals for various dietary applications. Triticale can be fractionated to yield a variety of components, including starch, dietary fibre, and protein, which can be utilised in both food and non-food applications. Scientists have discovered that the compounds found in triticale grain have a beneficial effect on the human body at the cellular level, making it even more valuable and opening new possibilities for its application in the food industry. It should be mentioned that triticale grain contains gluten, making it unsuitable for celiac disease sufferers. Future research should look at the chemical composition of different varieties of triticale, as well as the influence of these elements on the human body at the cellular level, to identify the beneficial properties of the triticale grains' components.

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Received: April 27, 2023
Accepted: July 4, 2023
Published online: August 7, 2023