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Buckwheat: an underutilized crop with attractive sensory qualities and health benefits

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ABSTRACT

The pseudocereal buckwheat is one of the ancient domesticated crops. The aim of the present review was to outline the potential of buckwheat as an agricultural crop and brings studies on buckwheat into a new larger perspective combining current knowledge in agricultural history and practice, nutritional and sensory properties, as well as possible benefits to human health. Historically, buckwheat was an appreciated crop because of its short growth period, moderate requirements for growth conditions, and high adaptability to adverse environments. Nowadays, interest in buckwheat-based food has increased because of its nutritional composition and many beneficial properties for human health. Buckwheat is a rich source of proteins, dietary fibers, vitamins, minerals, and bioactive compounds, including flavonoids. Moreover, it contains no gluten and can be used in the production of gluten-free foods for individuals diagnosed with celiac disease, non-celiac gluten sensitivity, or wheat protein allergies. Buckwheat is traditionally used in the production of various foods and can be successfully incorporated into various new food formulations with positive effects on their nutritional value and attractive sensory properties. Further research is needed to optimize buckwheat-based food development and understand the mechanism of the health effects of buckwheat consumption on human well-being.

KEYWORDS

Cultivation; *Fagopyrum esculentum*; *Fagopyrum tataricum*; food applications; nutrition

Introduction

Globally, the negative effects of agriculture on biodiversity are the result of both habitat elimination through land clearing, and extensive areas of monocultures, which are virtually biological deserts (Small 2017). Other reasons for biodiversity loss include pollution, soil and water degradation by fertilizers and pesticides. Exploring the potential of underutilized crops could increase resilience through a more diversified agricultural production system in sustaining food and nutritional security under climate change and biodiversity degradation.

In many countries, where agricultural production is based on a few crops only, biodiversity might dramatically decrease. Buckwheat (*Fagopyrum* sp.) is a promising environmentally friendly crop that can contribute to the balance between biodiversity benefits and crop yield and can be used as a cover crop for weed suppression and for the vegetation restoration of degraded ecosystems (Björkman and Shail 2013). Moreover, buckwheat is a rich source of a broad gene pool and can be used to both increase biodiversity and improve the quality of other crops in the food and biotechnology industries (Singh, Malhotra, and Sharma 2020). Buckwheat can increase the

presence of pollinator species in agriculture (Taki et al. 2009). Finally, buckwheat is known for its high nutritional value and superior sensory qualities and has the potential to be a part of a healthy diet (Wijngaard and Arendt 2006).

Buckwheat is a pseudocereal belonging to the genus *Fagopyrum* of the family Polygonaceae. Although there are many buckwheat species grown across the world, only nine are used in agriculture and food industry (Krkošková and Mrázová 2005). Common buckwheat (*F. esculentum*) and Tartary buckwheat (*F. tartaricum*) are the two most commonly cultivated species of buckwheat. The wild species are mainly used as forage in Southern Asia and in traditional medicine (Luthar, Fabjan, and Mlinarič 2021). Buckwheat has been consumed for a long time in Nordic countries. Already in July 1749, when visiting Scania, Carl Linnaeus, noted the snow-white fields of buckwheat. During the eighteenth century, the cultivation of buckwheat was widespread, especially in southern Sweden. It was commonly used for porridge and gruel (Olsson et al. 2021).

This review outlines the potential of buckwheat as an agricultural crop, with a focus on recent research findings. In contrast to numerous recently published review articles

on buckwheat, the present review brings studies on buckwheat into a new larger perspective combining current knowledge in agricultural history and practice, nutritional and sensory properties, as well as possible benefits to human health. A literature review was conducted by collecting, evaluating, and analyzing data from publications in peer-reviewed scientific journals from the Scopus, PubMed, and Web of Science databases written in English, Ukrainian, and Russian languages. Conference articles and reports were also included if relevant.

History and genetic diversity of buckwheat

The origin and wild progenitors of modern buckwheat species were largely unknown until recently. Several controversial hypotheses of buckwheat origin were suggested, including India, Siberia, or Tibet (Ohnishi 2004). Modern advanced technology and phylogenetic analyses pointed to several regions in China as the buckwheat origin (Fan et al. 2020). Modern palynological and archaeological records suggested that the cultivation history of buckwheat in China was initiated 4000–4500 years ago, although where exactly domestication started in China is still unknown (Hunt, Shang, and Jones 2018; Krzyzanska et al. 2022; Yao et al. 2023).

The expansion of cultivated buckwheat to Europe is also controversial. Common buckwheat is likely to derive to Europe from China through the Land Silk Road, but this needs to be further verified (Wang et al. 2022). According to Beug (2011), buckwheat spread to Western Europe only in the late fifteenth century. However, in Eastern Europe, some modest amount of buckwheat pollen was recorded already during the Stone Age (Alenius, Mökkönen, and Lahelma 2013). Alenius, Mökkönen, and Lahelma (2013) explained this modest amount by the fact that they might be carried up to 2 km by wind and insects.

Morphology, genetic diversity and geographical distribution investigations suggested that southwestern China is also the center of buckwheat diversity (Yao et al. 2023). High genetic diversity among buckwheat cultivars has been revealed with the help of allozyme analysis, Random Amplified Polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), and simple sequence repeat analyses (Iwata et al. 2005; Kump and Javornik 1996). The modern powerful genomic technologies open up a broad new area and allow future research and breeding programs toward buckwheat cultivars with improved agronomic characteristics and superior nutritional qualities, such as reduced content of antinutrients or development of low-allergen lines.

Cultivation of buckwheat

Nowadays, buckwheat is commonly grown as a conventional food crop in many parts of the world, especially Asia, Central and Eastern Europe. In Sweden, buckwheat cultivation is increasing and has reached 500 ha in 2022. Bielski, Marks-Bielska, and Wiśniewski (2022) provided an economic analysis of buckwheat production for Central Europe,

comparing low-input and high-input production systems in Poland, and showed the potential of economic efficiency of buckwheat production. However, further research on energy use efficiency and greenhouse gas emissions in buckwheat production is needed. Grain yield greatly depends on genotype, applied growing technology as well as climate and soil quality.

Growing conditions

Historically, buckwheat was an appreciated crop because of its short growth period and high adaptability to adverse environments. Buckwheat has the ability to grow well in poor soils (Ikanović et al. 2013; Kreft 2007; Small 2017) and prefers sandy soil because of its thin roots. Buckwheat has a higher tolerance to soil acidity compared to cereals, but as with many other crops, it is salt sensitive. High salinity can lead to a decreased germination rate of buckwheat seeds and a lower fresh weight of sprouts (Lim et al. 2012).

Buckwheat is sensitive to frost, although it is tolerant to high temperatures (Pomeranz 1983). For example, photosynthetic processes remain active up to approximately 40°C (Kajfež-Bogataj and Gaberščik 1986), which indicated higher resistance to global warming than other crops (Germ and Gaberščik 2016). It should be noted that at extremely high temperatures and consequently dried soil, buckwheat could be exposed to water stress because of the thin root system. Common buckwheat is more sensitive to climate conditions compared to Tartary buckwheat (Germ and Gaberščik 2016), although there are large variations within species (Aubert and Quinet 2022).

The critical periods for buckwheat yield determination are not well established. Flowering is probably the most sensitive period since water stress can inhibit fertilization and the newly formed zygotes are aborted, leading to crop failure (Pomeranz 1983). Guglielmini, Forcat, and Miralles (2019) described the critical period, during which the final yield can be reduced by 50%, from the appearance of the first open flowers to the first brown fruits.

The nutrient requirements of buckwheat are low, and intensive fertilization is not required because buckwheat can easily absorb macro- and microelements from the soil. However, it also easily accumulates toxic metals such as cadmium and lead (Domańska, Leszczyńska, and Badora 2021), which makes buckwheat useful even in non-food applications such as cleaning the soil from toxic metals.

Sowing

Buckwheat varieties used in the last 15 years have a growing season of 85 to 110 days. Seeds germinate in moist soil at a temperature of + 7–8°C. The optimum soil moisture for buckwheat is at the level of 70–75% of the total field moisture capacity.

The sowing date varies with the geographical region because of the susceptibility of buckwheat to frost conditions. Buckwheat is sensitive to frost, at a temperature of –1.5°C, the crops are damaged, and at –2.0°C and below,

they die. The best sowing date for buckwheat in Western Europe is from mid-May to July (Halbrech, Romedenne, and Ledent 2005). Mariotti, Masoni, and Arduini (2016) suggested early spring (mid-April) as an optimal sowing time in Mediterranean environments. In Northern India, buckwheat is sown in July, and in Nilgiris in April (Ratan and Kothiyal 2011). The sowing date is selected to avoid the risk of frost and avoid high temperatures during the period of seed formation. The recommended sowing depth of seeds also varies. For example, the recommended depth in Belarus for tetraploid cultivars is 4–5 cm, while for diploid cultivars it is 3–4 cm. In China, the optimum depth of 4 cm is recommended (Xiang et al. 2014). Generally recommended depth is therefore 4–6 cm (Farooq et al. 2016). On dry soils, the seeding depth is usually increased by 2 cm. On soils of light granulometric composition, rolling after sowing is mandatory.

Sowing rate is an important factor determining the grain yield. The highest average grain yield on carbonate meadow black soil in Serbia was obtained at the rate of 160 grains per m² (Nikolic et al. 2019). It should be emphasized that in that study only slight differences between the rates of 120 and 160 grains per m² were observed, thus, due to economy reasons, the sowing rate of 120 grains per m² was recommended. Similar results were obtained in Croatia (Jukić et al. 2021). In Latvia, the highest yield was obtained at the sowing rate of 250 grains per m² (Vilcāns, Volkova, and Gaile 2011). Higher density might be needed if the soil is too wet, cold, or poorly prepared for sowing. In a semiarid zone of Northern Kazakhstan, the optimal sowing rate was 300 germinated seeds/m² (Syzykova et al. 2016). Kumskova (2004) suggested that with a continuous sowing method, the optimal sowing rate is 250–500 grains/m² (80–120 kg/ha), and with a wide row sowing – 100–250 grains/m² (25–60 kg/ha). Berdin, Straholis, and Klitsenko (2018) suggested the optimal sowing rate from 200 to 300 grains/m². The effectiveness greatly depends on the soil and buckwheat variety. The differences in recommendations are due to the fact that the sowing rate depends on the sowing method, buckwheat variety, and type of soil cultivation. Wide-row sowing with a row spacing of 45–60 cm is effective for tetraploid varieties, and middle-row spacing of 12–15 cm is commonly used when cultivating diploid varieties.

Harvest

Buckwheat is usually harvested approximately 10 wk after sowing (Farooq et al. 2016). Windrowing is one of the traditional methods. The crop is cut when approximately 70–80% of the seeds have turned brown and kept in windrows until the moisture content of the seeds reach 16–18%. Then, the bundles are made to minimize the shattering losses (Babu et al. 2018). It was suggested that the shattering is low during morning harvesting (Joshi et al. 2020). There were also numerous attempts to decrease shattering problems by genetic selection, and several shattering resistant genes were identified (Morishita, Hara, and Hara 2020). We believe that these new approaches could certainly be

beneficial for buckwheat production; however, further research is required to develop new cultivars with desired characteristics and without negative effects on other production traits.

Direct combining is another common method to harvest buckwheat. This method, however, increases the risk of shattering during direct combining (Björkman 2009), and therefore morning harvesting is recommended.

The buckwheat seeds often contain higher water content, particularly in direct combining; therefore, it is important to reduce water content directly after the harvest to a common storage level for grain of 14%. Dehulling is another required postharvest procedure of buckwheat prior to final buckwheat product processing.

To summarize, the cultivation of buckwheat has multiple benefits for agriculture sustainability over other grain crops, as it requires low inputs and is well adapted to adverse environments.

Diseases

Buckwheat is usually considered a healthy crop. However, in the regions with intensive buckwheat cultivation, some damage has been observed. Infections of the fungal pathogens *Fusarium oxysporum* and *Rhizoctonia solani* might cause 50% loss due to wilting and root rot diseases, respectively (Agarwal et al. 2017). Buckwheat might also suffer from root lesion nematodes (*Pratylenchus penetrans*), and be susceptible to leaf spot (*Ramularia* sp.), stipple spot (*Bipolaris Sorokiniana*), aster yellows (phytoplasma), and sclerotinia stem rot (*Sclerotinia* sp.) diseases (Babu et al. 2018). A buckwheat burn virus, a highly virulent pathogen that belongs to the *Rhabdoviridae* family virus, was characterized in Ukraine (Yuzvenko et al. 2011). Buckwheat burn virus might cause up to 80% of crop losses, but some buckwheat varieties have higher resistance to this virus (Shevchuk, Demchenko, and Yuzvenko 2011; Sindarovska et al. 2014). It is obvious that varieties with high resistance can serve as valuable material to select varieties for production in regions with a high prevalence of the buckwheat burn virus.

Nutritional composition of buckwheat

The nutritional quality of food is one of the most important factors for human health and well-being. The growing popularity of buckwheat is largely due to its attractive nutritional quality and deficiency in gluten. Buckwheat is similar to conventional cereals in its usage and chemical composition. Environmental factors and genetic differences are mainly responsible for the differences in nutritional composition between common buckwheat versus Tartary buckwheat. Geographic region is also an important determinant of the nutritional composition of untreated grains, even within the same variety (Zhang and Xu 2017). The nutrient composition of final buckwheat-based products depends on the milling fraction and processing conditions (Liu et al. 2018; Steadman et al. 2001a, 2001b).

Table 1. Protein content in buckwheat species in different studies.^a

Species	Sample	Total protein, %	Data are presented as	Reference
<i>F. esculentum</i>	Whole grain	11.1	mean of three years	Sinkovič et al. (2022)
	Seeds without hull	8.8–18.7	range	Guo et al. (2007)
	Hull	4.7	mean of three years	Sinkovič et al. (2022)
	Flour	8.1–12.4	range of 18 varieties	Qin et al. (2010)
<i>F. tataricum</i>	Whole grain	11.2	mean of three years	Sinkovič et al. (2022)
	Seeds without hull	7.8–18.9	range	Guo et al. (2007)
	Hull	3.2	mean of three years	Sinkovič et al. (2022)
	Flour	9.0–14.9	range of 23 varieties	Bhinder et al. (2020)
	Flour	6.8–15.0	range of 21 varieties	Qin et al. (2010)
<i>F. megaspartanium</i>	Seeds without hull	10.9–18.9	range	Guo et al. (2007)
<i>F. cymosum</i>	Seeds without hull	16.5–16.6	range	Guo et al. (2007)
Commercially available. No information on variety	Dehulled flour	14.2	mean of triplicates	Alonso-Miravalles and O'Mahony (2018)
Commercially available. No information on variety	Protein-enriched flour achieved by a dry milling approach	20.5	mean of triplicates	Alonso-Miravalles and O'Mahony (2018)

^aProtein content in all studies was measured using the Kjeldahl method.

Proteins

Plant proteins are regarded as a sustainable alternative to animal proteins due to their lower carbon footprint and health benefits. Nowadays, buckwheat protein is underutilized by the food industry.

Although buckwheat does not provide as much protein as other pseudocereals, such as amaranth and quinoa, buckwheat seeds are generally richer in protein than rice and wheat (Yeşil and Levent 2022). The protein content of buckwheat grains varies, ranging from 7% to 34% (Alonso-Miravalles and O'Mahony 2018; Guo et al. 2007; Sinkovič et al. 2022) (Table 1). The differences in protein content may be due to cultivars variability and growing conditions, as well as sample preparation. Generally, protein content is similar in the common and Tartary buckwheat (Sinkovič et al. 2022).

The nutritional quality of proteins depends on the amino acid composition and bioavailability of essential amino acids. A number of studies have demonstrated that buckwheat protein is of high biological value and has a balanced amino acid profile. In contrast to cereal proteins, lysine is abundantly present in the buckwheat protein fraction (5.2–5.9%) (Huda et al. 2021; Kowalski et al. 2022). This is two-fold higher than in wheat. Buckwheat protein is also rich in arginine and aspartic acid (Kowalski et al. 2022). Ration lysine/arginine in buckwheat is higher compared to many other plant proteins (Dzakhmishva and Khokonova 2021). Some buckwheat varieties had undetectable levels of cysteine. Bonafaccia, Marocchini, and Kreft (2003) reported cysteine as one of the limiting amino acids in Tartary buckwheat. A low content of cysteine (179–243 mg/100 g) was also reported in common buckwheat (Mota et al. 2016; Motta et al. 2019).

Variations in protein content due to sowing time are usually low (Domingos and Bilsborrow 2021). Sowing at early spring (mid-April) and late June–early July might result in slightly lower protein content compared to later sowing in Italy and Iran, respective, probably due to decreased roots development and efficiency of nitrogen absorption (Mariotti et al. 2015; Sobhani et al. 2014). Protein content also varies between years due to different weather conditions (Bárta et al. 2004). Thus, late-developed buckwheat seeds might result in a lower content of protein due to insufficient conversion of nitrogenous substances into proteins (Bárta et al.

2004). Nitrogen fertilization can also change protein yield and accumulation (Wang et al. 2023). Yet, knowledge of the effects of growing conditions and technology on buckwheat proteins is insufficient, and further research is warranted.

Buckwheat protein has a relatively lower digestibility (70–80%) than cereal protein (Jin, Ohanenye, and Udenigwe 2022; Luthar, Fabjan, and Mlinarič 2021). This is likely due to the presence of fibers and reduced susceptibility for the proteolytic enzymes to the protein fractions. Another explanation of lower digestibility is the interactions between proteins and phenolic substances in the intestine (Li et al. 2023; Luthar, Fabjan, and Mlinarič 2021) or the formation of denser aggregates from buckwheat starch during the gelatinization-cooling process (Du et al. 2022). Protein digestibility can be improved by appropriate processing, such as ultrasonic pretreatment (Jin et al. 2021).

Carbohydrates

The main carbohydrate in buckwheat groats is starch, which content varies from 68 to 73% (Kreft and Skrabanja 2002), with 19–34% of amylose and approximately 70% of amylopectin (Gao et al. 2016; Qin et al. 2010; Wang et al. 2021a). The amylose content of buckwheat starch is therefore comparable with or slightly lower than that of cereals, and similar in common buckwheat and Tartary buckwheat (Izydorczyk et al. 2014; Qin et al. 2010; Wijngaard and Arendt 2006). The amylose content in starch is an important parameter as it determines the digestibility of starch because amylose is more resistant to digestion. The starch granules in common buckwheat groats have rough surfaces and are mainly polygonal, which is associated with high stabilizing and thickening properties (Juan, Yan, and Zhengbiao 2009). Gelatinization and cooling of buckwheat starch result in the formation of a strong rigid gel with an elasticity modulus significantly higher than that of cereal starches (Izydorczyk et al. 2014). Environmental and genetic factors are important in the determination of the physicochemical properties of buckwheat starch, such as solubility, relative crystallinity, and gelatinization enthalpy (Wang et al. 2023). Total starch content is affected by the sowing date. For example, buckwheat sowed at earlier August in Iran contained a higher amount of starch (Sobhani et al. 2014). The application of nitrogen fertilizer

also affects the total starch content by changing the activities of enzymes involved in starch synthesis (Gao et al. 2021).

Buckwheat is a rich source of dietary fibers. The total content of dietary fibers of six common buckwheat varieties with hulls was measured to be 20–26% (Dziadek et al. 2016) with brans containing more fibers than refined flour. After de-hulling, the content of insoluble fibers decreases. Dehulled common buckwheat seeds, grown and harvested in China, had 2.9% insoluble fiber and 2.4% of soluble fiber (Wefers and Bunzel 2015). The water-soluble fiber of buckwheat includes pectins, arabinogalactans, and xyloglucans (Izydorczyk et al. 2014).

Both of Tartary and common buckweats are rich sources of D-chiro-inositol (DCI) and its galactosyl derivatives fagopyritols (Steadman et al. 2000). Generally, buckwheat, in contrast to most plant seeds, accumulates R-galactosyl D-chiro-inositols rather than the R-galactosyl sucrose series (raffinose, stachyose, and verbascose) (Horbowicz and Obendorf 2005). The concentrations of fagopyritols are generally higher than DCI in seeds (Steadman et al. 2000). Bioavailability of DCI is relatively low (Zieliński et al. 2019) but might be improved by processing. However, information on potential enhancers or inhibitors of DCI absorption is still limited.

Vitamins and minerals

Buckwheat is a rich source of certain vitamins. It is especially known for the contents of thiamin (vitamin B1), niacin (vitamin B3), pyridoxine (vitamin B6), vitamin E, and vitamin K (Gallo and Montesano 2023; Huda et al. 2021). Bonafaccia, Marocchini, and Kreft (2003) reported that the concentrations of total vitamin B, thiamin, niacin, and pyridoxine were lower in common compared to Tartary buckwheat. On the other hand, common buckwheat contained higher concentrations of vitamin E than Tartary buckwheat with γ -tocopherol being the main component of vitamin E (Joshi et al. 2020; Kalinova, Triska, and Vrchotova 2006). Total tocopherol concentrations in buckwheat grains ranged from 14.3 to 21.7 mg/kg (Kim, Kim, and Park 2002).

Buckwheat grains contain a large number of essential minerals. The concentrations of minerals in buckwheat flour depend on the milling method (Liu et al. 2018). The greatest concentrations of most of the minerals were observed in stone-milled flour (Liu et al. 2018). The largest portion of minerals in buckwheat accounts for iron, manganese, copper, and zinc (Bonafaccia, Marocchini, and Kreft 2003; Dzakhmishева and Khokonova 2021; Krupa-Kozak, Wronkowska, and Soral-Śmietana 2011). The contents of some minerals in Tartary buckwheat flours were the following: iron (1.75 to 17.21), manganese (0.08 to 2.72), copper (0.64 to 2.81), zinc (1.23 to 5.79), potassium (280.6 to 648.7), magnesium (66.90 to 362.90), and calcium (30.0 to 331 mg/100 g) (Bhinder et al. 2020). Thus, buckwheat foods can improve the intake of iron and manganese in the Swedish population, as the average intake of these minerals is below the daily recommended intake for adults in Sweden (Becker et al. 2011).

Bioactive compounds

Buckwheat contains a variety of bioactive compounds, which in addition to basic nutrients, contribute to positive health benefits. Until now, approximately 180 bioactive compounds were detected and identified in buckwheat (Huda et al. 2021). Buckwheat is particularly known for its high flavonoid content. Total phenolic content was higher in Tartary buckwheat than in common buckwheat (Liu et al. 2019). Rutin (quercetin-3-d-rutinosid) was the dominant phenolic compound in the flour from Tartary buckwheat grown in China (Liu et al. 2018). Fabjan et al. (2003) found that higher rutin concentrations were observed in the Chinese variety when these in Slovenia, likely due to different growth conditions. Another study investigated three varieties of common buckwheat and identified rutin and epicatechin as dominant in buckwheat grains, whereas quercetin was not detected (Kalinova and Vrchotova 2011). In the flour from Tartary buckwheat, quercetin was detected in relatively high concentrations, especially if the flour was prepared by wet milling (Liu et al. 2018). This is due to the hydrolysis of rutin to quercetin endogenous rutin-degrading enzymes, such as rutinoidase (Yasuda and Nakagawa 1994). Generally, Tartary buckwheat has higher contents of rutin and quercetin than common buckwheat seeds (Zielińska et al. 2012), although rutin levels are highly dependent on cultivation conditions, such as sowing date and stand density (Kalinová and Dadáková 2013; Nikitina, Vagner, and Martynova 2020). Even though both rutin and quercetin have positive health effects, a new Tartary buckwheat variety with higher rutin than quercetin levels was recently bred in Japan (Luthar et al. 2020). This variety is characterized by lower rutinoidase activity and thus a lower degree of rutin degradation to quercetin. Food products from this variety are less bitter and more acceptable by consumers (Suzuki et al. 2014). Dehulling greatly affects rutin concentrations (Błaszczak et al. 2013; Klepacka and Najda 2021). The level of phenolic compounds is highly dependent on the roasting process, which affects the total content, and may cause severe losses in the levels of coumaric acid and rutin (Klepacka and Najda 2021).

Antinutrients

Buckwheat, similarly to cereals, contains common anti-nutrients, phytic acid and tannins that can bind to carbohydrates, proteins, some vitamins, and minerals, reducing their intestinal absorption.

Phytic acid content in untreated buckwheat grains is 1.1–1.4 g/100 g dry matter (Egli et al. 2002; Thakur et al. 2021). For comparison, untreated wheat grains contain 1.0 g/100 g dry matter of phytic acid (Egli et al. 2002). The highest concentration of phytic acid was found in the hull, up to 3.25% (Kasar et al. 2021). Buckwheat flakes also had higher content (22 mg/g dry matter) of phytic acid compared to wheat flakes (11 mg/g dry matter) (Kiewlicz and Rybicka 2020). The apparent phytase activity of untreated buckwheat grains was 2.9 PUa/g dry matter (phytase unit (PU) equivalent to the enzymatic activity which liberates 1 μ mol inorganic phosphate per min), which is comparable to the activity in wheat

3.1 PUa/g dry matter, but lower than in rye 6.9 PUa/g dry matter (Egli et al. 2002). Due to high phytase activity, buckwheat can be used as an ingredient in foods based on mixtures of cereals and legumes and provide sufficient enzymatic activity to degrade phytic acid in cereals and legumes with low phytase activity.

Buckwheat also contains condensed tannins, a group of polyphenols with antinutrient properties (Xiao et al. 2022). The concentrations of condensed tannins in common buckwheat ranged from 15 to 41 mg/100g, and in a hybrid (*F. esculentum* × *F. homotropicum*) can be up to 220 mg/100g (Olschläger et al. 2008). The content of tannins was the lowest in bran and the highest in the fine flour (Kasar et al. 2021; Steadman et al. 2001b). Buckwheat flakes had a slightly lower content of total tannins (7 mg/g dry matter) compared to wheat flakes (9 mg/g dry matter) (Kiewlicz and Rybicka 2020).

Approaches and sensory aspects of buckwheat and buckwheat food products

Due to its nutritional composition and sensory qualities, buckwheat is traditionally used in the production of various foods (Kreft et al. 2020) (Figure 1). Cooked buckwheat groats (“kasha”) are an important part of traditional cuisine in central and Eastern Europe, including Slovenia, Croatia, Poland, Ukraine, Belarus, and Russia. In Japan, buckwheat is mainly consumed as noodle soba (Mikami, Motonishi, and Tsutsui 2018). Buckwheat flour is unmixed or mixed with wheat flour to prepare bakery products, including bread, blini, and cookies. Buckwheat is also used to make beverages (Kowalska and Ziarno 2020; Xu et al. 2019).

Sensory quality and consumer acceptance of buckwheat products were investigated using both common buckwheat and Tartary buckwheat as raw materials. These two varieties differ in the content of flavonoids (Liu et al. 2019), which greatly affects palatability (Ma et al. 2013). This led to

recommendations that the use of Tartary buckwheat in different food products should not exceed 30% as the higher portion might lead to undesirable sensory properties such as bitterness and astringency (Appiani et al. 2021).

Aroma components of buckwheat

The number of studies evaluating aroma components of buckwheat and buckwheat products is limited, and the use of different methodology to identify these components complicates the between-studies comparison. A flavor analysis on Tartary buckwheat performed by gas chromatography-olfactometry-mass spectrometry (GC-O-MS) showed 49 aroma-active components, where the major flavor compounds were geranylacetone (green, fruity, woody), phenethyl alcohol (floral, rose-like), and β -damascone (fruity, floral) (Shi et al. 2021). In the same study, omission tests identified geosmin (fresh, earthy, musty), α -isomethylionone (floral, woody), α -methylionone (fruity, floral, woody), β -ionone (floral, woody), linalool (citrus, floral), β -damascone (fruity, floral), geranylacetone (green, fruity, woody), guaiacol (phenolic, smoky), ethyl hexanoate (fruity), geraniol (floral, fruity), vanillin, tetrahydrolinalool (fresh, floral), and 2,5-dimethyl-4-hydroxy-3-(2H)-furanone (caramel) as the key odorants. Interestingly, the aroma of common and Tartary buckwheat differs, mainly due to the presence of salicylaldehyde in common buckwheat (Janeš and Kreft 2008; Janeš, Prosen, and Kreft 2012). It was suggested that the presence of salicylaldehyde could be used to detect adulteration of Tartary buckwheat products (Janeš, Prosen, and Kreft 2012). The concentrations of aroma components differ between geographical regions. Thus, the concentrations of salicylaldehyde were higher in the common buckwheat from the Ukraine compared to Slovenian buckwheat (Janeš and Kreft 2008). Additionally, storage and milling conditions affect buckwheat aroma.

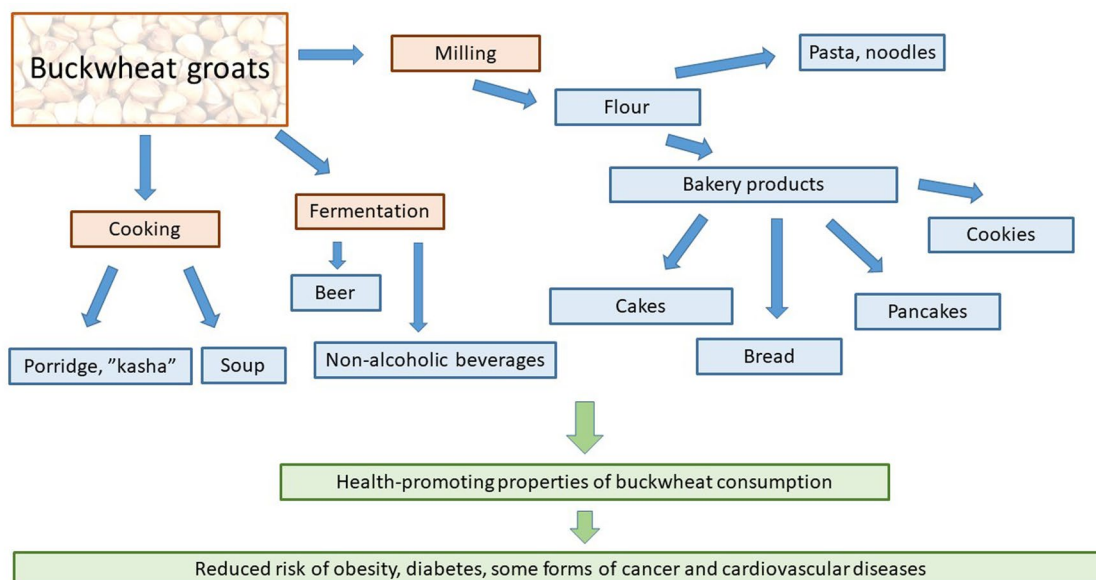


Figure 1. Buckwheat-based foods and associated health effects.

Buckwheat groats

Buckwheat groats are the hulled and roasted seeds of the buckwheat, which are commonly consumed after cooking in water as an alternative to rice or other cereals, or potatoes. To obtain the best nutritional value of buckwheat groats, the roasting process should be carried out at a temperature close to 100°C at a time that will ensure the appropriate sensory attributes (Klepacka and Najda 2021). The recommended method of cooking buckwheat groats is boiling for 30 min in a ratio of 2:1 (water:groats) (Heś et al. 2014). This method increased the content of polyphenolic compounds and did not alter the rutin content (Heś et al. 2014). With a longer cooking time up to 60 min, rutin content significantly decreased (Kreft, Fabjan, and Yasumoto 2006). Cooked buckwheat is soft and has a pleasant aroma. Unfortunately, the main research on cooked buckwheat was focused on technological parameters, and sensory evaluation of the cooked buckwheat in comparison with cereals or other pseudocereals is still lacking. The preparation of buckwheat groats of high quality is highly dependent on the technological processes applied in buckwheat groats production since they affect the content of phenolic compounds and antioxidant activity of the groats.

Bread

Bread is the most common baked product and a staple food in many parts of the world. Buckwheat is an attractive ingredient in gluten-free breads, although there are numerous limitations in using buckwheat in the baking industry. Generally, the results on the sensory quality of bread made from buckwheat, with or without a combination with other flours, are conflicting. Gluten-free bread based on rice and buckwheat (husked and unhusked) with the proportions of rice:buckwheat: 90:10, 80:20, and 70:30, showed very similar rheological properties as wheat-based bread. All breads were sensory acceptable (Torbica, Hadnadev, and Dapčević 2010). Bread based on wheat and rye with an addition of 3, 5, 7, 10, and 15% of buckwheat flour also received high consumer acceptability scores, although the porosity and specific loaf volume of the bread were reduced with increasing buckwheat portion (Temnikova et al. 2021). Thus, the portion of buckwheat flour in bread correlates with the rheological properties of dough and consumer acceptability. The incorporation of a higher portion of buckwheat flour (above 20%) negatively affected the technological and sensory parameters of bread and increases crumb hardness (Wronkowska et al. 2020). On the contrary, Aguiar et al. (2021) suggested that the maximum amount of buckwheat flour in bread can be up to 85% based on the acceptance of appearance, color, odor and texture. The same study demonstrated that using 35%, 45%, or even up to 50% buckwheat in bread resulted in rheological and thermomechanical properties similar to conventional bread, and the specific volumes may even be higher than the conventional bread. Southgate et al. (2017) used a blend of buckwheat, rice, and cassava flours and demonstrated that increasing the buckwheat flour portion from 15% to 45% caused an increase in insoluble fiber content,

crumb cell circularity, and loaf specific volume. A sensory test showed that buckwheat flour had a positive impact on bread quality and bread was accepted by consumers (Southgate et al. 2017). It should, however, be noted that bread with the highest content of buckwheat flour received the lowest sensory acceptability scores. When fermenting rice-buckwheat or pure buckwheat dough, an addition of teff flour increased consumer preferences (Campo et al. 2016). The combination of teff (10%) with rice and/or buckwheat sourdough enhanced the bread aroma, increasing fruity, cereal, and toasty notes. However, high levels of teff (20%) induced a decrease on the loaf area. The visual appearance of breads with 20% teff was highly appreciated by consumers, while bread combining 10% teff was preferred in terms of flavor. The bitter taste of buckwheat sourdough was generally considered a negative attribute. However, a group of consumers liked bitter bread as they associated it with a traditional, artisan, “malty-like” product (Campo et al. 2016). Generally, Tartary buckwheat products have a bitter taste, because of the degradation of the high rutin content to quercetin. Hydrothermal processing directly on buckwheat flour it is possible to reduce the bitter taste in breads with Tartary buckwheat (Wang, Fan, and Zhang 2017).

Bilgiçli and İbanoğlu (2015) pointed out that a blend of quinoa and buckwheat flour could replace 20% of wheat flour in the formulation of bread with maintained sensory acceptability. However, the addition of quinoa and buckwheat had a negative effect on the volume and the hardness of the breads.

In conventional bread based on refined wheat flour, a supplementation of buckwheat flour may increase the dough's qualities. Moisture content, ash, proteins, lipids, and carbohydrates vary according to the particle sizes of the buckwheat. The medium-sized particle fraction is the richest in protein, lipid, and ash, which contribute to increased water and swelling properties and reduced volumetric density. Amylase activity increases with the particle size in composite flour. A decrease of particle size increases water absorption, dough viscosity during starch gelatinization and retrogradation, while the level of added buckwheat may increase the dough development time and gel stability as well as decrease the rate of protein weakening (Coțovanu and Mironeasa 2021).

A study on rolls with or without added buckwheat showed significant differences between the breads in the intensity of the sensory properties sweet odor, bread crust odor, crust and crumb color, pore distribution, “sand-feeling” texture, or buckwheat taste in buckwheat-enriched bakery products (Wronkowska et al. 2019). However, these differences did not affect consumer acceptance. Furthermore, it was shown that buckwheat ingredients may improve the microbial qualities of the bread during storage (Wronkowska et al. 2019). Consumers evaluated the acceptability of the appearance, color, aroma, flavor, texture and overall liking of the gluten-free yeast rolls where whole grain flours from buckwheat, rice, sorghum, millet, amaranth, or quinoa, were replacing the flour-starch base in the original recipe (Drub et al. 2021). The new yeast rolls were accepted in all sensory attributes, varying from 6.0 to 8.6 on a 9-point scale, and did not differ from the control gluten-free yeast rolls. In

addition, brown rice or buckwheat flour presence in the yeast roll resulted in a product that can receive the claim of “fiber source” as it contains more than 3% of dietary fiber (Drub et al. 2021).

Discrepancies in the results from different studies concerning buckwheat qualities underline the importance to develop innovative approaches to enhance the sensory properties of buckwheat-based breads. The application of transglutaminase (TG), which modifies proteins through cross-linking, can improve the overall quality of a gluten-free bread, especially if used in buckwheat sourdough. The use of sourdough significantly reduces the specific bread volume, whereas the crumb becomes more cohesive and springier. When adding TG, the crumb is also more cohesive and springier, but has a lower density, similar to that of conventional bread. Moreover, the overall sensory qualities of buckwheat sourdough bread with added TG increase, as the characteristic bitter aftertaste of buckwheat is less noticeable (Diowski and Sadowska 2021). The overall sensory acceptability can also be increased by the addition of calcium and sodium caseinates, as it was demonstrated in a study on rice-buckwheat bread (Burešová et al. 2016). More studies are needed to evaluate calcium and sodium caseinates on buckwheat bread quality.

Biscuits, sweet bread, cakes, and cookies

Sweet bread, biscuits, cakes, and cookies are popular products in many parts of the world and can also be produced from buckwheat. The incorporation of buckwheat and amaranth flour (33% and 50%) into muffins based on wheat had a positive effect on nutritional properties by substantially increasing the unsaturated fatty acid profile and fiber content (Antoniewska et al. 2018). Furthermore, the antioxidative capacity of those muffins increased, and shelf life could be prolonged. The incorporation of buckwheat significantly affected the sensory attributes by increasing the intensities of cereal and nut aroma and taste (Antoniewska et al. 2018).

The exchange of rice flour for buckwheat flour (10, 20, and 30%) in gluten-free cookies resulted in significantly higher mineral content (Sakač et al. 2016). The 20% buckwheat cookie was the most acceptable. Another study successfully replaced wheat flour with 20% buckwheat and 10% sprouts flour in baked buns (Sturza et al. 2020). The nutritional value increased without any negative consequences on sensory and texture properties. The addition of guar gum improved gumminess, springiness, and adhesiveness (Sturza et al. 2020). Kaur et al. (2015) reported that gluten-free biscuits were sensorially improved if 1% of gums (guar gum, gum acacia, xanthan, or gum tragacanth) were added to the buckwheat flour. Among the gums, the addition of xanthan gum resulted in significant improvement in biscuit color, appearance, flavor, and overall acceptability. For the evaluation of the shelf life of rice-buckwheat cookies, it was found that sensory was a better method to use, than measurements of volatile aldehydes (Sakač et al. 2016).

Biscuits with gluten-free flours (buckwheat, sorghum, and lentil) and without rice and maize flours and starches, had

an enhanced nutritional profile and were accepted by consumers, however, different consumers groups differed in preferences (Di Cairano et al. 2022). Hussain and Kaul (2018) also carried out a study on biscuits. In that study, barley flour (10%) and buckwheat flour (10%, 20%, 30%, 40%, and 50%) were incorporated into wheat flour. The resulting biscuits were evaluated for sensory attributes as well as physicochemical and functional properties. All the blended samples exhibited high fiber, fat, ash, carbohydrate, and mineral contents when compared to those prepared from 100% wheat flour. Considering the taste, flavor, texture, and overall acceptability, the biscuit with 10% added buckwheat flour was found to be the most preferred. The incorporation of buckwheat flour increased the antioxidant potential and hence increased the functional property of the blended product. A reduction in negative oil aroma and the bitter after-taste in buckwheat-oat based biscuits was observed by the addition of herbs from the *Lamiaceae* family (sage, mint, rosemary, oregano, thyme) (Starowicz et al. 2020). It was noted that mint and rosemary significantly lowered the hexanal share, probably due to their antioxidative effects. The addition of rosemary increased functional properties and was the most effective in forming a positive aroma profile with high sensory acceptance (Starowicz et al. 2020).

Germinated buckwheat improved the liking of texture in rice crackers, which could be due to a decrease in starch retrogradation (Kim, In, and Rho 2017). Added buckwheat and corn flour to waffles did not have any negative impact on the sensory experience, although some changes in flavor (by a slight aroma of buckwheat) and color (brownier with added buckwheat) occurred (Dorohovych, Hrytsevich, and Isakova 2018). A study on wheat-based crackers showed that the addition of buckwheat and sourdough could improve taste, texture, and chewiness (Selimović et al. 2017).

Farzana et al. (2021) showed that cakes with up to 30% added buckwheat were highly accepted and had higher nutritional values due to the presence of fibers, proteins, and micronutrients. Another study on cookies with incorporated buckwheat flour at different levels (0, 20, 40, 60, 80, and 100%) into wheat flour found significant variation in the physicochemical and functional properties of the blended flour (Jan et al. 2015). The addition of buckwheat increased the antioxidant properties of blended flour proportionally, decreased hardness, and increased the non-enzymatic browning. The overall acceptability of cookies by sensory analysis was highest at 40% level of blending (Jan et al. 2015).

Pasta

Generally, the addition of buckwheat to pasta decreases the consumer acceptability. However, pretreatment of the buckwheat may improve the final product, for example, one study indicated that hydrothermal treatment seems to decrease bitterness and grittiness (Škrobot et al. 2022). The same authors suggested that maximum 20% of buckwheat can be added to maintain consumer acceptability. Sun et al. (2018) concluded that pregelatinization treatment of

buckwheat flours, including roasting, steaming, extrusion, boiling, and microwaving might be a potential way to enhance its use in food formulation as those treatments significantly influence the physiochemical, morphological, and functional properties of the flours. Sensory analysis showed that noodles based on pregelatinized buckwheat flour had higher scores than native buckwheat flour noodle in appearance, color, flavor, palatability, toughness, stickiness smoothness, taste, and overall acceptability (Sun et al. 2018). Using mixtures with different components might also be an attractive option. Pasta based on a mixture of rice-buckwheat flour showed good quality, specifically for high nutritional composition, low cooking loss and stickiness, and acceptable score for sensory attributes such as appearance, color, flavor, taste stickiness, and overall acceptability (Bouasla and Wójtowicz 2019). The texture was homogeneous and had a compact microstructure. Thus, gluten-free rice-buckwheat pasta would constitute a good alternative for persons diagnosed with celiac disease. Wang et al. (2019) showed that extruded buckwheat flour greatly may improve the cooking, texture, and eating qualities (hardness, elasticity, and resilience) of buckwheat noodles. The dynamic viscosity of extruded buckwheat flour was significantly related to the molecular size of whole molecules.

A comparison of cooked pasta based on dried or fresh pasta with added buckwheat showed that fresh pasta exhibited more desirable cooking qualities, in the form of lower cooking loss and breakage ratio, and more elastic texture than dried pasta (Wang et al. 2021b). The dried pasta had a harder texture. This was explained by the higher mobility of water in the fresh pasta and a more dense inner structure in the dried.

Hoehnel et al. (2022) evaluated the sensory characteristics of pasta with added flour from buckwheat, faba beans and/or lupin protein isolate and compared them with pasta made of 100% wheat. The most notable differences in the sensory profile between the wheat-based pasta and the pastas with buckwheat, faba beans and/or lupin protein isolate were observed for odor and color. The wheat-based pasta had a significantly stronger flour odor than the other kinds of pasta, while the legume odor was much more pronounced for the pastas with added flours. Furthermore, the perception of a beige color was much lower for the wheat-based pasta. No significant differences were detected in cooking loss, firmness, tensile strength, and stickiness. The pastas with added flour from buckwheat, faba beans and/or lupin protein isolate also scored high in overall sensory quality (Hoehnel et al. 2022). The addition of 20% buckwheat to gnocchi pasta based on potatoes was shown to increase the liking due to texture properties such as the increase of uni-form structure and firm texture (Cappa et al. 2021).

Snacks and drinks

Ready-to-eat snacks are very popular foods and perceived by many consumers as tasty and convenient. Sensory tests have revealed that snacks made from buckwheat were liked to a similar or higher degree compared to the reference snack products, which shows commercial potential for developing

buckwheat-containing snacks (Defries et al. 2018). Extruded snacks based on buckwheat and bread waste, such as dry bread milled to flour, were positively evaluated due to appearance, texture, mouthfeel, and overall sensory experiences (Iqbal et al. 2021). Another study focused on extruded protein-rich snacks based on a mix of pulses and pseudo-cereals, where a mix of blue lupin and buckwheat received the highest scores, especially regarding the texture attributes. The studied materials included lentil, lupin or faba bean mixed with quinoa, amaranth or buckwheat (Martin et al. 2022). Singh et al. (2019) analyzed extrudates based on corn grit with added buckwheat at three levels (0, 10, 20, and 30%), at different temperatures (130, 150, and 170°C), and with or without roasting (92°C for 15 min) and found that roasting improved flavor and texture. Extrudates with 20% added buckwheat and a temperature of 150°C yielded the highest sensory scores.

Ertugay, Yangilar, and Çebi (2020) added buckwheat fibers to ice cream and found that both freezing and melting points significantly decreased with the increase in the fiber content. The evaluated sensory properties showed high acceptance among consumers regarding overall impression and attributes concerning taste/flavor, texture, and appearance. In fact, the overall acceptance was higher in samples with added fibers than without.

To develop nutritious and functional yogurt with added buckwheat, an encapsulation methodology was used to form capsules of Tartary buckwheat flavonoids using polymeric whey protein as wall material (Sun, Zhou, and Huang 2020). Beside the effective delivery of the flavonoids to the small intestine, the encapsulation also masked the bitter taste and enhanced the color of the yogurt.

To develop a lager beer with high rutin content, a bioflavonoid and a strong antioxidant (Holasova et al. 2002), and with desirable sensory characteristics, Tartary buckwheat malt can be used as a brewing adjunct (Deng et al. 2019). In comparison to conventional beer, the rutin content in the buckwheat beers was significantly higher. The total flavonoid content in buckwheat beers was strongly dependent on the mashing method. The rutin-rich beers also showed better oxidative stability during forced-aging and were found to be acceptable regarding flavor and taste (Deng et al. 2019).

Two buckwheat cultivars in Poland were both distilled in different ways to produce raw spirits. It was shown that pressure-thermal treatment was a beneficial method for starch liberation. However, both cultivars were given high sensory scores when using the pressure-thermal treatment (Ługowoj, Balcerek, and Pielech-Przybylska 2019).

To conclude, buckwheat-based products are generally accepted by consumers with varying degrees, although some challenges remain for product developers and technologists.

Health effects of buckwheat

Historically, in many countries, buckwheat was considered as a source of compounds with therapeutic potential and as a pool for the identification and development of new drugs. Consumption of buckwheat has been associated with various beneficial effects on health, such as reduced risk of obesity,

diabetes, some forms of cancer, and cardiovascular diseases (CVD) (Kreft 2016) (Figure 1). Buckwheat-based foods such as noodles and breads generally have a lower predicted glycaemic index compared to wheat foods. Due to the presence of resistant starch, buckwheat grains have prebiotic properties (Skrabanja and Kreft 1998). The effects of buckwheat consumption on health were recently reviewed by Kreft (2016); thus, in the present review, we only briefly touch those aspects.

Type 1 diabetes mellitus

Generally, there is limited information about food intake and type 1 diabetes mellitus (T1DM) because this type of diabetes is an autoimmune disease that is not associated with lifestyle factors. However, hypoglycemia might be a problem for people with type 1 diabetes mellitus. Vetrani et al. (2019) studied the effect of fiber-enriched buckwheat pasta on postprandial blood glucose in 8 women and 2 men, with T1DM and celiac disease using corn pasta as a control. The postprandial response to buckwheat pasta in that study was more stable, indicating a lower risk of hypoglycemia.

Type 2 diabetes mellitus

In a parallel randomized 4-week dietary intervention trial, Tartary buckwheat (110g/d) has improved insulin resistance and lipid profile in patients with type 2 diabetes mellitus (T2DM) (Qiu et al. 2016). In that study, Tartary buckwheat as a whole food was used to replace a portion of dietary wheat or rice. Although the mechanism behind this improvement is not yet elucidated, there are indications that fagopyritols might be responsible for reduced symptoms of non-insulin dependent diabetes mellitus (Steadman et al. 2000). To understand the potential role of fagopyritols and DCI in glucose metabolism, Wu et al. (2018) investigated the ability of fagopyritols and DCI to regulate glucose consumption in normal and insulin-resistant HepG2 cells. It was demonstrated that fagopyritols and DCI enhanced the glucose consumption in normal and insulin-resistant HepG2 cell, with fagopyritol B1 being more effective than DCI. The same study demonstrated that purified fagopyritols A1 and B1 suppressed the increase of blood glucose, improved the serum lipid profile, and enhanced insulin resistance in an insulin-resistant mice model after 6 wk.

Generally, the main indications of beneficial effects of buckwheat on health were observed in *in vitro* and in animal studies. Kawa, Taylor, and Przybylski (2003) observed lower serum glucose after an acute dose of buckwheat concentrate in male Sprague–Dawley rats in the fed state. A decrease in the risk of T2DM development was also attributed to the presence of flavonoids, especially quercetin, which have been reported to inhibit the activity of α -glucosidase and α -amylase, thus reducing starch digestibility (Peng et al. 2019). The presence of fibers in buckwheat foods also contributes to health improvement in T2DM conditions. Supplementation with soluble dietary fibers from Tartary buckwheat bran at the levels of 0.5, 1, and 2% in the

diet reduced levels of blood glucose and improved lipid profiles in diabetic mice (Wu et al. 2021). A buckwheat protein product was able to reduce serum cholesterol levels and the lithogenic index in rats. Both reductions were associated with enhanced excretion of fecal neutral sterols and fecal bile acid, respectively (Tomotake et al. 2007). The oral administration of buckwheat-albumin hydrolysates reduced the postprandial blood glucose, but not insulin, in rats after oral starch loading (Ninomiya et al. 2022). This effect was explained by inhibition of α -amylase in the gut (Ninomiya et al. 2018). Thus, buckwheat can potentially be used as a functional ingredient to prevent or improve diabetes mellitus and reduce associated healthcare costs.

Despite the positive effects of buckwheat observed *in vitro* and in animal studies, the results from clinical human studies are contradictory. Thus, Stringer et al. (2013) did not observe any alterations in acute post-prandial glucose or insulin in healthy individuals or in patients with type 2 diabetes after buckwheat consumption. In contrast, Zhang et al. (2007) suggested that buckwheat positively affected glucose metabolism and hyperglycemia in the pastureland Mongolian population in China.

Allergy

Besides the positive health effect of buckwheat consumption, there are potential negative effects. Buckwheat flour and meal might cause allergic reactions, including hypersensitivities such as asthma and gastrointestinal disorders (Norbäck and Wieslander 2021). The allergy to buckwheat proteins is one of the most common food allergies worldwide (Satoh, Jensen-Jarolim, and Teshima 2020). Several clinically relevant IgE-binding proteins in common buckwheat have been identified as allergens with the 22kDa protein being the major allergen, with the molecular mass belonging to the globulin protein legumin-like β subunit (Wang et al. 2004). Interestingly, it was suggested that the allergenicity and surface functionalities of proteins can be altered by conjugation with the polysaccharides (Nakamura et al. 2008).

Peripheral nerve damage

To the best of our knowledge, only one study reported an association between toxic peripheral neuropathy and buckwheat consumption. Toxic peripheral neuropathy was reported in 5 male diabetic patients taking buckwheat composite tablets (Yang et al. 2014). It should be, however, noted that these patients used the tablets from the same batch and the exact source of the peripheral neuropathy is still unknown.

Conclusion

Buckwheat is an attractive but underutilized crop for food production that could contribute to higher biodiversity when used in mixed crop systems. Moreover, buckwheat has the ability to adjust to adverse climatic conditions. Buckwheat is

an excellent source of protein with a well-balanced amino acid composition, dietary fibers, vitamins, minerals, and bio-active compounds. Buckwheat contains no gluten and can serve as valuable food for persons suffering from gluten intolerance. Consumption of buckwheat has been associated with various beneficial effects on health, such as reduced risk of obesity, diabetes, some forms of cancer, and CVD. Fagopyritols are of special interest for the treatment of non-insulin dependent diabetes mellitus. Buckwheat-based products are generally accepted by consumers and have a potential to be a part of a healthy diet. Thus, the use of buckwheat in agriculture and food industry can improve world food security and economic growth. Future research should be focused on breeding programs toward buckwheat cultivars with improved agronomic characteristics and superior nutritional qualities, such as reduced content of antinutrients or development of low-allergen lines. The long-term effects of buckwheat consumption on human health and buckwheat's contribution to more resilient farming systems and promotion of biodiversity should also be further studied. Finally, more research is needed to facilitate the successful development of tasty and safe buckwheat-based foods with environmental and health benefits.

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