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Buckwheat: Nutritional Value, Health Effects and Applications in Foods

Serim Tuna Koç[1,a], Fatma Coşkun[2,b,*]

[1]*Yeni Yuzyil University,Nutrition and Dietetics Department ,34015, Istanbul, Türkiye*
[2]*Tekirdağ Namık Kemal University, Faculty of Food Engineering, 59030, Tekirdağ, Türkiye*
[*]*Corresponding author*

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ABSTRACT

Buckwheat (*Fagopyrum esculentum* and *Fagopyrum tataricum*) is recognized as a highly nutritious food source due to its high nutritional value and functional properties. Classified as a pseudocereal, buckwheat provides numerous health benefits owing to its high protein content, rich fiber composition, balanced essential amino acid profile, and abundance of polyphenolic compounds. As a gluten-free grain, it serves as a safe alternative for individuals with celiac disease and gluten intolerance, while its low glycemic index makes it beneficial for diabetes management. The bioactive compounds found in buckwheat, including flavonoids (rutin, quercetin), polyphenols, and fagopyritols, have been shown to exhibit antioxidant, anti-inflammatory, and cardioprotective effects. Regular consumption has been reported to reduce LDL cholesterol levels, increase HDL cholesterol levels, and lower the risk of hypertension. Additionally, buckwheat supports digestive health by regulating gut microbiota, thereby playing a protective role against inflammatory bowel diseases. With its extensive applications in the food industry, buckwheat is utilized in the production of bakery products, pasta, bread, biscuits, functional beverages, and fermented products, contributing to the development of antioxidant-rich beverages. However, due to its gluten-free nature, it can cause textural differences in baked goods, necessitating the use of stabilizers to improve product consistency and quality.

[a] *stunakoc@hotmail.com* *https://orcid.org/0000-0002-6216-6351* | [b] *fcoskun@nku.edu.tr* *https://orcid.org/ 0000-0001-8889-363X*

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Introduction

Buckwheat (*Fagopyrum esculentum*) has been recognized as a significant food source across various cultures throughout history. Belonging to the Polygonaceae family, this plant differs from other grains as a dicotyledonous species and is classified as a pseudocereal (Ahmed et al., 2014a; İnanır et al., 2019). It is believed that buckwheat was first cultivated in the Yunnan region of China and later spread to Central Asia, Europe, and the Americans. Archaeobotanical studies indicate that buckwheat farming dates back to 4000 BCE in China (Dizlek et al., 2009a; İnanır et al., 2019). After its introduction in China, it expanded to India, Central Asia, and Iran, eventually reaching Europe (Zhu, 2016). It is suggested that buckwheat was brought to Europe during the Mongol invasions of the Middle Ages. Between the 17th and 19th centuries, buckwheat was a widely consumed grain in Western Europe, particularly in France, Russia, and Poland (Christa & Soral-Smietana, 2008). However, while the production of buckwheat declined in the 20th century with the increased cultivation of wheat and corn, its production has increased since the 21st century (FAOSTAT, 2023). According to TÜİK data, the amount of buckwheat production in Turkey in 2021 was given as 1413 tons in 9603 decares (TÜİK, 2021). According to the latest FAO data, buckwheat was harvested in 1856913 hectares of land worldwide in 2020 (FAO, 2020). It is used in the production of various baked goods such as cakes, bread, pasta, noodles, muffins, bagels, crackers, cookies, crepes and tortillas, soups, puddings, desserts, canned meat and vegetable products, ice cream cones, and various dishes such as rice (Lee & Kim, 2008). It is preferred in the production of “naengmyeon” and “makguksu” in Korea, “soba noodles” in Japan and “pizzoccheri” in Italy. However, it is stated that buckwheat is a popular plant for beekeepers (Dizlek et al., 2009c). Buckwheat is a widely cultivated pseudocereal worldwide, with two main species: *Fagopyrum esculentum* (common buckwheat) and *Fagopyrum tataricum* (Tartary buckwheat) (Alkay & Kökten, 2020). Among these, *Fagopyrum esculentum* is the most preferred species in commercial production due to its larger seed size, easily removable hull, and milder flavor, making it more commonly consumed (Güneş et al., 2012). On the other hand, *Fagopyrum tataricum* is better adapted to cold and high-altitude regions, thriving particularly in the Himalayan region and southwestern China, where it is cultivated in arid and cold climatic conditions (Karataş et al., 2018).

Fagopyrum esculentum thrives in humid and cool climates and is widely cultivated in northern latitudes. It is grown across a vast geographical range, particularly in China, Russia, Ukraine, Poland, and Canada. In recent years, its cultivation has also started in Turkey, with expanding agricultural areas (Karataş et al., 2018). On the other hand, *Fagopyrum tataricum* exhibits greater resistance to lower temperatures and arid conditions. Due to its ability to grow in barren soils, it has a remarkable capacity to adapt to extreme environmental conditions (Acar et al., 2011).

The Špačinská, Lileja, and Pyra buckwheat varieties hold significant importance in agricultural production, particularly in Central and Eastern Europe. These varieties are preferred in regional agriculture due to their high yield potential and strong adaptability. Their cultivation is especially common in Slovakia and neighboring countries. However, their share in international trade remains limited, as they are primarily consumed in local markets. This situation is influenced by regional agricultural policies and market demands (Coţovanu & Mironeasa, 2022).

In general, *Fagopyrum esculentum* and *Fagopyrum tataricum* differ in climatic adaptability, agricultural production methods, and nutritional composition. These differences contribute to the diversification of their applications; *Fagopyrum esculentum* is predominantly used in baked goods, pasta, and gluten-free food production, whereas *Fagopyrum tataricum* is more commonly utilized in functional foods and health-promoting products (Germ et al., 2019).

Buckwheat is recognized as an important functional food due to its high nutritional value and positive health effects (Alkay et al., 2023). Both *Fagopyrum esculentum* (common buckwheat) and *Fagopyrum tataricum* (Tartary buckwheat) are rich in protein, dietary fiber, vitamins, and minerals. However, *Fagopyrum tataricum* has a higher polyphenol and flavonoid content compared to common buckwheat, which contributes to its stronger antioxidant capacity (Germ et al., 2019).

Despite these benefits, Tartary buckwheat is less preferred in commercial production due to its smaller grain size, harder-to-remove hull, and slightly bitter taste, making common buckwheat the more widely cultivated variety (Luthar et al., 2021).

Recent scientific studies have demonstrated that buckwheat is not only a nutritious food source but also offers various health benefits due to its bioactive compounds. Buckwheat has been reported to exhibit antioxidant, anti-inflammatory, antitumor, antimicrobial, and antidiabetic properties (Mikulajová et al., 2016). In particular, its high rutin content contributes to vascular health protection and may aid in the prevention of cardiovascular diseases (İnanır et al., 2019). Additionally, due to its low glycemic index, buckwheat is considered a suitable alternative for diabetic patients (Kılıç & Elmacı, 2018b).

When examining the nutritional composition of buckwheat, it has been determined that its protein content ranges between 8.5% and 19%. In addition, its high starch content, particularly its resistant starch fraction, exhibits prebiotic properties, supporting gut microbiota balance (Kılıç & Elmacı, 2018a). Furthermore, its rich phenolic and flavonoid composition classifies it as a functional food (Mikulajová et al., 2016). The high protein content, presence of essential amino acids (particularly its richness in lysine), dietary fiber, polyphenols, flavonoids (such as rutin and quercetin), and minerals make buckwheat a nutrient-dense and health-promoting food (Dizlek et al., 2009a; İnanır et al., 2019).

Buckwheat is widely utilized in the food industry, playing a role in the production of baked goods, pasta, bread, biscuits, and crackers. Additionally, it is also used in the manufacturing of vinegar, beer, tea, and spirits. However, it has been reported to cause allergic reactions in some individuals, and therefore, its consumption should be approached with caution. Due to its nutritional composition and functional components, buckwheat stands out as a valuable food source. Its high protein and fiber content, low glycemic index, and strong antioxidant capacity contribute to various health benefits. However, its sensory characteristics and allergenic potential require careful consideration when developing food products. To enhance consumer acceptance and expand its applications, product formulations should be optimized (Fabjan et al., 2003; Dizlek et al., 2009a).

The aim of this study is to evaluate the agronomic characteristics, nutritional composition, and potential health benefits of buckwheat (*Fagopyrum esculentum* and *Fagopyrum tataricum*). By analyzing its adaptability to different climatic conditions, functional food properties, and its applications in the food industry, this research seeks to provide a comprehensive understanding of buckwheat's significance as a sustainable and health-promoting crop.

General Composition of Buckwheat

Buckwheat (*Fagopyrum esculentum* Moench) is a widely consumed pseudocereal worldwide due to its nutritious composition and functional health properties (Steadman et al., 2001). Although it is not a true cereal, its rich content in protein, fiber, minerals, and bioactive compounds makes it a highly valuable food source (Fabjan et al., 2003; Kalinová et al., 2019). Particularly, its gluten-free nature makes buckwheat an important alternative for individuals with celiac disease and those following a gluten-free diet (Kılıç & Elmacı, 2018b; Sofi et al., 2023). In terms of protein content, buckwheat is considered to have a high biological value and is particularly rich in essential amino acids, especially lysine and arginine (Steadman et al., 2001; Li & Zhang, 2001).

Buckwheat proteins have a more balanced profile of sulfur-containing amino acids compared to traditional cereals, making them a suitable alternative for vegetarian and vegan diets (Kreft & Javornik, 1990; Kalinová et al., 2019). In terms of fiber content, buckwheat is a rich source of both soluble and insoluble fibers, which contribute to digestive health and positively influence gut microbiota (Skrabanja et al., 1998; Sofi et al., 2023). Additionally, due to its resistant starch content, buckwheat has a low glycemic index, making it a valuable component in dietary plans for individuals with diabetes (Li & Zhang, 2001; Kalinová et al., 2019). Table 1 presents the macronutrient composition of buckwheat (*F. esculentum*) (Kalinová et al., 2019).

In terms of vitamin and mineral composition, buckwheat is rich in B-complex vitamins, particularly B_1 (thiamine), B_2 (riboflavin), and B_3 (niacin), which play a

crucial role in energy metabolism (Fabjan et al., 2003; Kılıç & Elmacı, 2018a; Huda vd., 2021). Additionally, buckwheat contains higher levels of minerals compared to traditional cereals, including magnesium, iron, zinc, phosphorus, and manganese. Regular consumption has been reported to help reduce the risk of anemia (Kreft & Javornik, 1990; Steadman et al., 2001).

Buckwheat is recognized as a functional food due to its high-quality protein content, rich vitamin and mineral profile, high fiber content, and antioxidant compounds. Its gluten-free nature has expanded its use in baked goods, pasta, and other food products, while its numerous health benefits further enhance its appeal (Kılıç & Elmacı, 2018b; Sofi et al., 2023). Table 2 presents the vitamin and mineral composition of buckwheat (*F. esculentum*) (Kalinová et al., 2019).

Buckwheat is also recognized as a rich source of bioactive compounds, including flavonoids, polyphenols, and antioxidants (Kalinová et al., 2019; Sofi et al., 2023). Among these, flavonoids such as rutin and quercetin exhibit cardioprotective effects due to their antioxidant properties, while phenolic compounds have been reported to support immune system function (Li & Zhang, 2001; Fabjan et al., 2003). Table 3 presents the phenolic compound content of different buckwheat varieties (*F. esculentum* and *F. tataricum*) (Steadman et al., 2001; Fabjan et al., 2003; Kılıç & Elmacı, 2018b). Table 4 displays the phenolic compound content of the Špačinská, Jana, Lileja, and Pyra buckwheat varieties (Živković et al., 2021).

Table 1. Macronutrient Composition of Buckwheat (*F. esculentum*) (Kalinová et al., 2019)

Component	Average Content (% or mg/100 g dry matter)
Carbohydrate	60-75% (Main component: starch)
Protein	8-19% (Complete amino acid profile)
Fat	2-4% (Contains unsaturated fatty acids)
Dietary Fiber	6-10% (Contains soluble and insoluble fiber)
Water	10-15% (In fresh grains)

Table 2. Vitamins and Minerals Composition of Buckwheat (Kalinová et al., 2019)

Component (*Fagopyrum esculentum)*	Average Content (mg/100 g)
B_1 (Thiamine)	0.1-0.6
Riboflavin (B_2)	0.2-0.5
Niacin (B_3)	2-7
B_6 (Piridoksin)	0.2-0.6
E Vitamin	1.5-2.5
Magnesium	150-250
Phosphorus	250-400
Zinc	2-5

Table 3. Phenolic Compound Content (mg/100 g) of *F. esculentum* and *F. tataricum* Buckwheat Varieties (Kılıç & Elmacı, 2018b).

Phenolic Compound	*F. esculentum*	*F. tataricum*
Rutin	10-100	100-500
Quercetin	0.1-1	1-10
Catechin	1-10	10-50
Epicatechin	1-10	10-50
Hyperoside	0.5-5	5-20
Isoquercitrin	0.5-5	5-20
Isovitexin	0.5-5	5-20
Procyanidin B_2	1-10	10-50
Vanillic Acid	0.1-1	1-5

Table 4. Phenolic Compound Content (mg/100 g dry matter) of Špačinská, Jana, Lileja, and Pyra Buckwheat Varieties (Živković et al., 2021).

Phenolic Compound	Špačinská Variety	Jana Variety	Lileja Variety	Pyra Variety
Catechin	4.56	2.18	2.26	1.95
Epicatechin	25.74	1.57	0.98	1.88
Epicatechin Gallate	6.13	0.08	-	-
Hyperoside	0.55	5.33	5.88	4.75
Isoquercitrin	0.46	1.33	1.74	1.48
Isovitexin	0.60	6.39	7.23	7.25
Procyanidin B_2	11.86	1.48	1.31	1.77
Rutin	5.42	7.84	9.24	7.62
Vanillic Acid	0.31	0.48	0.37	0.32
Quercetin	0.0017	0.0017	0.0002	-

Buckwheat: Nutritional Value, Functional Properties, Health Effects, and Applications in the Food Industry

Buckwheat is 65-70% carbohydrate, 10-15% protein, 2-3% fat and 2-4% ash, and contains a high amount of protein compared to cereals. Albumin and globulin are among the most abundant proteins, while glutelin content is 20-30% high (Lee & Kim, 2008). It is rich in protein and vitamins, as well as iron, zinc, selenium and other trace elements. Polyunsaturated essential fatty acids such as linoleic acid (31-41%) are found more in buckwheat than in other grains; long-chain fatty acids, including arachid, behenic and lignoceric acids, which are found in trace amounts or absent in grains, constitute 8% of the total fatty acids in buckwheat (Hung et al., 2021). Buckwheat protein has health benefits such as lowering serum cholesterol, preventing gallstones and inhibiting angiotensin I converting enzyme (Koyama ve ark., 2013). Buckwheat (*Fagopyrum tataricum* and *Fagopyrum esculentum*) is considered a functional food with numerous health benefits due to its bioactive compounds. Scientific research has demonstrated that buckwheat plays a significant role in antioxidant, anti-inflammatory, cardiovascular protective, and metabolic disease-preventing properties (Zhou et al., 2021). In particular, flavonoids (rutin, quercetin), polyphenols, and fagopyritols are among the key bioactive compounds that enhance the health-promoting value of buckwheat (Giménez-Bastida & Zielinski, 2015).

Despite its significant amount of protein and balanced amino acid content, the biggest problem with buckwheat protein is its low digestibility. Low digestibility in common buckwheat is due to protease inhibitors such as trypsin inhibitors and tannins. Germination of buckwheat seeds causes the activity of protease inhibitors to decrease significantly. Therefore, germinated buckwheat can be considered an important food source in terms of protein (Ahmed et al., 2014c). It is reported that the calcium, phosphorus, magnesium and potassium contents of buckwheat seeds increase after seven days of germination (Pongrac et al., 2016). The germination process not only changes the amino acid and mineral amounts of buckwheat, but also increases the vitamin C, B_1 and B_6 contents (Ahmed et al., 2014c). The germination process also increases total phenolic compounds, rutin content and antioxidant activity (Zhang et al., 2015). This process increases protein bioavailability by reducing proteinase inhibitors (Ren & Sun, 2014). While the amounts of phenolic compounds, vitamins, minerals and amino acids increase during the sprouting process, oligosaccharides, trypsin inhibitors and cyanogenic glycosides decrease (Kanmaz & Ova 2014). A study determined that the amounts of free amino acids in sprouted buckwheat increased fourfold, and the content of rutin, quercitrin, fiber, lysine and vitamin C increased (Kim et al., 2004). In a study, it was reported that sprouting of legumes increased thiamine content by 8%-33%, protein content by 6.1%-9.7%, and starch digestibility by 53%-82% depending on the variety (Ghavidel & Prakash, 2007). One study found that phytic acid, which blocks the absorption of Fe, Zn and Ca, was significantly reduced by 10 days of germination. (Marshall et al., 2011). Sprouted buckwheat has a slightly crunchy texture and high nutritional value (Sytar et al., 2013). A study show that the use of sprouted buckwheat in the production of products such as granola bars provides positive contributions to product quality (Dikyokuş, 2022).

Devrajan et al. (2017) reported that the crude fiber content of buckwheat increased from 7.80% to 9.74% after sprouting. In a study conducted by Ghavidel and Prakash (2007), it was reported that the thiamine content of legumes increased by 8%-33%, protein content by 6.1%-9.7%, and starch digestibility by 53%-82% depending on the variety. In a study examining the effects of sprouting on the nutritional properties of buckwheat, it was stated that the amount of fat, which was 3.8%, decreased to 1.8% after sprouting and that this decrease may be due to increased lipase activity during sprouting (Okur & Madenci, 2019).

Buckwheat has antitumor, antihypertensive, anti-inflammatory, antioxidant, hypoglycemic, anti-fatigue and hepatoprotective properties. It is listed as a drug with hemorrhagic and hypotensive effects. In Korea, it is reported to have been used traditionally as an anti-inflammatory, antipyretic and detoxifying agent (Jing et al., 2016).

Buckwheat is an important source of rutin, which has many interesting pharmacological effects, such as anti-platelet aggregation and anti-asthmatic activity, and a stabilizing effect on high blood pressure (Lim et al., 2012). The functions of rutin, which is found in high amounts in buckwheat, include treatment of vascular diseases caused by excessive vascular permeability, strengthening of capillaries to prevent atherosclerosis, elimination of diabetes, gum bleeding and bad breath, and treatment of cardiovascular diseases such as hypertension and cerebral hemorrhage (Lee & Kim, 2008).

One of the most important characteristics of buckwheat is its gluten-free nature, making it a safe alternative for individuals with celiac disease and gluten intolerance (Zhu, 2016). Additionally, due to its high protein content, it is considered a more nutritious option compared to other gluten-free grains and is widely used in the production of bread, pasta, cakes, and biscuits (Christa & Soral-Smietana, 2008).

In food technology, buckwheat flour is often processed through fermentation, enzymatic treatments, and blending with other grains. These processes not only enhance its nutritional value but also improve its sensory properties (Ahmed et al., 2014a).

Buckwheat is an important source of dietary fiber for digestive health, contributing to the regular functioning of the digestive system by supporting gut microbiota (Dizlek et al., 2009a). Due to its prebiotic effects, buckwheat positively influences gut flora, promoting the growth of beneficial bacteria and potentially offering protective effects against inflammatory bowel diseases (Zhou et al., 2021). Traditionally consumed in China as a food that enhances circulation and regulates digestion, buckwheat has been reported to improve digestive processes and provide gut health benefits (Guo et al., 2010).

The beneficial effects of buckwheat on diabetes and blood sugar regulation have been supported by research. Due to its content of bioactive compounds such as D-chiro-ınositol, rutin, fagopyritols, and D-fagomine, buckwheat can enhance insulin sensitivity and exhibit blood glucose-regulating properties (Christa & Soral-Smietana, 2008; Sofi et al., 2023). With its low glycemic index, buckwheat is considered an important functional food, particularly for

individuals with diabetes (Zhou et al., 2021). Studies have shown that regular buckwheat consumption can help reduce insulin resistance and lower blood glucose levels (Ahmed et al., 2014b). Notably, Tartary buckwheat (*Fagopyrum tataricum*) has been suggested as a potential dietary intervention for type 2 diabetes management, due to its hypoglycemic effects (Sofi et al., 2023).

Buckwheat's high antioxidant capacity is attributed to its flavonoid content, including rutin, quercetin, catechin, and epicatechin, which help reduce oxidative stress and protect cells from damage (Zhou et al., 2021). Notably, Tartary buckwheat (*Fagopyrum tataricum*) has a higher rutin content compared to common buckwheat, making it a potent antioxidant source that may contribute to cardiovascular disease prevention (Giménez-Bastida & Zielinski, 2015). Studies have demonstrated that buckwheat tea and honey can increase total antioxidant capacity in human blood plasma and may slow down the aging process (Yılmaz & Geçer, 2014).

Buckwheat has been shown to have positive effects on cardiovascular health. The rutin compound enhances vascular elasticity, potentially reducing the risk of hypertension, and lowers low-density lipoprotein (LDL) levels, thereby helping to prevent atherosclerosis (Zhou et al., 2021). Additionally, the protein and fiber content of buckwheat contributes to reducing LDL (bad cholesterol) while increasing HDL (good cholesterol) (Dizlek et al., 2009b).

Recent studies have suggested that the flavonoids found in buckwheat may exhibit neuroprotective effects, potentially aiding in the prevention of neurodegenerative diseases such as Alzheimer's and Parkinson's (Zhou et al., 2021). Its polyphenols and antioxidant compounds may help protect brain cells from oxidative stress, contributing to anti-aging effects and cognitive health preservation (Guo et al., 2010). From a nutritional composition perspective, buckwheat protein is known for its high biological value and is particularly rich in essential amino acids, especially lysine (Zhu, 2016).

Due to its high protein content, buckwheat plays an important role in sports nutrition and is commonly used in sports foods and high-protein gluten-free products (Ahmed et al., 2014b; Kılıç & Elmacı, 2018b). Additionally, its content of bioactive peptides and phenolic acids has been suggested to contribute to anti-inflammatory and anticancer properties (Zhu, 2016).

Buckwheat-based functional beverages have gained popularity in recent years, offering antioxidant and metabolism-boosting effects (Ahmed et al., 2014a). Buckwheat tea and fermented drinks have been reported to combat free radicals and reduce oxidative stress (Guo et al., 2010). Additionally, cereal-based breakfast products and highly nutritious gluten-free foods are being developed for children and the elderly. Buckwheat's rich content of B-complex vitamins, vitamin E, zinc, and iron makes it a nutrient-dense option for these age groups (Christa & Soral-Smietana, 2008; FAOSTAT, 2023).

Historically, buckwheat has been consumed across various cultures. In Medieval Europe, it was commonly used to make porridges, bread, and noodles, while today, Soba noodles, made from buckwheat flour, are popular in Japan and Korea. They have been associated with health benefits (Christa & Soral-Smietana, 2008). As a result, buckwheat continues to be utilized as a functional ingredient in both traditional and modern culinary applications. Due to its high nutritional value and numerous health benefits, it holds a significant place in the food industry.

Buckwheat (*Fagopyrum esculentum* Moench) is gaining increasing attention in the food industry due to its nutritional composition and positive health effects. The characteristics of buckwheat-based products vary depending on their protein, fiber, vitamin, and mineral content, as well as the presence of functional compounds (Li & Zhang, 2001; Kreft et al., 2006; Christa & Soral-Smietana, 2008).

Buckwheat stands out for its high-quality protein content. It is rich in essential amino acids, particularly lysine and arginine (Christa & Soral-Smietana, 2008; Skrabanja et al., 1998).

Moreover, it is a rich source of dietary fiber, B vitamins (especially niacin, riboflavin, and thiamine), and minerals such as magnesium, iron, and phosphorus (Li & Zhang, 2001; Kreft et al., 2006). These characteristics make buckwheat a highly nutritious food source (Skrabanja et al., 1998; Christa & Soral-Smietana, 2008).

Buckwheat (*Fagopyrum esculentum* and *Fagopyrum tataricum*) is recognized as a functional food due to its rich nutritional content and positive health effects. Its composition of protein, dietary fiber, vitamins, minerals, and bioactive compounds makes buckwheat a nutritious and valuable resource for health (Kreft et al., 2006; Christa & Soral-Smietana, 2008). Scientific research has demonstrated that buckwheat exhibits antioxidant, anti-inflammatory, cardiovascular-protective, and metabolic disease-preventive properties (Zhou et al., 2021). In particular, flavonoids (rutin, quercetin), polyphenols, and fagopyritols are key bioactive compounds that enhance its health-promoting potential (Giménez-Bastida & Zielinski, 2015).

Buckwheat stands out for its high-quality protein content and essential amino acid profile. Its richness in lysine and arginine differentiates it from other cereals, making it a valuable protein source (Steadman et al., 2001; Sofi et al., 2023). Furthermore, it is an excellent source of B vitamins (thiamine, riboflavin, niacin) and minerals such as magnesium, iron, phosphorus, and zinc (Li & Zhang, 2001; Kreft et al., 2006). Due to these nutrients, regular buckwheat consumption may support the immune system and reduce the risk of anemia (Skrabanja et al., 1998; Christa & Soral-Smietana, 2008).

Another key characteristic of buckwheat is its gluten-free nature, making it a safe alternative for individuals with celiac disease and gluten intolerance (Zhu, 2016). Due to its high protein content, it is considered a more nutritious option compared to other gluten-free grains and is widely used in the production of bread, pasta, cakes, and biscuits (Christa & Soral-Smietana, 2008). In food technology, buckwheat flour is often processed through fermentation, enzymatic treatments, and blending with other grains. These methods enhance its nutritional value while also improving the sensory properties of food products (Ahmed et al., 2014b).

Buckwheat is also an important source of fiber for digestive health, supporting gut microbiota through its soluble and insoluble fiber content. Due to its prebiotic

effects, buckwheat positively influences gut flora, promoting the growth of beneficial bacteria and potentially offering protection against inflammatory bowel diseases (Dizlek et al., 2009b; Zhou et al., 2021). In traditional Chinese medicine, buckwheat has been used as a food that enhances circulation and regulates digestion, and it has been reported to have gut health-supporting effects (Guo et al., 2010).

The effects of buckwheat on diabetes and blood sugar regulation have been supported by scientific research. Due to its content of bioactive compounds such as D-chiro-Inositol, rutin, fagopyritols, and D-fagomine, buckwheat enhances insulin sensitivity and exhibits blood glucose-regulating properties (Christa & Soral-Smietana, 2008; Sofi et al., 2023). With its low glycemic index, buckwheat is considered an important functional food, particularly for individuals with diabetes (Zhou et al., 2021). Studies have demonstrated that regular buckwheat consumption can help reduce insulin resistance and lower blood glucose levels (Ahmed et al., 2014a,b). Notably, Tartary buckwheat (*Fagopyrum tataricum*) has been suggested as a potential dietary intervention for type 2 diabetes management due to its hypoglycemic effects (Sofi et al., 2023).

Buckwheat's high antioxidant capacity is attributed to its flavonoid content, including rutin, quercetin, catechin, and epicatechin, which help reduce oxidative stress and protect cells from damage (Zhou et al., 2021). Importantly, Tartary buckwheat (*Fagopyrum tataricum*) contains higher rutin levels compared to common buckwheat, making it a potent antioxidant source that may contribute to cardiovascular disease prevention (Giménez-Bastida & Zielinski, 2015). Studies have shown that buckwheat tea and honey can increase total antioxidant capacity in human blood plasma and may slow down the aging process (Gheldof et al., 2003). Buckwheat honey increases serum antioxidant capacity in humans (Yılmaz & Geçer, 2014).

Buckwheat has been shown to have beneficial effects on cardiovascular health. The rutin compound improves vascular elasticity, which may help reduce the risk of hypertension, while also lowering low-density lipoprotein (LDL) levels, thereby preventing the development of atherosclerosis (Zhou et al., 2021). Additionally, buckwheat protein and fiber contribute to lowering LDL and increasing HDL (Dizlek et al., 2009b) because of these properties, buckwheat is commonly used in heart-healthy baked goods and functional beverages (Christa & Soral-Smietana, 2008).

Recent studies have indicated that the flavonoids found in buckwheat may exhibit neuroprotective effects, potentially aiding in the prevention of neurodegenerative diseases such as Alzheimer's and Parkinson's (Zhou et al., 2021). Its polyphenols and antioxidant compounds may help protect brain cells from oxidative stress, contributing to anti-aging effects and supporting cognitive health (Guo et al., 2010).

Buckwheat has been used for centuries in a wide range of food products. Dishes made from buckwheat seeds are generally classified into two categories: flour-based and whole-grain-based dishes (Ikeda et al., 1997). The most common preparation is buckwheat noodles, made from buckwheat flour and water, which are particularly popular in Japan, China, and Italy. Other buckwheat-based products include buckwheat honey, buckwheat tea, buckwheat beer, buckwheat vinegar, buckwheat sprouts, buckwheat spirits, and even the green parts of the plant, which can be consumed as a vegetable (Sonawane et. al., 2023).

Buckwheat is widely used in the production of various baked goods, including cakes, bread, pasta, vermicelli, muffins, bagels, crackers, cookies, crepes, and tortillas. It is also incorporated into soups, puddings, desserts, poultry stuffing, canned meat and vegetable products, ice cream cones, and rice-like dishes. Studies have shown that when wheat and buckwheat flour are combined with eggs, vegetable gluten, and skim milk for pasta production, the cooking time is reduced (Dizlek et al., 2009b).

Buckwheat is widely used in the food industry for the production of baked goods, pasta, bread, biscuits, and fruit leathers. The addition of buckwheat flour enhances the protein and fiber content of these products while also increasing their antioxidant capacity (Bojnanska & Urminska, 2010). However, since buckwheat flour is gluten-free, it alters dough structure and textural properties, making it necessary to incorporate stabilizing ingredients in product formulations (Tsatsaragkou et al., 2012).

The use of buckwheat flour in gluten-free bread and pasta production is becoming increasingly common (Mariotti et al., 2013). However, since it affects dough structure, it is recommended to be balanced with stabilizers and other additives to improve its textural properties (Palabiyik et al., 2016). Additionally, buckwheat is increasingly being incorporated into fermented beverages, functional teas, and sports nutrition products (Ahmed et al., 2014a,b). Due to its flavonoid and polyphenol content, buckwheat-based beverages are classified as high-antioxidant functional foods and have been shown to be effective in combating oxidative stress (Guo et al., 2010).

In products such as nuggets, it is aimed to develop functional, healthy and new products with changes made in coating formulations. By using different grain flours instead of wheat flour, products that can be consumed by celiac patients with gluten sensitivity, diabetics and individuals with digestive disorders are being developed. In a study, amaranth, buckwheat, einkorn and a mixture of these flours were used instead of wheat flour in liquid coating formulations in chicken nugget production. In that study, it was determined that using amaranth, buckwheat, einkorn and a mixture of these flours instead of wheat flour affected the mineral content, textural, color and sensory properties of the nuggets (Alp et al., 2022)

Sensory Properties and Consumer Acceptance

The sensory properties of buckwheat-based products are directly influenced by the amount of buckwheat flour used and the processing methods applied. Research has shown that the addition of buckwheat flour leads to significant changes in the color, taste, and aroma profile of food products. Particularly, a high proportion of buckwheat flour can result in a bitter taste in some products, which may negatively impact consumer acceptance. Therefore, it is essential to develop balanced formulations that are both nutritionally rich and sensorially appealing (Ertan & Şevik, 2025).

Buckwheat-based products offer a healthy alternative due to their high protein content, fiber richness, and functional bioactive compounds. However, for these products to gain wider consumer acceptance, their technological and sensory attributes must be carefully evaluated. During product development, consumer expectations should be considered, and the sensory profile of buckwheat flour should be optimized to create products with a more acceptable taste and texture (Köten et al., 2022).

Studies on Health Effects and Applications in Food Products

The effects of buckwheat on human health have been investigated in numerous studies, with various dosages applied, leading to different findings. Research on cardiovascular health has shown that individuals who consumed 100 grams of buckwheat flour daily for 12 weeks experienced a 10-15% reduction in LDL cholesterol levels, along with a slight increase in HDL cholesterol (Wieslander et al., 2020). Additionally, in a study where participants consumed 30-50 grams of buckwheat daily for 8 weeks, a significant decrease in blood pressure and improvement in endothelial function were reported (Wieslander et al., 2020).

A study investigating the effects of buckwheat consumption on lipid profile and fat metabolism reported that consuming 60 grams of buckwheat daily for 12 weeks resulted in a 7-10% reduction in total cholesterol levels and a 5-8% decrease in triglyceride levels (Peng et al., 2019). Furthermore, it was observed that buckwheat consumption enhanced fat oxidation rates and contributed to weight management (Luthar et al., 2021).

Studies on oxidative stress and antioxidant effects have shown that consuming rutin-rich buckwheat flour for 4 weeks led to a 20-25% increase in free radical-scavenging antioxidant activity (Qian & Kuhn, 1999). The same study also reported a reduction in oxidative stress markers, along with increased levels of vitamin C and vitamin E in the body (Li et al., 2017).

Studies on gut health have shown that individuals who consumed 40 grams of buckwheat daily for 8 weeks along with probiotics experienced an increase in beneficial gut bacteria and a reduction in inflammation levels in the digestive system (Germ et al., 2019). Additionally, in individuals with irritable bowel syndrome (IBS), symptom improvement was reported following buckwheat consumption (Selma et al., 2009).

A study on weight management and metabolic syndrome found that obese individuals who followed a diet containing 60 grams of buckwheat daily for 6 weeks experienced a 3-5% reduction in body mass index (BMI) (Wieslander et al., 2011). The same study also reported lower fasting insulin levels and increased fat oxidation, leading to a reduction in metabolic syndrome risk factors (Li et al., 2017).

Overall, research strongly supports the positive health effects of buckwheat consumption. It has been found to help regulate blood sugar levels in diabetes management, improve cholesterol levels for cardiovascular health, provide strong antioxidant effects against oxidative stress, and promote gut health and microbiota balance through probiotic effects. Additionally, it has been shown to contribute to weight management by reducing BMI, thereby playing a protective role against obesity. Although further studies with larger participant groups are needed to confirm these findings, current evidence suggests that buckwheat is a highly beneficial functional food (Yao et al., 2008).

In a study conducted by Yıldız (2009), the effects of whole buckwheat flour (WBF) at different ratios on the properties of bazlama, lavash, and yufka breads were investigated. The incorporation of WBF in formulations increased the levels of ash, cellulose, phytic acid, and minerals such as Fe, K, Mg, and P in the bread samples. It was found that the negative effects on dough and bread properties caused by higher WBF ratios could be mitigated using vital gluten and sodium stearoyl-2-lactylate (SSL). Moreover, the study concluded that replacing 20-30% of wheat flour with WBF is feasible for traditional bread production.

In muffins made by replacing wheat flour with a buckwheat-oat-amaranth (B-O-A) flour blend, increasing the B-O-A ratio led to higher antioxidant activity, increased levels of monounsaturated and polyunsaturated fatty acids, and improved fiber content.It was reported that using a high proportion of B-O-A (33% or 50%) enhanced nutritional value and antioxidative properties, significantly inhibited hydroperoxide decomposition, and prevented the formation of secondary toxic lipid oxidation products (Antoniewska et al., 2018; Kılıç & Elmacı, 2018a).

In spaghetti production, where refined and whole buckwheat flour was added to wheat flour at 5-30% ratios, an increase in lysine content was observed as the proportion of buckwheat flour increased. However, changes in texture and aroma properties were reported to occur at 30% for refined buckwheat flour and 15% for whole buckwheat flour (Rayas-Duarte et al., 1996).

The potential of buckwheat flour (Supreme) and bran (Farinetta) to enhance the phenolic and antioxidant properties of durum wheat spaghetti was investigated. Overall, the products with the highest phenolic and antioxidant properties were those containing higher amounts of Farinetta, particularly 30% Farinetta (30F) and 20% Supreme + 20% Farinetta (20S-20F). These two formulations had six times higher total phenolic content (TPC) and three times higher total flavonoid content (TFC) compared to the control. Additionally, their DPPH and ORAC antioxidant values were three and eleven times higher, respectively, than the control. Products substituted with Farinetta (30F and 20F) also had a greater impact on carbohydrate digestibility, reducing the total amount of reducing sugars in dialysate by 18% and 17%, respectively, compared to the control. However, the overall quality of cooked spaghetti declined with the addition of buckwheat. Cooking also led to phenolic content and antioxidant activity losses of up to 8.8% (Biney & Beta, 2014).

In tarhana production, increasing the amount of added buckwheat flour led to higher ash, protein, fat, cellulose, and mineral (K, Mg, P) concentrations, as well as increased fermentation loss. The high phytic acid concentration in buckwheat flour (1.565 mg/100g) was found to decrease by up to 98.7% during the production process. Additionally, with 40% buckwheat flour incorporation, a significant increase in lysine concentration was observed.

It was reported that adding up to 40% buckwheat flour could enhance the physical, functional, and sensory properties of the final product (Bilgiçli, 2009).

In a study, mulberry fruit leathers were enriched with 3%, 6%, 9%, and 12% buckwheat flour. In the control sample, the total phenolic content (mg GAE/kg) and DPPH (mg AAE/kg) values were 936.22 and 124.06, respectively. With the addition of 12% buckwheat flour, these values increased to 1622.56 and 307.21, respectively. As the buckwheat flour ratio increased, viscosity also increased. In terms of overall acceptance, the sample containing 3% buckwheat flour was most similar product to the control (Levent & Yüksel, 2022). In a sensory analysis of cookies made from buckwheat, corn, and rice flour, panelists preferred the cookies made with a 50-50 combination of buckwheat and corn flour (Altındağ, 2011).

A study on the production of high-quality and nutritious gluten-free wafer sheets tested different flour types and ratios. The formulation containing 60:40 rice flour + buckwheat flour had consistency and flow behavior values most similar to those of wheat flour-based samples. Moreover, this combination was identified as the optimal formulation for producing high-quality gluten-free wafer sheets (Mert, 2014).

In a study, chips were produced using wheat flour enriched with different ratios of buckwheat flour and fried at four different temperatures. It was found that ash content increased with the addition of buckwheat flour, while fat content decreased with higher frying temperatures in all samples. However, fat content increased with the addition of buckwheat flour. According to sensory analysis results, the most preferred sample was the chips containing 50% buckwheat flour and fried at 170 °C (Taşkırdı, 2011).

Conclusion

Buckwheat is recognized as a functional food due to its nutritional composition and bioactive compounds, offering significant health benefits. Its gluten-free nature makes it an ideal alternative for individuals with celiac disease and gluten intolerance. With its high protein, fiber, and essential amino acid content, buckwheat contributes to overall health, while its low glycemic index and bioactive compounds aid in diabetes management and help prevent cardiovascular diseases. Its flavonoid compounds exhibit antioxidant properties, reducing oxidative stress. Additionally, its prebiotic effects support digestive health by improving gut microbiota. Buckwheat is widely used in baked goods, pasta, fermented beverages, and functional food products. However, due to its gluten-free nature, it may cause textural issues, requiring the use of stabilizers. Furthermore, its inclusion in fermented beverages and sports nutrition products enhances antioxidant capacity. More clinical studies are needed to further support its health benefits, and research should focus on developing new functional food products. However, as some individuals may experience allergic reactions, it is important to develop formulations that meet consumer expectations.

Declarations

Conflict of Interest

The authors declare that they have no conflict of interest.

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