We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

The Importance of Buckwheat as a Pseudocereal: Content and Stability of Its Main Bioactive Components

Amela Džafić and Sanja Oručević Žuljević

Abstract

The production of various bakery and non-bakery products based on buckwheat with components that positively affect health (fiber, antioxidants, and/or minerals), the optimization of recipes and technological process parameters, as well as giving character to final products in terms of their sensory acceptability and potential functional properties, gained significant interest last few years. Therefore, buckwheat products such as bread, biscuits, snacks, noodles, and cakes are commercialized and increasingly consumed. In addition, the use of non-bakery buckwheat products, such as tea, sprouts, honey, and other products, is becoming more common. In order to obtain potentially functional food with buckwheat of high nutritional quality, it is important to understand the effect of processing on bioactive components. The baking process, inevitable in the production of bakery products, is especially important. It is also important to understand the effect of storage on bioactive components. To this end, in the light of available literature, this chapter will provide an overview of bioactive components in buckwheat and discuss their stability in buckwheat and its products during processing and storage.

Keywords: common and Tartary buckwheat products, sensory acceptability, functional properties, effect of processing and storage, stability of bioactive components

1. Introduction

Buckwheat is an annual herbaceous plant that botanically belongs to the order *Polygonales*, family *Polygonaceae*, genus *Fagopyrum* [1], but in terms of processing, similar use, chemical composition, and the seed structure itself, it is similar to cereals. It is therefore often classified as a pseudocereal [2, 3]. In the genus *Fagopyrum*, 15 species were discovered and described, among which nine have agricultural and nutritional value. However, only two species are most commonly grown: common (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*Fagopyrum Tataricum* L.). Common buckwheat is the most common and cultivated species from temperate Europe to Japan, while Tartary buckwheat is grown in some mountainous areas [4].

Buckwheat grains are the main form of consumption of this pseudocereal. Hulled grains are mostly used for human consumption in the form of breakfast cereals or

as flour for the production of various bakery products (bread, cakes, snacks) and noodles enriched with buckwheat flour (0.3–60%), buckwheat-improved non-bakery products (tea, honey, and tarhana) [5] and products made of buckwheat husks such as pillows, quilts, mattresses, collars, eye masks, and children's toys [6]. In addition to flour and groats, buckwheat sprouts are increasingly used to improve bakery products [5, 7].

Since buckwheat is gluten-free, these products can be included in a gluten-free diet for patients with gluten intolerance [8, 9].

The addition of buckwheat into bakery products is of particular importance. This pseudocereal is gaining increasing attention as potentially functional food [4, 10]. Namely, buckwheat is recognized as a good source of nutritious proteins, lipids, dietary fiber and minerals and, in combination with other components that have a positive impact on health such as phenolic components and sterols, it is attracting increasing attention as a functional food. *In vitro* and *in vivo* studies have shown that the consumption of buckwheat and products enriched with this pseudocereal is associated with a wide range of biological and health activities: hypocholesterolemic, hypoglycaemic, anticancer, and anti-inflammatory. According to the recent phytochemical and pharmacological researches polysaccharides of buckwheat present also important bioactive components with numerous biological activities [11].

Buckwheat is the only pseudocereal that contains rutin, which has shown anti-inflammatory, anticancer, antiatherogenic, and antioxidant activity [4, 12]. Buckwheat protein extracts are associated with anticancer and cholesterol-lowering effects in animals [13, 14]. Apparently, the incorporation of buckwheat into bread results in significantly lower blood glucose and insulin responses compared to white wheat bread [15]. Buckwheat grain contains very rare *D-chiro*-inositol, which has been associated with reducing the symptoms of type 2 diabetes mellitus (non-insulin-dependent diabetes mellitus) [16].

2. Bioactive components in buckwheat

2.1 Proteins

Buckwheat proteins have a high biological value thanks to a well-balanced amino acid composition. The protein content of buckwheat is relatively lower than the protein content of legumes. However, the amino acid score of buckwheat protein is 100 and the content of essential amino acids corresponds to the recommended amino acid intake for children and adults [17].

They are rich in lysine, which is the first limiting amino acid of plant proteins, and arginine [18, 19]. However, the content of glutamine and proline is much lower compared to wheat [20], and threonine and methionine are the first and second limiting acids in buckwheat. Furthermore, Giménez-Bastida et al. [5] stated that buckwheat proteins are rich in albumin and globulin and that they are very poor in prolamin and gluten. Therefore, buckwheat flour is suitable for use in the diet of people with celiac disease due to its low non-toxic prolamin content [21]. The protein content in buckwheat flour is significantly higher compared to rice, wheat, corn, millet, and sorghum flour. While it is lower only compared to the protein content of oat flour [19]. Guo et al. [22] pointed out that the average protein content in buckwheat is 12.94%.

The digestibility of buckwheat proteins is about 80%, which is lower compared to proteins of animal origin such as hemoglobin and ovalbumin. However, it is higher

than cereal proteins (e.g., sorghum 55–59%; corn 66–75%) and has a value approximate to rice bran (89%) and wheat germ (77–93%). Despite the balanced composition of essential amino acids, the bioavailability of buckwheat protein after digestion is not complete. Relatively low digestibility is attributed to the molecular structure of buckwheat protein and the presence of antinutritive factors in flour and protein isolates [17].

Buckwheat, along with other pseudocereals such as quinoa and amaranth, is recommended for use in creating new value-added bakery products because it can provide high levels of essential amino acids in the human diet [23].

The literature states that buckwheat proteins have many unique physiological functions, such as treating chronic diseases in humans, reducing serum cholesterol, suppressing gallstones and tumors, inhibiting angiotensin I-converting enzyme (ACE), and so on [17, 24, 25]. An ACE inhibitory tripeptide (Gly-Pro-Pro) was isolated and identified from common buckwheat [26]. In humans, buckwheat consumption has also been associated with a lower prevalence of hyperglycemia and improved glucose tolerance in people with diabetes [27]. Since many health benefits of buckwheat are inherently related to peptide radical binding activity from digested proteins, it is hypothesized that buckwheat protein hydrolysis may release peptide fragments capable of stabilizing reactive oxygen kinds and inhibiting lipid oxidation. By in vitro digestion of buckwheat protein six peptide fractions were obtained, whereas LC-MS/MS identified Trp-Pro-Leu, Val-Pro-Trp, and Val-Phe-Pro-Trp (IV), Pro-Trp (V), and tryptophan (VI) as the prominent peptides/amino acid in these fractions [28]. Six peptides DVWY (H-Asp-Val-Trp-Tyr-OH), FDART (H-Phe-Asp-Ala-Arg-Thr-OH), FQ (H-Phe-Gln-OH), VAE (H-Val-Ala-Glu-OH), VVG (H-Val-Val-Gly-OH), and WTFR (H-Trp-Thr-Phe-Arg-OH) identified from buckwheat sprouts fermented with *Lactobacillus Plantarum* revealed significant blood pressure-lowering effect, thereby the most potent were DVWY, FQ, and VVG [29]. From the seeds of common buckwheat were purified two peptides (Fa-AMP1 and Fa-AMP2) which have antimicrobial properties [30]. Studies have shown that buckwheat protein extracts show anticancer activity, activity of lowering cholesterol, as well as anti-constipation and anti-obesity activities in animals [13, 17, 24]. An unusual antitumor protein TBWSP31 isolated from water-soluble Tartary buckwheat extracts was also examined [31].

2.2 Phenolic components

Many health benefits of buckwheat are attributed to the high content of phenolic components and high antioxidant activity [18]. Whole grain buckwheat was found to contain 2–5 times more phenolic components than barley and oats, while the husk and bran of buckwheat have 2–7 times higher antioxidant activity compared to barley, triticale, and oats [32, 33]. The research by Begić et al. [34] showed that Tartary buckwheat contains about 20 times more total phenol content and that it shows antioxidant activity nine times higher than common buckwheat.

Among the polyphenolic components present in buckwheat, those from the group of flavonoids, and among them rutin, are the most important ones.

2.2.1 Flavonoids

The presence and amount of flavonoids in buckwheat grain make it specific compared to cereals, which contain small amounts of flavonoids. This group of

polyphenolic components is the basic antioxidant of buckwheat [35, 36]. Buckwheat is considered to be one of the best dietary sources of rutin [36]. The content and composition of flavonoids are different in different types of buckwheat. In general, the flavonoid content in *F. Tataricum* (40 mg/g) is higher than in *F. esculentum* (10 mg/g), reaching concentrations of 100 mg/g in flowers, leaves, and stems [37]. The content of flavonoids in Tartary buckwheat can be up to 7% [38].

Flavonoids demonstrate a protective effect in lipid oxidation in vitro as “scavengers” of free radicals and metal chelators [39]. They generally occur as O-glycosides in which one or more hydroxyl groups are bound to sugars.

Six flavonoids were isolated and identified from whole buckwheat grains: rutin, quercetin, orientin, isoorientin, vitexin, and isovitexin. The presence of rutin and isovitexin was found in hulled grain while buckwheat husk contained all 6 flavonoids [40, 41]. Buckwheat is the only pseudocereal that contains rutin and is, therefore, a useful source of this flavonoid [25]. Except in buckwheat, rutin has not been detected in cereals and pseudocereals [41, 42]. Rutin (quercetin-3-O- β -rutoside), a secondary metabolite present in buckwheat, is the best-known glycoside derived from flavonol quercetin. Buckwheat is considered the best source of dietary rutin. Buckwheat grains (groats and husk) and sprouts are important sources of rutin and their content depends on the type and conditions of growth [43, 44]. It is important to develop new well-adaptive varieties with a high content of rutin, and improved biological value of the proteins [45].

Tartary buckwheat groats contain more rutin—80.94 mg/g dry matter (DM) than common buckwheat groats—0.20 mg/g DM [46, 47] while Tartary buckwheat sprouts have 2,2 times more rutin than common buckwheat sprouts [48]. Li et al. [49] stated that Tartary buckwheat can contain up to 100 times more rutin than common buckwheat.

Rutin has attracted much attention mainly because of its many health benefits observed in vitro and in vivo: anti-inflammatory, antidiabetic, hypocholesterolemic, antiatherogenic, antiatherosclerotic, and anticancer ones [4, 12, 36, 50–53] and its activity are related to antioxidant capacity [54]. Furthermore, rutin may be effective in preventing the toxic effects of methotrexate on the kidneys [55].

Rutin has relaxing effects on smooth muscles and is effective in preventing capillary apoplexy and retinal bleeding, lowers high blood pressure and shows antioxidant activity and lipid peroxidation activity. It also has lipid-lowering activity by reducing dietary cholesterol absorption, as well as reducing plasma and liver cholesterol [56, 57]. In addition, possibilities of rutin as a new strategy for the prevention of type 2 diabetes are noted [58]. Alkaline luminol chemiluminescence and electron spin resonance analysis revealed the formation of the rutin-ovalbumin complex which significantly increases the radical-binding activity in rutin. Rutin has also demonstrated antioxidant activity against hydroxyl radicals in a DNA protection test [59].

Quercetin (quercetin-3-ramnoside) is another glycoside present in buckwheat in concentrations ranging from 0.01 to 0.05% DM in Tartary and from 0.54 to 1.80% DM in common buckwheat [46, 60]. Isoquercetin (quercetin-3-glucoside) is present in buckwheat hypocotyl (1.4 μ M/g DM) [61] and has been shown to exhibit antidiabetic and anticancer activity [36, 49, 62, 63]. Quercetin, an aglycone of rutin, is present in hulled grain (semolina) of buckwheat (0.001 mg/g DM) and husk (0.009–0.029 mg/g DM) in lower concentrations than rutin [18, 47]. Quercetin is the most studied flavonoid, primarily due to its pronounced antioxidant activity, as well as significant absorption in the digestive tract. It is predominantly in the form of glycoside as rutin (quercetin-3-O- β -rutoside). In addition to this, kaempferol-3-O-rutinoside and quercetin 3-O-rutinoside-3'-O- β glucopyranoside have been found in buckwheat seeds [49, 64].

Three flavonoids from Tartary buckwheat bran: quercetin, isoquercetin and rutin were evaluated as R-glucosidase inhibitors (controlling blood glucose) using fluorescence spectroscopy and enzyme kinetics. The R-glucosidase activity was clearly influenced by extractives (mostly rutin) and their hydrolysis products (a mixture of quercetin, isoquercetin, and rutin) from buckwheat bran [65].

Recent research relating to the examination of the antiviral activity of rutin in the treatment of patients with COVID-19 symptoms have been topical [66, 67].

In addition to rutin, catechins, the antioxidant activity of which is higher than the antioxidant activity of rutin, were isolated from ethanol extracts of buckwheat groats. Four catechins were isolated and their structures were determined as: (-)-epicatechin, (+)-catechin-7-O- β -D-glucopyranoside, (-)-epicatechin 3-O-p-hydroxybenzoate, and (-)-epicatechin 3-O-(3,4-di-O-methyl)gallate [68]. The following components from the catechin group were identified in buckwheat: catechin, epicatechin, catechin glucoside (A or B isomers), catechin gallate, epicatechin gallate, epicatechin-O-3,4-dimethylgallate, epiaphzelchin-(4–8)-epicatechin-3,4-O-dimethylgallate, while catechin-3,4-O-dimethylgallate was identified in thermally treated buckwheat and epiaphzelchin-(4–6)-epicatechin was identified in green buckwheat [69].

These ingredients in plant tissue are influenced by numerous environmental factors such as ultraviolet (UV) radiation, harvest time and damage caused by pests, and genetic and aging-related factors. Studies have shown significant positive correlations between the mean altitude of the growth site and the amount of individual phenolic antioxidants [70, 71]. Buckwheat, as a source of rutin, can be successfully grown in Mediterranean conditions, too [72]. Flavon-3-glycosides present in buckwheat (vitexin, isovitexin, orientin, and homoorientin), anthocyanin and proanthocyanin content [61] and the presence of squalene, epicatechin, and vitamin E [73] make buckwheat a good antioxidant source in the human diet.

2.2.2 Phenolic acids

Phenolic acids in buckwheat also contribute to its antioxidant activity. In the grain of different varieties of Tartary buckwheat, p-hydroxybenzoic, ferulic and protocatechuic stand out, and other acids, including p-coumaric, gallic, caffeic, vanillic, and syringic acid, were also detected [74]. Several phenolic acids have been described during the flowering of different varieties of buckwheat: chlorogenic, p-anisic, salicylic, and methoxycinnamic [75].

2.3 Vitamins

Buckwheat is also an important source of vitamins, especially those of the B group. The total content of B vitamins, including B1 (thiamine, 2.2–3.3 $\mu\text{g/g DM}$), B2 (riboflavin, 10.6 $\mu\text{g/g DM}$), B3 (niacin, 18 $\mu\text{g/g}$), B5 (pantothenic acid, 11 $\mu\text{g/g}$) and B6 (pyridoxine, 1.5 $\mu\text{g/g}$) is higher in Tartary buckwheat compared to common buckwheat. The levels of vitamin C indicated for it in the literature go as high as 50 $\mu\text{g/g DM}$ while its content, as well as the total amount of vitamins B1 and B6, increases by germination of buckwheat and, consequently, the content of vitamin C in buckwheat sprouts reaches 250 $\mu\text{g/g DM}$ [4, 54, 76, 77]. Vitamin B1 is found in thiamine-binding proteins of buckwheat grains, which, according to Li and Zhang [37] increases the availability of vitamin B1 and improves its stability during storage. The content of vitamin E (tocopherols) in buckwheat is higher compared to wheat, barley, oats, and

rye [18]. The most common tocopherol in buckwheat is γ -tocopherol. In addition to γ -tocopherol, α - and δ -tocopherol have also been identified in buckwheat [78]. The concentration of total tocopherols in buckwheat grains ranges from 14.3 to 21.7 mg/kg [79]. Tocopherols, along with the other components mentioned above, make buckwheat a good antioxidant source in the human diet. Tocotrienols were not detected in buckwheat [80, 81], while Piironen et al. [82] identified traces of tocotrienols in whole buckwheat grains. High levels of vitamin E intake are associated with a reduction in cardiovascular disease, a reduction in the risk of Alzheimer's disease, and an improvement in the immune system [73].

2.4 Isoprenoids

Squalene is an isoprenoid component that has six isoprene units and antioxidant activity and is widely produced in buckwheat plants. Squalene protects cells from radicals, strengthens the immune system, and reduces the risk of various types of cancer. There are some differences between buckwheat species, especially in the content of squalene and rutin [73].

2.5 Phagopyritols

Buckwheat grains contain a very rare *D-chiro*-inositol, which is mostly found in the form of phagopyritols [18]. Phagopyritols are mono-, di- and trigalactosyl derivatives of *D-chiro*-inositol and are called phagopyritol B1, B2, and B3. Phagopyritols A1, A2, and A3 have been identified as isomers of phagopyritols B1, B2, and B3 [83–85]. Phagopyritols are concentrated in aleurone and embryonic grain cells, with phagopyritol B1 (0.392 mg/g DM of integral common buckwheat semolina) being the most abundant. *D-chiro*-inositol, free form, is present in lower concentrations (0.21–0.42 mg/g DM) [18].

So far, several studies have described the role of *D-chiro*-inositol and phagopyritol as molecules that exhibit insulin-like activity [18, 86, 87]. In particular, *D-chiro*-inositol has attracted much interest due to its ability to lower glucose in animal models [88], and an important number of studies have shown that chemically synthesized *D-chiro*-inositol lowers elevated plasma glucose levels [89, 90]. Although no studies have been conducted to date to explore the effects of *D-chiro*-inositol and phagopyritol in humans, these components may have positive effects in the treatment of diabetes. In animal models, *D-chiro*-inositol has been associated with a reduction in the symptoms of type 2 diabetes mellitus [16]. The potential of *D-chiro*-inositol in the treatment of polycystic ovary syndrome has been extensively investigated [57, 91–93].

2.6 Phytosterols

Buckwheat is also significant for its phytosterol content. Phytosterols present in buckwheat, although in low concentrations, also show a positive effect in lowering blood cholesterol levels. In addition, phytosterol intake significantly reduces in vivo cholesterol absorption. Buckwheat phytosterols are present throughout the grain, but their content varies by grain parts [37]. The most abundant phytosterol in buckwheat flour is β -sitosterol (0.86 mg/g DM) and makes up about 70% of total sterols, followed by campesterol (0.11 mg/g DM) and stigmasterol (0.02 mg/g DM) [94].

According to the research of Dziedzic et al. [95], the sterols content in Tartary buckwheat whole grains was 15,398 mg/kg of lipids and the most prevalent was the β -sitosterol (10,944 mg/kg of lipids).

2.7 Iminosugars

D-fagomin is a minor component from the group of iminosugars detected in the dehulled grain of common buckwheat which shows a glucose-lowering effect [96, 97].

Similar to D-fagomin, other imino sugars such as 1-deoxynojirimycin (DNJ) are intestinal glucosidase inhibitors, associated with a reduced risk of developing insulin resistance, gaining weight, and suffering from excess potentially pathogenic bacteria [97, 98]. Anthraquinone emodin is present in buckwheat concentrations between 1.72 and 2.71 mg/kg DM [99]. Due to the wide range of biological activities that emodin exhibits, it can be considered an important bioactive factor in buckwheat [100].

2.8 Other components

Along with vitamins, other components were detected, such as glutathione (1.10 mmol/g DM in buckwheat groats), phytic acid (35–38 mg/g DM in bran), carotenoids (2.10 mg/g DM in grain), and melatonin (470 pg/g DM in groats). These components may contribute to the antioxidant activity of buckwheat [4, 47].

Both types of buckwheat, common and Tartary, have a high tannin content (1.76 and 1.54%). Tannins isolated from buckwheat showed a relatively high level of activity against *Listeria monocytogenes* [101].

It has also been found that γ -aminobutyric acid (GABA) and 2''-hydroxynicotianamine (2HN) serve as functional components in buckwheat. Grains and sprouts contain GABA, while 2HN was identified in flour. Literature states that these components lower blood pressure in humans and inhibit the activity of angiotensin I-converting enzyme (ACE) [102–104]. Suzuki et al. [105] quantified GABA and 2HN concentrations in common and Tartary buckwheat leaves 14, 28, and 42 days after sowing (DAS). The concentration of GABA reached a peak at 42 DAS, while the concentration of 2HN decreased with the age of the plant.

3. Stability of bioactive components in buckwheat and its products during processing

It is well known that processing can cause chemical changes in food products. Therefore, it is important to consider the effects on bioactive components in buckwheat. Today, there are several technological processes related to buckwheat, which will be presented below.

3.1 Milling

Milling is one of the technological processes that is inevitable during the processing of buckwheat into flour. During the processing of buckwheat grains into white flour, the husk and outer layers are separated, which lowers the ratio of fibers, minerals, and polyphenolic components.

Hung and Morita [106] explored the possibility of improving the functionality of buckwheat flour by successively milling buckwheat and they found that in 16

different fractions of flour the content of ferulic acid and rutin increases with an increased ratio of outer grain layers. The same authors found that the antiradical activity on DPPH extracts of free and bound polyphenolic components of buckwheat, the fraction of the successive milling of buckwheat is highest for fractions containing external grain parts. Additionally, better antiradical activity on DPPH was registered for extracts of free polyphenolic components compared to extracts of bound polyphenolic components in buckwheat grain.

Inglett et al. [107] examined the antioxidant activity of ethanolic extracts of four types of commercial buckwheat flour and found the highest antiradical activity on DPPH in buckwheat flour containing a high ratio of husk and aleurone layer, while the lowest antiradical activity was registered in white flour consisting exclusively of the endosperm. The highest content of total polyphenolic components and total flavonoids was registered in whole buckwheat flour. Gallardo et al. [108] established that the content of rutin in buckwheat flour is 0.7 mg/100 g and 11.2 mg/100 g in buckwheat husk.

A recent study found that the buckwheat protein contents decreased from the exterior to the interior parts of the groats [109]. Significantly higher content of amino acids, fatty acids, polyphenols, and flavonoids was found in the bran of Tartary buckwheat, compared to the flour [110].

It should be noted that the milling conditions should be adapted to the type of buckwheat. The granulation composition of common and Tartary buckwheat flour differed under the same milling conditions and affected the physical characteristics of the obtained flour fractions. Tartary buckwheat flour contained larger fractions compared to common buckwheat flour under the same milling conditions [111]. By adjusting the grinding and knowing the content of different components in the fractions of Tartary buckwheat, it is possible to obtain products of different nutritional value [45, 111].

3.2 Heat treatment

The number of studies researching the effects of heat treatment on buckwheat foods has increased significantly. Today, many new thermal techniques are used in the food industry to improve the quality of functional buckwheat food. The extrusion process has become important in the production of pasta, ready-to-eat cereals, snacks, animal feeds, and textured plant proteins. Microwave heating has gained popularity in food processing due to the ability of this technique to achieve high heating rates, significantly reduce cooking time, provide more uniform heating and safe handling. This technique could change the taste and nutritional properties of food to a lesser extent, as opposed to conventional heating during the cooking process [112]. However, data on the effects of heat treatments on the antioxidant capacity of buckwheat and its products are still limited. In general, most studies are aimed at determining the effect of heat treatment on the content of total phenols and flavonoids due to their role in the management of human health and diseases.

It was established that the heat treatment of buckwheat causes changes in its chemical composition and, above all, that it affects the functional properties of the selected bioactive components. The results published so far on the effects of the heat treatment on buckwheat grain and processed flour are contradictory.

One of the first studies was conducted by Dietrych-Szostak and Oleszek [40] who examined the effect of heat processing on flavonoid content in hulled grains and buckwheat husks by removing the husk using heat. Removing the husk from

buckwheat grain by applying heat treatment resulted in a product that was both visually and chemically different. The peeling process removed primarily the multitude of tannins and crude fibers that are naturally present in the husk. As for the concentration of total flavonoids, dehulling process with different temperature treatments caused a drastic reduction of the total flavonoid concentration in the grain (by 75% of the control) and smaller but significant (15–20%) reduction in the hulls.

Kreft et al. [12] compared the content of rutin in buckwheat products with its content in the raw materials used to obtain these products. Noodles prepared with 70% of integral buckwheat flour contained much less rutin (78 mg/kg DM) compared to the integral buckwheat flour (218 mg/kg DM) out of which they were produced. As a possible explanation for this reduction in rutin content in the product, the authors cited the presence and activity of an enzyme that degrades rutin, flavonol 3-glucosidase, during dough mixing. The presence of this enzyme in buckwheat was confirmed by Suzuki et al. [113]. In raw (uncooked) hulled buckwheat grain (raw buckwheat semolina) the rutin content was 230 mg/kg DM, while in pre-cooked hulled buckwheat grain its content was 88 mg/kg DM. The aforementioned authors explained the established reduction of rutin content in hulled buckwheat grain due to hydrothermal treatment by possible degradation of rutin molecules or its combination with some other molecules, in such a way that it becomes insoluble in the applied solvent. A similar reduction in rutin content was observed during bread production in different combinations of wheat and Tartary buckwheat flour (100:0; 70:30; 50:50; and 0:100) where the effect of making bread and baking on the content of rutin, quercetin, and polyphenols and the antioxidant activity of said loaves was examined. After baking, rutin (0.47 mg/g) was present in bread which is made of 100% Tartary buckwheat flour, together with quercetin (4.83 mg/g). The dough that this bread was made of contained a lower concentration of rutin and greater concentration of quercetin compared to flour used to prepare it; wherein 0.0175 mmol of rutin degraded with the addition of water and yeast to Tartary buckwheat flour, and 0.0149 mmol of quercetin was obtained at the same time. This indicates that 85% of the rutin was converted to quercetin by adding water and yeast to the flour [114].

Degradation of rutin can be the result of activities of the rutin-degrading enzyme found in buckwheat. This enzyme is stable and active at pH 5–7 and below 40°C. Based on the comparison of the level of concentration, it appears that quercetin is more stable compared to rutin in the process of proofing and baking bread. There were no significant differences in the content of rutin and quercetin between the bread crumb and crust. Additionally, the results showed a reduction in the total polyphenol content in all samples of bread as a result of the heat treatment in the baking process [112].

The obtained results were consistent with the results of the authors Alvarez-Jubete et al. [21] which showed a significant decrease in the concentration of total polyphenols, particularly phenolic acids in bread made of common buckwheat flour (0.65 mg GAE/g) compared to the concentrations of these components in buckwheat grain (3.23 mg GAE/g). During the process of mixing and proofing the bread, there was a modest increase in the concentration of total polyphenols in bread samples made with 100% wheat flour and 100% Tartary buckwheat flour, and a slight reduction in the other samples, containing a combination of both kinds of flour (70:30 and 50:50).

Reductions in polyphenol content and antioxidant activity were also reported during baking of bread samples prepared in different combinations (90:10; 80:20; and 70:30) of rice and buckwheat flour (wholemeal and white) relative to their content in flours. It was noticed that the baking process resulted in a higher percentage

of reduction in total polyphenols in bread samples made with white buckwheat flour, while only minor or insignificant changes were observed in lower percentages (10 and 20%) in samples with wholemeal buckwheat flour, and only the sample with 30% of wholemeal buckwheat flour had a decrease of about 17%. In addition, the decrease in antioxidant activity was more pronounced in bread samples prepared with white buckwheat flour. During baking, there was a loss in rutin content in bread samples relative to its assumed (calculated) content, and this loss increased with increasing the proportion of buckwheat flour, both types (wholemeal and white), in the range of 4.57–40.4%. The opposite trend was observed in the quercetin content, which increased from 1.5 to 7 times, probably due to the hydrolysis of rutin into quercetin [115].

Similar results were shown in bread samples produced with the addition of buckwheat in the amount of 15 g/100 g and 30 g/100 g. A decrease in the content of total phenols, total flavonoids, and antioxidant activity in bread samples relative to their content in flour was found. The content of total flavonoids in bread samples was 2 to 4 times lower compared to its content in flour [116].

The thermal treatment of Tartary buckwheat bran and flour significantly reduced the content of fatty acids, polysaccharides, and polyphenols. As for the content of amino acids and total flavonoids, their content in bran after heat treatment decreased, while increased in the flour of Tartary buckwheat [110].

In addition to bread and cakes, a decrease in the content of bioactive components was observed in the production and cooking of other products with the addition of buckwheat such as spaghetti, pasta, noodles, etc. A decrease in the content of free (about 74.5%) and bound (about 80%) phenolic components “farm to table”, i.e., from flour to cooked spaghetti with buckwheat was found. Regarding the content of total phenolic components, the spaghetti production process (mixing, extrusion, and drying) caused a loss of 45.9%, which the authors explain by the increase in temperature during the extrusion process and the high temperature (about 95°C) reached during drying. Further degradation of phenolic components was found after cooking spaghetti. The boiling process caused the degradation of 52.9% of the total phenolic components. This degradation was significantly different ($p < 0.05$) compared to post-production degradation. This effect can be attributed to the solubility of phenolic components in boiled water. Of the total phenolic components that were present in the spaghetti after the drying process, 11.6% were dissolved in water after cooking [117].

Biney and Beta [118] also reported that the production and cooking process led to a reduction in phenol content and antioxidant activity in spaghetti enriched with buckwheat flour and bran. The production process did not cause statistically ($p < 0.05$) significant changes in the content of total phenols between flour mixtures and uncooked products. However, cooking significantly reduced total phenols in all spaghetti samples. Although the addition of buckwheat flour resulted in a significantly higher content of these components in all spaghetti samples, the average percentage of decrease in total cooking phenols due to cooking was higher in samples containing buckwheat flour or bran, compared to control samples prepared from semolina. The production and cooking process also led to a significant reduction in the content of rutin and total flavonoids in spaghetti samples. The higher the proportion of buckwheat in the spaghetti formulation, the greater the losses in rutin content.

The results of similar research (pasta enriched with buckwheat flour in the amount of 20%) showed a reduction of about 44% of total phenolic components after cooking compared to their content in pasta after drying; 8.37% of total phenols

from dried pasta was present in the water in which it was boiled, and 35.63% was degraded. The cooking process reduced the rutin content by about 8.50%. During cooking, rutin was converted from its bound form to quercetin, which is shown in the increase of quercetin content by about 20%. The results also showed that catechin showed a minimum tolerance to the cooking process, with a loss of about 57% [119].

Furthermore, the autoclaving of buckwheat grains caused a decrease in free and an increase in bound phenolic forms in flour. Similarly, this was found in noodles produced by adding this flour to the formulation with wheat flour, compared to the content of these components in noodles produced in the same way with flour obtained from untreated buckwheat grains. Although autoclaving caused an initial reduction in rutin in treated grain flours, it prevented further degradation and conversion of rutin to quercetin in uncooked and cooked samples obtained from these flours, causing a possible improvement in the sensory acceptability of noodles. The loss of phenolic components in noodle samples with added buckwheat flour during cooking (48.1–61.1%) was at the same level as in the control sample with wheat flour only, indicating that buckwheat-containing pasta can maintain the quality during cooking [120].

Cho and Lee [121] examined the thermal stability of rutin in wheat instant fried noodles fortified with rutin-enriched material (REM) from buckwheat milling fractions. The noodles were fried at different temperatures (150, 170, and 190°C) during different periods of time (1, 2, and 3 minutes). Also, noodles were placed in boiling water at different periods (0, 3, and 6 minutes) to examine the effect of cooking on rutin content. The results showed that different temperatures and frying times did not negatively affect the rutin content, while a marked loss of rutin was observed after cooking the noodles.

However, the results of another study showed a reduction in bioactive components in buckwheat products during various heat treatment processes and reported an increase in the total antioxidant activity in buckwheat sprouts and shoots after autoclaving treatment. Furthermore, an increase of 20% and a reduction of 7% of total phenols were observed in buckwheat sprouts and shoot respectively [122].

Contradictory results were also found by Zieliński et al. [123] during extrusion of buckwheat, which showed a decrease in antioxidant capacity accompanied by a reduction in rutin and isovitexin, but at the same time an increase in free phenolic acids and those freed from ester bonds. The authors stated that the reported increase in phenolic acids could be due to the increased release of these bioactive components from the matrix, making them available for extraction. The same authors report that, although the extrusion caused a marked reduction in antioxidant content in hulled buckwheat grain, the amount of bioactive component in hulled buckwheat grain after thermal treatment was still significant, resulting in a decrease in antioxidant activity of only 10%.

Hes et al. [124] also reported contradictory results when testing the impact of cooking in water on the antioxidant properties and dietary fiber of hulled buckwheat grain. It was shown that cooking in water for 30 minutes in a ratio of 2:1 (water: grain) has no negative effects on the nutritional characteristics of the hulled buckwheat grain. Extracts of cooked hulled grain showed a significantly higher content of polyphenols and total dietary fiber compared to raw grain. The detected higher content of polyphenols in cooked hulled grain is explained by the authors as a result of their partial release from the bound form of the protein as a result of cooking. Additionally, phenols can also be associated with other components such as carbohydrates. In terms of individual phenolic components, a significantly higher content

of catechin particularly stands out, and, in contrast to that, a considerably lower content of p-coumaric acid in the extracts of cooked buckwheat grain compared to the extracts of the raw buckwheat grain. Cooking did not cause any changes in rutin content.

It has been recognized that the possible beneficial effects of phytochemicals present in buckwheat may be related to the inherent antioxidant capacity of these components. Therefore, during the last decade, the relationship between antioxidant capacity and these components after heat treatment has been exposed. The antioxidant capacity of buckwheat products is linked to flavonoid concentrations after hydrothermal treatment [125]. Kreft et al. [12] described significant correlations between rutin content and antioxidant activity of buckwheat grain and buckwheat food products. Chlopicka et al. [116] found positive and significant correlations between total phenols and antioxidant activity in buckwheat bread samples, as well as between total phenols and antioxidant activity of buckwheat bread samples, and, finally, between antioxidant activities themselves. Zhang et al. [126] reported that the baking, heating under steam pressure, and microwave heating of integral buckwheat flour had a statistically significant ($P < 0.05$) effect on the decrease in total flavonoids and antioxidant activity of flour, while the decrease in total phenols in buckwheat flour was less pronounced for all three applied treatments. As a possible explanation, the authors cited the creation of Maillard reaction products, which react with Folin-Ciocalteu reagent, resulting in masking the actual decrease in polyphenol content.

Similar conclusions regarding the formation of Maillard reaction products were reached by the authors Constantini et al. [127] during the production of bread with the addition of Tartary buckwheat flour, where a loss in the total antioxidant capacity and content of total polyphenols and flavonoids was observed, relative to their values in flour mixtures. The aforementioned authors pointed out that it is possible that the real reduction is greater than what was found in this study. As an explanation, they stated that heat treatment of cereals and pseudocereals, such as during baking, can also result in the synthesis of substances with antioxidant properties, including certain products of the Maillard reaction that occur in the crust of bread. These syntheses can mask the actual decrease in the content of total phenols and flavonoids (which are able to react with Folin-Ciocalteu reagent), as well as any loss in total antioxidant capacity.

Aside from phenols, other components, such as proteins, appear to be involved in the formation of the antioxidant activity of buckwheat products. The frying hulled buckwheat grain, in addition to reducing antioxidant activity, also resulted in a decrease in protein content and quality, while heat treatment did not show an effect on whole grain proteins [125]. In addition, during thermal treatment, Maillard components are generated due to a chemical reaction between the free amino groups of lysine and the carbonyl groups of reducing sugars [128]. It was observed the formation of Maillard products was caused by heat treatment of both whole and hulled buckwheat grains. Although Maillard components may be harmful to health, they may contribute to an increase in antioxidant activity, masking the actual decrease in total phenolic components, as highlighted in the above studies [125–127]. In addition, it has been suggested that antioxidant capacity may increase as a result of dissociation (separation) of phenolic forms and release of phenols bound to cell walls due to heat treatment followed by polymerization/oxidation of phenolic constituents or by-product generation [122].

The influence of baking on the content of tocopherols in buckwheat bread was investigated. Vitamin E loss was found to be about 30%. Smaller losses were observed

in bread samples of 100% buckwheat flour compared to samples in which the share of buckwheat flour was 50% [81]. A significant reduction in vitamin E content (about 63%) in buckwheat was also found during the extrusion process [123].

The importance of common and Tartary buckwheat is generally recognized. However, one should also keep in mind some disadvantages of their application in the bakery in terms of sensory impression. This primarily refers to the particle size and the proportion of bran that can negatively affect the rheological properties of the dough and result in an inappropriate texture of bakery products. In addition, the finished products with Tartary buckwheat may appear a slightly bitter taste [6].

Based on all of the above, it is indicative that the contradictory results obtained so far greatly emphasize the importance of determining the exact composition and ratio of bioactive components. In addition, more studies are needed to identify the effect of heat treatment on the functional components, including proteins and phenolic components, of buckwheat products, in order to ultimately obtain buckwheat of consumption quality. Therefore, processing conditions, such as time and temperature, need to be optimized to preserve the functionality of bioactive components.

3.3 High pressure

High pressure has been shown to be a viable alternative to heat treatment, with no adverse effects such as forming an off flavor, loss of vitamins and phytochemical properties, and discoloration [129]. The effect of high hydrostatic pressure treatment (200 MPa at 2, 4, and 9 minutes) on total antioxidant capacity (TAC), reducing capacity (RC), and rutin content of raw and roasted buckwheat groats were examined. After high-pressure treatment, the content of TAC and rutin differed in the case of raw and fried semolina. The TAC of raw and fried semolina subjected to high-pressure treatment was 16–20% and 12.5–17% lower, respectively, compared to the TAC of untreated semolina. Hydrophilic antioxidants were the main components contributing to the TAC of raw and fried semolina subjected to high-pressure treatment. RC decreased in the case of raw buckwheat (raw semolina), while the rutin content dropped in a shorter time compared to fried semolina. In contrast, overpressure in fried semolina increased the RC formed by hydrophilic antioxidants by 18% when measured by cyclic voltammetry on average and decreased the concentration of rutin after treatment [130].

The results of Zhou et al. [131] suggested that treatment under high pressure at 45 °C improves the nutritional properties of buckwheat compared to untreated and treated under high pressure at room temperature.

3.4 Ionization and radiation

Radiation is a method of treating food to make it safer to eat and to extend its shelf life. Traditionally, this process is used to control surface microorganisms on vegetables and fruits without affecting nutritional quality. Hayashi et al. [132] reduced the microbial load to a lower level by exposing buckwheat grains to soft-electrons without affecting their quality. Chun and Song [133] conducted a study in which aqueous chlorine dioxide, fumaric acid, modified packaging atmosphere enriched with CO₂, and ultraviolet radiation (UV) were combined in the treatment of buckwheat sprouts to improve microbiological quality. A decrease in total aerobic bacteria, yeasts and moulds, and enterobacteria to low levels was observed without affecting sensory quality. However, after the treatment, there was an increase in the

concentration of rutin. A comparative study by Orsák et al. [134] studied the effects of UV, microwave, and γ -radiation on three buckwheat samples. Different effects were observed depending on the radiation system and the applied dose on the content of polyphenols and rutin. In addition, it has been described that the content of rutin and flavone C-glycosides is improved in sprouts after exposure to LED (light-emitting diodes) [135].

Therefore, radiation could be offered as a way to increase the half-life of food, maintain sensory quality, improve microbiological quality and increase nutritional value due to bioactive components in buckwheat products. Although public knowledge about radiation remains limited, interest in buying “safe—radiation-enhanced food” is increasing, especially after obtaining information about the potential benefits and risks.

4. Stability of bioactive components in buckwheat and its products during storage

A detailed review of the literature showed that the data on the stability of the most important bioactive components in all types of buckwheat products (bakery and others) during storage is quite limited. Unlike stability during processing, which can still be stated to have been the subject of a significant number of studies in recent years, and that the number of studies is constantly increasing, stability during storage is still almost unexplored. One of the studies that could be related to a certain extent to the mentioned topic is the one conducted by the authors Cho and Lee [121].

Namely, these authors established experimental extraction procedures for preparing rutin-enriched material (REM) from buckwheat milling fractions. Then the REM was used for the fortification of wheat instant fried noodles with rutin. After frying, the noodle samples were stored for 14 days at 60°C and its peroxide value was measured every other day in order to examine the effect of REM on the oxidative stability of the noodles. The monitoring showed that the peroxide number of noodle samples tended to increase with increasing storage time. However, it was noted that the rate of increase in peroxide value was markedly lower in noodle samples with incorporated REM compared to the control sample which did not contain REM. This indicates that the oxidizing improvement of instant fried noodles in storage was reduced using REM. These results can be expected from the high level of rutin in REM, since rutin has strong antioxidant activity [32].

Tabaković et al. [136] found that the most suitable way to store buckwheat seeds for a long period is paper material in order to retain their physiological and morphological properties to the greatest extent.

5. Conclusion

Buckwheat, a pseudocereal belonging to the *Polygonaceae* family, is used as an important raw material for the development of functional foods due to its functionality and content of components such as proteins, flavonoids, phytosterols, phagopyritols, phenolic acids, vitamins, and others. Scientific research confirms many biological and health properties of buckwheat: hypocholesterolemic, hypoglycaemic, anticancer, and anti-inflammatory activity. The increase in the amount of data focused on the positive nutritional and functional characteristics of buckwheat,

which affect the prevention and treatment of chronic diseases, reduction of plasma and liver cholesterol, etc., results in an increase in the number of newly created buckwheat-based food products and their increased use in the population's diet. In the category of bakery products, the following ones stand out: buckwheat-enhanced bread, wheat bread enhanced with fermented buckwheat sourdough, buckwheat biscuits and snacks, and many others. However, in order for these products to be of high nutritional quality, it is important to understand the effect of processing on bioactive components. And it is also important to know the effect of storage on bioactive components.

When it comes to processing, there are several processes associated with buckwheat, the first and inevitable one being the milling process. Milling is the processing (conversion) of buckwheat grains into flour, the primary raw material for the production of bakery products. During the processing of buckwheat grains into white flour, the husk and outer layers are separated, which removes the ratio of fibers, minerals, and polyphenolic components. Then there is the process of heat treatment, and baking, which belongs to the category of heat treatment, is also inevitable during the production of bakery products. In general, when it comes to the effects of heat treatment on bioactive components in buckwheat, a considerable amount of research has been conducted so far. However, the results of the conducted studies are contradictory. Although in most cases heat treatment resulted in a decrease in bioactive components, on the other hand, there are studies in which heat treatment did not have a significant effect on bioactive components. Therefore, it is necessary to conduct more studies with an emphasis on optimizing the conditions of heat treatment in order to ultimately obtain buckwheat and buckwheat-based products of appropriate quality for use. Recently, high-pressure treatments and the application of radiation are becoming increasingly important. However, although knowledge about radiation remains limited, there is an increased interest in buying "safe—radiation-enhanced food", especially after obtaining information about the potential benefits and risks.

Although a considerable number of studies have been conducted on the effects of processing, and primarily on the effects of heat treatment, there are still significant gaps in this area. They are primarily related to the fact that most of the conducted studies are aimed at determining the effects of processing on the content of phenolic components, especially flavonoids, due to their recognized role in health benefits. Therefore more research that focuses on the effects of processing on all other bioactive components in buckwheat is needed in the future.

When it comes to the effects of storage, this topic is still almost unexplored. A review of the literature revealed that there is a small number of studies dealing with this topic, and therefore further research is needed to identify the effect of storage on bioactive components of buckwheat products, and ultimately to preserve their quality for as long as possible.

IntechOpen

IntechOpen

Author details

Amela Džafić* and Sanja Oručević Žuljević
Faculty of Agriculture and Food Sciences, University of Sarajevo, Sarajevo,
Bosnia and Herzegovina

*Address all correspondence to: amela.b.dzafic@gmail.com

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

- [1] Subhash B, Yadav GS, Singh R, Avasthem RK, Das A, Mohapatra KP, et al. Production technology and multifarious uses of Buckwheat (*Fagopyrum* spp.): A review. *Indian Journal of Agronomy*. 2018;**63**(4):118-130
- [2] Campbell CG. Buckwheat. *Fagopyrum esculentum* Moench. Promoting the conservation and use of underutilized and neglected crops. 19. In: Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute. Rome, Italy: CAB International; 1997
- [3] Keskitalo M, Ketoja E, Kontturi M, Maarit M, Pihlava JM, Rantamäki P, et al. Buckwheat—An old crop with new health prospects. *NJF Report, Nordic Association of Agricultural Scientists*. 2007;**3**(1):23-26
- [4] Zhang Z, Zhou M, Tang Y, Li F, Tang Y, Shao J, et al. Bioactive components in functional buckwheat food. *Food Research International*. 2012;**49**(1):389-395. DOI: 10.1016/j.foodres.2012.07.035
- [5] Giménez-Bastida J, Piskula M, Zieliński H. Recent advances in processing and development of buckwheat derived bakery and nonbakery products—A review. *Polish Journal of Food and Nutrition Sciences*. 2015;**65**(1):9-20. DOI: 10.1515/pjfn-2015-0005
- [6] Oručević Žuljević S, Gadžo D. Proizvodnja i prerada heljde u Bosni i Hercegovini—Dosadašnja iskustva i budući izazovi. In: Raspor P, Smole Možina S, editors. *Hrana in prehrana za zdravlje, Ajda od njive do zdravlja*. Izola, Slovenija: Inštitut za živila, prehrano in zdravje; 2015. pp. 153-163
- [7] Sturza A, Paucean A, Chis MS, Mures V, Vodnar DC, Man SM, et al. Influence of buckwheat and buckwheat sprouts flours on the nutritional and textural parameters of wheat buns. *Applied Sciences*. 2020;**10**(22):7969-7969. DOI: 10.3390/app10227969
- [8] Saturni L, Ferrett G, Bacchetti T. The gluten-free diet: Safety and nutritional quality. *Nutrients*. 2010;**2**(1):16-34. DOI: 10.3390/nu20100016
- [9] Oručević Žuljević S, Akagić A. Flour-based confectionery as functional food. In: Arshad MS, Ahmad MH, editors. *Functional Foods—Phytochemicals and Health Promoting Potential*. Rijeka: IntechOpen; 2021. DOI: 10.5772/intechopen.95876
- [10] Yilmaz HO, Ayhan NY, Meric CS. Buckwheat: A Useful Food and its Effects on Human Health. *Current Nutrition and Food Science*. 2020;**16**:29-34. DOI: 10.2174/1573401314666180910140021
- [11] Ji X, Han L, Liu F, Yin S, Peng Q, Wang M. A mini-review of isolation, chemical properties and bioactivities of polysaccharides from buckwheat (*Fagopyrum* Mill). *International Journal of Biological Macromolecules*. 2019;**127**:204-209. DOI: 10.1016/j.ijbiomac.2019.01.043
- [12] Kreft I, Fabjan N, Yasumoto K. Rutin content in buckwheat (*Fagopyrum esculentum* Moench) food materials and products. *Food Chemistry*. 2006;**98**(3):508-512. DOI: 10.1016/j.foodchem.2005.05.081
- [13] Liu Z, Ishikawa W, Huang X, Tomotake H, Kayashita J, Watanabe H, et al. A buckwheat protein product

suppresses 1,2-dimethylhydrazine-induced colon carcinogenesis in rats by reducing cell proliferation. *The Journal of Nutrition*. 2001;**131**(6):1850-1853. DOI: 10.1093/jn/131.6.1850

[14] Tomotake H, Yamamoto N, Yanaka N, Ohinata H, Yamazaki R, Kayashita J. High protein buckwheat flour suppresses hypercholesterolemia in rats and gallstone formation in mice by hypercholesterolemic diet and body fat in rats because of its low protein digestibility. *Nutrition*. 2006;**22**(2):166-173. DOI: 10.1016/j.nut.2005.01.012

[15] Skrabanja V, Liljeberg Elmstahl HG, Kreft I, Björck IM. Nutritional properties of starch in buckwheat products: Studies in vitro and in vivo. *Journal of Agricultural and Food Chemistry*. 2001;**49**(1):490-496. DOI: 10.1021/jf000779w

[16] Kawa JM, Taylor CG, Przybylski R. Buckwheat concentrate reduces serum glucose in streptozotocin-diabetic rats. *Journal of Agricultural and Food Chemistry*. 2003;**51**(25):7287-7291. DOI: 10.1021/jf0302153

[17] Jin J, Ikenna C, Ohanenye and Chibuike C, Udenigwe. Buckwheat proteins: Functionality, safety, bioactivity, and prospects as alternative plant-based proteins in the food industry. *Critical Reviews in Food Science and Nutrition*. 16 Nov 2020:1-13. DOI: 10.1080/10408398.2020.1847027

[18] Wijngaard HH, Arendt EK. Buckwheat—Review. *Cereal Chemistry*. 2006;**83**(4):391-401. DOI: 10.1094/CC-83-0391

[19] Ahmed A, Khalid N, Ahmad A, Abbasi NA, Latif MSZ, Randhawa MA. Phytochemicals and biofunctional properties of buckwheat. *The Journal of*

Agricultural Science. 2014;**152**:349-369. DOI: 10.1017/S0021859613000166

[20] Aubrecht E, Biac P. Characterization of buckwheat grain proteins and its products. *Acta Alimentaria*. 2001;**30**:71-80

[21] Alvarez-Jubete L, Arendt EK, Gallagher E. Nutritive value and chemical composition of pseudocereals as gluten-free ingredients. *International Journal of Food Sciences and Nutrition*. 2009;**60**(Suppl 4):240-257. DOI: 10.1080/09637480902950597

[22] Guo YZ, Chen QF, Yang LY, Huang YH. Analyses of the seed protein contents on the cultivated and wild buckwheat *Fagopyrum esculentum* resources. *Genetic Resources and Crop Evolution*. 2007;**54**:1465-1472. DOI: 10.1007/s10722-006-9135-z

[23] Škrobot D, Milovanović I, Jovanov P, Pestorić M, Tomić J, Mandić A. Buckwheat, quinoa and amaranth: Good alternatives to nutritious food. *Journal on Processing and Energy in Agriculture*. 2019;**23**(3):113-116

[24] Tomotake H, Shimaoka I, Kayashita J, Yokoyama F, Nakajoh M, Kato N. A Buckwheat protein product suppresses gallstone formation and plasma cholesterol more strongly than soy protein isolate in hamsters. *The Journal of Nutrition*. 2000;**130**(7):1670-1674. DOI: 10.1093/jn/130.7.1670

[25] Koyama M, Nakamura C, Nakamura K. Changes in phenols contents from buckwheat sprouts during growth stage. *Journal of Food Science and Technology*. 2011;**50**(1):86-93. DOI: 10.1007/s13197-011-0316-1

[26] Ma MS, Bae IY, Lee HG, Yang CB. Purification and identification of angiotensin I-converting enzyme

inhibitory peptide from buckwheat (*Fagopyrum esculentum* Moench). Food Chemistry. 2006;**96**(1):36-42. DOI: 10.1016/j.foodchem.2005.01.052

[27] Zhang HW, Zhang YH, Lu MJ, Tong WJ, Cao GW. Comparison of hypertension, dyslipidaemia and hyperglycaemia between buckwheat seed-consuming and non-consuming Mongolian-Chinese populations in Inner Mongolia, China. Clinical and Experimental Pharmacology and Physiology. 2007;**34**(9):838-844. DOI: 10.1111/j.1440-1681.2007

[28] Ma Y, Xiong YL, Zhai JJ, Zhu HN, Dziubla T. Fractionation and evaluation of radical scavenging peptides from in vitro digests of buckwheat protein. Food Chemistry. 2010;**118**(3):582-588. DOI: 10.1016/j.foodchem.2009.05.024

[29] Koyama MK, Naramoto T, Nakajima T, Aoyama T, Watanabe M, Nakamura K. Purification and identification of antihypertensive peptides from fermented buckwheat sprouts. Journal of Agricultural and Food Chemistry. 2013;**61**(12):3013-3021. DOI: 10.1021/jf305157y

[30] Fujimura M, Minami Y, Watanabe K, Tadera K. Purification, characterization, and sequencing of a novel type of antimicrobial peptides, Fa-AMP1 and Fa-AMP2, from seeds of buckwheat (*Fagopyrum esculentum* Moench.). Bioscience, Biotechnology, and Biochemistry. 2003;**67**(8):1636-1642. DOI: 10.1271/bbb.67.1636

[31] Guo XN, Zhu KX, Zhang H, Yao HY. Anti-tumor activity of a novel protein obtained from tartary buckwheat. International Journal of Molecular Sciences. 2010;**11**(12):5201-5211. DOI: 10.3390/ijms11125201

[32] Holasova M, Fiedlerova V, Smrcinova H, Orsak M, Lachman J,

Vavreinova S. Buckwheat—The source of antioxidant activity in functional foods. Food Research International. 2002;**35**(1-2):207-211. DOI: 10.1016/S0963-9969(01)00185-5

[33] Zdunczyk Z, Flis M, Zieliński H, Wroblewska M, Antoszkiewicz Z, Juskiewicz J. In vitro antioxidant activities of barley, husked oat, naked oat, triticale, and buckwheat wastes and their influence on the growth and biomarkers of antioxidant status in rats. Journal of Agricultural and Food Chemistry. 2006;**54**(12):4168-4175. DOI: 10.1021/jf060224m

[34] Begić M, Oručević Žuljević S, Akagić A, Spaho N. Relationship between the physical and chemical quality parameters of common buckwheat (*Fagopyrum Esculentum* Moench) and tartary buckwheat (*Fagopyrum Tataricum* Moench). International Journal of Research in Agricultural Sciences. 2017;**4**(3):115-159

[35] Morishita T, Yamaguchi H, Degi K. The contribution of polyphenols to antioxidative activity in common buckwheat and tartary buckwheat grain. Plant Production Science. 2007;**10**(1):99-104. DOI: 10.1626/pps.10.99

[36] Patel K, Patel DK. The beneficial role of rutin, a naturally occurring flavonoid in health promotion and disease prevention: A systematic review and update. In: Watson RR, Preedy VR, editors. Bioactive Food as Dietary Interventions for Arthritis and Related Inflammatory Diseases. 2nd ed. Cambridge, MA: Academic Press; 2019. pp. 457-479

[37] Li S, Zhang QH. Advances in the development of functional foods from buckwheat. Critical Reviews in Food Science and Nutrition. 2001;**41**(6):451-464. DOI: 10.1080/20014091091887

- [38] Liu B, Zhu Y. Extraction of flavonoids from flavonoid-rich parts in tartary buckwheat and identification of the main flavonoids. *Journal of Food Engineering*. 2007;**78**(2):584-587. DOI: 10.1016/j.jfoodeng.2005.11.001
- [39] Afanas'ev IB, Dcrozsko AI, Brodskii AV, Kostyuk VA, Potapovitch AI. Chelating and free radical scavenging mechanisms of inhibitory action of rutin and quercetin in lipid peroxidation. *Biochemical Pharmacology*. 1989;**38**(11): 1763-1769. DOI: 10.1016/0006-2952(89) 90410-3
- [40] Dietrych-Szostak D, Oleszek W. Effect of processing on the flavonoid content in buckwheat (*Fagopyrum esculentum* Möench) grain. *Journal of Agricultural and Food Chemistry*. 1999;**47**(10):4383-4387. DOI: 10.1021/jf990121m
- [41] Kreft S, Knapp M, Kreft I. Extraction of rutin from buckwheat (*Fagopyrum esculentum* Moench) seeds and determination by capillary electrophoresis. *Journal of Agricultural and Food Chemistry*. 1999;**47**(11):2020-2023. DOI: 10.1021/jf990186p
- [42] Park CH, Kim YB, Choi YS, Heo K, Kim SL, Lee KC, et al. Rutin content in food products processed from groats, leaves and flowers of buckwheat. *Fagopyrum*. 2000;**17**:63-66
- [43] Zielińska D, Szawara-Nowak D, Zieliński H. Comparison of spectrophotometric and electrochemical methods for the evaluation of the antioxidant capacity of buckwheat products after hydrothermal treatment. *Journal of Agricultural and Food Chemistry*. 2007;**55**(15):6124-6131. DOI: 10.1021/jf071046f
- [44] Zielińska D, Szawara-Nowak D, Zieliński H. Determination of the antioxidant activity of rutin and its contribution to the antioxidant capacity of diversified buckwheat origin material by updated analytical strategies. *Polish Journal of Food and Nutrition Sciences*. 2010;**60**(4):315-321
- [45] Luthar Z, Zhou M, Golob A, Germ M. Breeding buckwheat for increased levels and improved quality of protein. *Plants*. 2021;**10**:14. DOI: 10.3390/plants10010014
- [46] Fabjan N, Rode J, Kosir IJ, Wang Z, Zhang Z, Kreft I. Tartary buckwheat (*Fagopyrum tataricum* Gaertn.) as a source of dietary rutin and quercitrin. *Journal of Agricultural and Food Chemistry*. 2003;**51**(22):6452-6455. DOI: 10.1021/jf034543e
- [47] Zielińska D, Zieliński H. Low molecular weight antioxidants and other biologically active components of buckwheat seeds. *European Journal of Plant Science and Biotechnology*. 2009;**3**:29-38
- [48] Kim SJ, Maeda T, Sarker M, Takigawa S, MatsuuraEndo C, Yamauchi H, et al. Identification of anthocyanins in the sprouts of buckwheat. *Journal of Agricultural and Food Chemistry*. 2007;**55**(15):6314-6318. DOI: 10.1021/jf0704716
- [49] Li D, Li X, Ding X. Composition and antioxidative properties of the flavonoid-rich fractions from tartary buckwheat grains. *Food Science and Biotechnology*. 2010;**19**(3):711-716
- [50] Liu CL, Chen YS, Yang JH, Chiang BH. Antioxidant activity of tartary (*Fagopyrum tataricum* (L.) Gaertn.) and common (*Fagopyrum esculentum* Moench) buckwheat sprouts. *Journal of Agricultural and Food Chemistry*. 2008;**56**(1):173-178. DOI: 10.1021/jf072347s

- [51] Liu JL, Tang Y, Xia ZM, Shao JR, Cai GZ, Luo Q. *Fagopyrum crispatifolium* J L. Liu, a new species of *Polygonaceae* from Sichuan. China. *Journal of Systematic and Evolutionary*. 2008;**46**:929-932
- [52] Sharma S, Ali A, Ali J, Sahni JK, Baboota S. Rutin: Therapeutic potential and recent advances in drug delivery. *Expert Opinion on Investigational Drugs*. 2013;**22**(8):1063-1079. DOI: 10.1517/13543784.2013.805744
- [53] Li L, Lietz G, Seal C. Buckwheat and CVD risk markers: A systematic review and meta-analysis. *Nutrients*. 2018;**10**(5):619. DOI: 10.3390/nu10050619
- [54] Giménez-Bastida JA, Zieliński H. Buckwheat as a functional food and its effects on health. *Journal of Agricultural and Food Chemistry*. 2015;**63**(36):7896-7913. DOI: 10.1021/acs.jafc.5b02498
- [55] Tambağ AK, Kazak F, Akalin PP, Kutlu T. The protective effect of rutin against methotrexate-induced nephrotoxicity in rats. *Turkish Journal of Nephrology*. 2021;**30**(3):218-223
- [56] Jiang P, Burczynski F, Campbell C, Pierce G, Austria JA, Briggs CJ. Rutin and flavonoid in three buckwheat species *Fagopyrum esculentum*, *F. tataricum*, and *F. homotropicum* and their protective effects against lipid peroxidation. *Food Research International*. 2007;**40**(3):356-364. DOI: 10.1016/j.foodres.2006.10.009
- [57] Yang N, Ren G. Application of near-infrared reflectance spectroscopy to the evaluation of rutin and D-chiro-inositol contents in Tartary Buckwheat. *Journal of Agricultural and Food Chemistry*. 2008;**56**(3):761-764. DOI: 10.1021/jf072453u
- [58] Cai EP, Lin JK. Epigallocatechin gallate (EGCG) and rutin suppress the glucotoxicity through activating IRS2 and AMPK signaling in rat pancreatic β Cells. *Journal of Agricultural and Food Chemistry*. 2009;**57**(20):9817-9827. DOI: 10.1021/jf902618v
- [59] Awatsuhara R, Harada K, Nomura T, Nikaido O, Nagao K. Alteration of antioxidative activity of rutin treated with food protein. *Journal of Clinical Biochemistry and Nutrition*. 2008;**43**:S512-S515
- [60] Zielińska D, Turemko M, Kwiatkowski J, Zieliński H. Evaluation of flavonoid contents and antioxidant capacity of the aerial parts of common and tartary buckwheat plants. *Molecules*. 2012;**17**(8):9668-9682. DOI: 10.3390/molecules17089668
- [61] Horbowicz M, Wiczkowski W, Koczkodaj D, Saniewski M. Effects of methyl jasmonate on accumulation of flavonoids in seedlings of common buckwheat (*Fagopyrum esculentum* Moench). *Acta Biologica Hungarica*. 2011;**62**(3):265-278. DOI: 10.1556/ABiol.62.2011.3.6
- [62] Zhang R, Yao Y, Wang Y, Ren G. Antidiabetic activity of isoquercetin in diabetic KK-Ay mice. *Nutrition and Metabolism*. 2011;**8**:85. DOI: 10.1186/1743-7075-8-85
- [63] Li Y, Duan S, Jia H, Bai C, Zhang L, Wang Z. Flavonoids from tartary buckwheat induce G2/M cell cycle arrest and apoptosis in human hepatoma HepG2 cells. *Acta Biochim Biophys Sin*. 2014;**46**(6):460-470. DOI: 10.1093/abbs/gmu023
- [64] Li XH, Park NI, Xu H, Woo SH, Park CH, Park SU. Differential expression of flavonoid biosynthesis genes and accumulation of phenolic components in common buckwheat (*Fagopyrum esculentum*). *Journal of*

Agricultural and Food Chemistry. 2010;**58**(23):12176-12181. DOI: 10.1021/jf103310g

[65] Li YQ, Zhou FC, Gao F, Bian JS, Shan F. Comparative evaluation of quercetin, isoquercetin and rutin as inhibitors of α -glucosidase. Journal of Agricultural and Food Chemistry. 2009;**57**(24):11463-11468. DOI: 10.1021/jf903083h

[66] Agrawal PK, Chandan Agrawal C, Blunden G. Rutin: A potential antiviral for repurposing as a SARS-CoV-2 main protease (Mpro) inhibitor. Natural Product Communications. 2021;**16**(4):1-12. DOI: 10.1177/1934578X21991723

[67] Rizzuti B, Grande F, Conforti F, Jimenez-Alesanco A, Ceballos-Laita L, Ortega-Alarcon D, et al. Rutin is a low micromolar inhibitor of SARS-CoV-2 main protease 3CLpro: Implications for drug design of quercetin analogs. Biomedicine. 2021;**9**:375. DOI: 10.3390/biomedicines9040375

[68] Watanabe M. Catechins as antioxidants from buckwheat (*Fagopyrum esculentum* Moench) groats. Journal of Agricultural and Food Chemistry. 1998;**46**(3):839-845. DOI: 10.1021/jf9707546

[69] Aleksenko SS. Antioxidant activity and phenolic components of buckwheat and barley by the data of spectrophotometry and HPLC. Journal of Analytical Chemistry. 2013;**68**(5):505-513. DOI: 10.1134/S106193481305002X

[70] Alonso-Amelot ME, Oliveros-Bastidas A, Calcagnopisarelli MP. Phenolics and condensed tannins of high altitude *Pteridium arachnoideum* in relation to sunlight exposure, elevation, and rain regime. Biochemical Systematics and Ecology. 2007;**35**(1):1-10. DOI: 10.1016/j.bse.2006.04.013

[71] Kishore G, Ranjan S, Pandey A, Gupta S. Influence of altitudinal variation on the antioxidant potential of tartar buckwheat of Western Himalaya. Food Science and Biotechnology. 2010;**19**:1355-1363. DOI: 10.1007/s10068-010-0193-9

[72] Mariotti M, Macchia M, Cerri D, Gatta D, Arduini I, Saccomanni G. Rutin content in the forage and grain of common buckwheat (*Fagopyrum esculentum*) as affected by sowing time and irrigation in a mediterranean environment. Crop and Pasture Science. 2020;**71**(2):171-182. DOI: 10.1071/CP19238

[73] Kalinova J, Triska J, Vrchotova N. Distribution of vitamin E, squalene, epicatechin, and rutin in common buckwheat plants (*Fagopyrum esculentum* Moench). Journal of Agricultural and Food Chemistry. 2006;**54**(15):5330-5335. DOI: 10.1021/jf060521r

[74] Guo XD, Ma YJ, Parry J, Gao JM, Yu LL, Wang M. Phenolics content and antioxidant activity of tartary buckwheat from different locations. Molecules. 2011;**16**(12):9850-9867. DOI: 10.3390/molecules16129850

[75] Sytar O. Phenolic acids in the inflorescences of different varieties of buckwheat and their antioxidant activity. Journal of King Saud University—Science. 2015;**24**(2):136-142. DOI: 10.1016/j.jksus.2014.07.001

[76] Bonafaccia G, Marocchini M, Kreft I. Composition and technological properties of the flour and bran from common and tartary buckwheat. Food Chemistry. 2003;**80**(1):9-15. DOI: 10.1016/S0308-8146(02)00228-5

[77] Giménez-Bastida JA, Piskula M, Zieliński H. Recent advances in development of gluten-free buckwheat products. Trends in Food Science and

Technology. 2015;**44**(1):58-65.
 DOI: 10.1016/j.tifs.2015.02.013

[78] Sedej I. Functional and antioxidant properties of new buckwheat products [thesis]. Serbia: Univerzitet u Novom Sadu. Tehnološki fakultet. 2011

[79] Kim SL, Kim SK, Park CH. Comparisons of lipid, fatty acids and tocopherols of different buckwheat species. Food Science and Biotechnology. 2002;**1**(4):332-336

[80] Zieliński H, Ciska E, Kozłowska H. The cereal grains: Focus on Vitamin E. Czech Journal of Food Sciences. 2001;**19**(5):182-188

[81] Alvarez-Jubete L, Holse M, Hansen Å, Arendt EK, Gallagher E. Impact of baking on vitamin E content of pseudocereals amaranth, quinoa, and buckwheat. Cereal Chemistry. 2009;**86**(5):511-515. DOI: 10.1094/CCEM-86-5-0511

[82] Piironen V, Syväoja EL, Varo P, Salminen K, Koivistoinen P. Tocopherols and tocotrienols in cereal products from Finland. Cereal Chemistry. 1986;**63**:78-81

[83] Horbowicz M, Brenac P, Obendorf RL. Fagopyritol B1, O-alpha-D-galactopyranosyl-(1→2)-Dchiro-inositol, a galactosyl cyclitol in maturing buckwheat seeds associated with desiccation tolerance. Planta. 1998;**205**(1):1-11. DOI: 10.1007/s004250050290

[84] Steadman KJ, Burgoon MS, Schuster RL, Lewis B, Edwardson SE, Obendorf RL. Fagopyritols, D-chiro-inositol, and other soluble carbohydrates in buckwheat seed milling fractions. Journal of Agricultural and Food Chemistry. 2000;**48**(7):2843-2847. DOI: 10.1021/jf990709t

[85] Steadman KJ, Fuller DJ, Obendorf RL. Purification and molecular structure of two digalactosyl D-chiro-inositols and two trigalactosyl D-chiro-inositols from buckwheat seeds. Carbohydrate Research. 2001;**331**(1):19-25. DOI: 10.1016/S0008-6215(00)00320-7

[86] Larner J, Huang LC, Schwartz CFW, Oswald AS, Shen TY, Kinter M, et al. Rat-liver insulin mediator which stimulates pyruvate-dehydrogenase phosphatase contains galactosamine and D-chiro-inositol. Biochemical and Biophysical Research Communications. 1988;**151**(3):1416-1426. DOI: 10.1016/S0006-291X(88)80520-5

[87] Obendorf RL, Horbowicz M, Ueda T, Steadman K. Fagopyritols: Occurrence, biosynthesis, analyses, and possible role. European Journal of Plant Science and Biotechnology. 2012;**6**:27-36

[88] Yao Y, Shan F, Bian J, Chen F, Wang M, Ren G. D-chiro-inositol-enriched tartary buckwheat bran extracts lowers the blood glucose level in KK-Ay mice. Journal of Agricultural and Food Chemistry. 2008;**56**(21):10027-10031. DOI: 10.1021/jf801879m

[89] Ortmeyer HK, Huang LC, Lu Z, Hansen BC, Larner J. Chiroinositol deficiency and insulin resistance. II. Acute effects of Dchiroinositol administration in streptozotocin-diabetic rats, normal rats given a glucose-load, and spontaneously insulin-resistant rhesusmonkeys. Endocrinology. 1993;**132**(2):646-651. DOI: 10.1210/en.132.2.646

[90] Ortmeyer HK, Larner J, Hansen BC. Effects of d-chiroinositol added to a meal on plasma glucose and insulin in hyperinsulinemic rhesus monkeys. Obesity Research. 1995;**3**(Suppl 4):605S-608S. DOI: 10.1002/j.1550-8528.1995.tb00232.x

- [91] Kalra B, Kalra S, Sharma JB. The inositols and polycystic ovary syndrome. *Indian Journal of Endocrinology and Metabolism*. 2016;**20**(5):720-724. DOI: 10.4103/2230-8210.189231
- [92] Benelli E, Del Ghianda S, Di Cosmo C, Tonacchera M. A combined therapy with myo-inositol and D-chiro-inositol improves endocrine parameters and insulin resistance in PCOS young overweight women. *International Journal of Endocrinology*. 2016;**2016**:3204083. DOI: 10.1155/2016/3204083
- [93] Kamenov Z, Gateva A. Inositols in PCOS. *Molecules*. 2020;**25**(23):5566. DOI: 10.3390/molecules25235566
- [94] Normen L, Bryngelsson S, Johnsson M, Evheden P, Ellegard L, Brants H, et al. The phytosterol content of some cereal foods commonly consumed in Sweden and in the Netherlands. *Journal of Food Composition and Analysis*. 2002;**15**(6):693-704. DOI: 10.1006/jfca.2002.1098
- [95] Dziedzic K, Kurek S, Mildner-Szkudlarz S, Kreft I, Walkowiak J. Fatty acids profile, sterols, tocopherol and squalene content in *Fagopyrum tataricum* seed milling fractions. *Journal of Cereal Science*. 2020;**96**:103118. DOI: 10.1016/j.jcs
- [96] Amézqueta S, Galán E, Vila-Fernández I, Pumarola S, Carrascal M, Abian J, et al. The presence of d-fagomine in the human diet from buckwheat-based foodstuffs. *Food Chemistry*. 2013;**136**(3-4):1316-1321. DOI: 10.1016/j.foodchem.2012.09.038
- [97] Gómez L, Molinar-Toribio E, Calvo-Torras MA, Adelantado C, Juan ME, Planas JM, et al. D-Fagomine lowers postprandial blood glucose and modulates bacterial adhesion. *The British Journal of Nutrition*. 2011;**107**(12):1739-1746. DOI: 10.1017/S0007114511005009
- [98] Amézqueta S, Galán E, Fuguet E, Carrascal M, Abián J, Torres JL. Determination of D-fagomine in buckwheat and mulberry by cation exchange HPLC/ESI-Q-MS. *Analytical and Bioanalytical Chemistry*. 2012;**402**(5):1953-1960. DOI: 10.1007/s00216-011-5639-2
- [99] Peng L-X, Wang J-B, Hu L-X, Zhao J-L, Xiang D-B, Zou L, et al. Rapid and simple method for the determination of emodin in tartary buckwheat (*Fagopyrum tataricum*) by high-performance liquid chromatography coupled to a diode array detector. *Journal of Agricultural and Food Chemistry*. 2013;**61**(4):854-857. DOI: 10.1021/jf304804c
- [100] Izhaki I. Emodin—A secondary metabolite with multiple ecological functions in higher plants. *The New Phytologist*. 2002;**155**(2):205-217. DOI: 10.1046/j.1469-8137.2002.00459.x
- [101] Amarowicz R, Dykes GA, Pegg RB. Antibacterial activity of tannin constituents from *Phaseolus vulgaris*, *Fagopyrum esculentum*, *Corylus avellana* and *Juglans nigra*. *Fitoterapia*. 2008;**9**(3):217-221. DOI: 10.1016/j.fitote.2007.11.019
- [102] Miyake K, Morita R, Handoyo T, Maeda T, Morita N. Characterization of graded buckwheat flours and some properties of germinated 'Mancan' buckwheat grains. *Fagopyrum*. 2004;**21**:91-97
- [103] Aoyagi Y. An angiotensin-I converting enzyme inhibitor from buckwheat (*Fagopyrum esculentum* Moench) flour. *Phytochemistry*. 2006;**67**(6):618-621. DOI: 10.1016/j.phytochem.2005.12.022

- [104] Maejima Y, Nakatsugawa H, Ichida D, Maejim M, Aoyagi Y, Maoka T, et al. Functional components in fermented buckwheat sprouts. *Bioscience, Biotechnology, and Biochemistry*. 2011;**75**:1708-1712. DOI: 10.1271/bbb.110241
- [105] Suzuki T, Watanabe M, Iki M, Aoyagi Y, Kim SJ, Mukasa Y, et al. Time-course study and effects of drying method on concentrations of γ -aminobutyric acid, flavonoids, anthocyanin, and 2'' hydroxynicotianamine in leaves of buckwheats. *Journal of Agricultural and Food Chemistry*. 2009;**57**(1):259-264. DOI: 10.1021/jf802731d
- [106] Hung P, Morita N. Distribution of phenolic components in the graded flours milled from whole buckwheat grains and their antioxidant capacities. *Food Chemistry*. 2008;**109**(2):325-331. DOI: 10.1016/j.foodchem.2007.12.060
- [107] Inglett GA, Chen D, Berhow M, Lee S. Antioxidant activity of commercial buckwheat flours and their free and bound phenolic compositions. *Food Chemistry*. 2011;**125**(3):923-929. DOI: 10.1016/j.foodchem.2010.09.076
- [108] Gallardo C, Jiménez L, García-Conesa M-T. Hydroxycinnamic acid composition and in vitro antioxidant activity of selected grain fractions. *Food Chemistry*. 2006;**99**(3):455-463. DOI: 10.1016/j.foodchem.2005.07.053
- [109] Chen XW, Chen YJ, Li JY, Wang YH, Yang XQ. Enzyme-assisted development of biofunctional polyphenol-enriched buckwheat protein: Physicochemical properties, in vitro digestibility, and antioxidant activity. *Journal of the Science of Food and Agriculture*. 2019;**99**(6):3176-3185. DOI: 10.1002/jsfa.9534
- [110] Ge RH, Wang H. Nutrient components and bioactive components in tartary buckwheat bran and flour as affected by thermal processing. *International Journal of Food Properties*. 2020;**23**(1):127-137. DOI: 10.1080/10942912.2020.1713151
- [111] Džafić A, Oručević S, Šehovac F, Melezović T, Berbić N. Granulation of common and tatrarty buckwheat at wholemeal flour and its effect on physical properties of flour. *Works of Faculty of Agriculture and Food Sciences University of Sarajevo*. 2014;**64**(2):91-99
- [112] Chandrssekaran S, Ramanathan S, Basak T. Microwave food processing—A review. *Food Research International*. 2013;**52**(1):234-261. DOI: 10.1016/j.foodres.2013.02.033
- [113] Suzuki T, Yutaka H, Funatsuki W, Nakatsuka K. Purification and characterization of flavonol 3-glucosidase, and its activity during ripening in tartary buckwheat seeds. *Plant Science*. 2002;**163**(3):417-423. DOI: 10.1016/S0168-9452(02)00158-9
- [114] Vogrinčić M, Timoracka M, Melichacova S, Vollmannova A, Kreft I. Degradation of rutin and polyphenols during the preparation of tartary buckwheat bread. *Journal of the Science of Food and Agriculture*. 2010;**58**(8):4883-4887. DOI: 10.1021/jf9045733
- [115] Sakač M, Torbica A, Sedej I, Hadnađev M. Influence of breadmaking on antioxidant capacity of gluten free breads based on rice and buckwheat flours. *Food Research International*. 2011;**44**(9):2806-2813. DOI: 10.1016/j.foodres.2011.06.026
- [116] Chlopicka J, Pasko P, Gorinstein S, Jedryas A, Zagrodzki P. Total phenolic and total flavonoid content, antioxidant activity and sensory evaluation of pseudocereal breads. *LWT-Food Science*

and Technology. 2012;**46**(2):548-555. DOI: 10.1016/j.lwt.2011.11.009

[117] Verardo V, Arráez-Román D, Segura-Carretero A, Marconi E, Fernández-Gutiérrez A, Fiorenza CM. Determination of free and bound phenolic components in buckwheat spaghetti by RP-HPLC-ESI-TOF-MS: Effect of thermal processing from farm to fork. *Journal of Agricultural and Food Chemistry*. 2011;**59**(14):7700-7707. DOI: 10.1021/jf201069k

[118] Biney K, Beta T. Phenolic profile and carbohydrate digestibility of durum spaghetti enriched with buckwheat flour and bran. *LWT—Food Science and Technology*. 2014;**57**(2):569-579. DOI: 10.1016/j.lwt.2014.02.033

[119] Jambrec DJ, Mišan A, Pestorić MV, Psodorov DB, Mandić AI, Sakač MB, et al. Functional and sensory properties of pasta enriched with light buckwheat flour. In: *Proceeding of the 6ths Central European Congress on Food, CEFood*. Novi Sad, Serbia: EFFoST (European Federation of Food Science and Technology), IUFoST (International Union of Food Science and Technology), CEI (Central European Initiative); 2012. pp. 1-6

[120] Jambrec D, Sakač M, Mišan A, Mandić A, Pestorić M. Effect of autoclaving and cooking on phenolic components in buckwheat-enriched whole wheat tagliatelle. *Journal of Cereal Science*. 2015;**66**:1-9. DOI: 10.1016/j.jcs.2015.09.004

[121] Cho YJ, Lee S. Extraction of rutin from tartary buckwheat milling fractions and evaluation of its thermal stability in an instant fried noodle system. *Food Chemistry*. 2015;**176**:40-44. DOI: 10.1016/j.foodchem.2014.12.020

[122] Randhir R, Kwon Y-I, Shetty K. Effect of thermal processing

on phenolics, antioxidant activity and health-relevant functionality of select grain sprouts and seedlings. *Innovative Food Science and Emerging Technologies*. 2008;**9**(3):355-364. DOI: 10.1016/j.ifset.2007.10.004

[123] Zieliński H, Michalska A, Piskula MK, Kozłowska H. Antioxidants in thermally treated buckwheat groats. *Molecular Nutrition and Food Research*. 2006;**50**(9):824-832. DOI: 10.1002/mnfr.200500258

[124] Heś M, Dziedzic K, Górecka D, Drożdżyńska A, Gujska E. Effect of boiling in water of barley and buckwheat groats on the antioxidant properties and dietary fiber composition. *Plant Foods for Human Nutrition*. 2014;**69**(3):276-282. DOI: 10.1007/s11130-014-0425-x

[125] Zieliński H, Michalska A, Amigo-Benavente M, Del Castillo D, Piskula MK. Changes in protein quality and antioxidant properties of buckwheat seeds and groats induced by roasting. *Journal of Agricultural and Food Chemistry*. 2009;**57**(11):4771-4776. DOI: 10.1021/jf900313e

[126] Zhang M, Chen H, Li J, Pei Y, Liang Y. Antioxidant properties of tartary buckwheat extracts as affected by different thermal processing methods. *LWT—Food Science and Technology*. 2010;**43**(1):181-185. DOI: 10.1016/j.lwt.2009.06.020

[127] Costantini L, Lukšič L, Molinari R, Kreft I, Bonafaccia G, Manzi L, et al. Development of gluten-free bread using tartary buckwheat and chia flour rich in flavonoids and omega-3 fatty acids as ingredients. *Food Chemistry*. 2014;**15**(165):232-340. DOI: 10.1016/j.foodchem.2014.05.095

[128] Delgado-Andrade C. Maillard reaction products: Some considerations

on their health effects. Clinical Chemistry and Laboratory Medicine. 2014;52(1):53-60. DOI: 10.1515/cclm-2012-0823

[129] Norton T, Sun D-W. Recent advances in the use of high pressure as an effective processing technique in the food industry. Food and Bioprocess Technology. 2008;1:2-34. DOI: 10.1007/s11947-007-0007-0

[130] Błaszczak W, Zielińska D, Zieliński H, Szawara-Nowak D, Fornal J. Antioxidant properties and rutin content of high pressure-treated raw and roasted buckwheat groats. Food and Bioprocess Technology. 2013;6:92-100. DOI: 10.1007/s11947-011-0669-5

[131] Zhou Z, Ren X, Wang F, Li J, Si X, Cao R, et al. High pressure processing manipulated buckwheat antioxidant activity, anti-adipogenic properties and starch digestibility. Journal of Cereal Science. 2015;66:31-36. DOI: 10.1016/j.jcs.2015.09.002

[132] Hayashi T, Takahashi Y, Todoriki S. Sterilization of foods with low-energy electrons ("soft-electrons"). Radiation Physics and Chemistry. 1998;52:1-6. DOI: 10.1016/S0969-806X(98)00077-2

[133] Chun HH, Song KB. Optimisation of the combined treatments of aqueous chlorine dioxide, fumaric acid and ultravioletC for improving the microbial quality and maintaining sensory quality of common buckwheat sprout. International Journal of Food Science and Technology. 2013;49(1):121-127. DOI: 10.1111/ijfs.12283

[134] Orsák M, Lachman J, Vejdová M, Pivec V, Hamouz K. Changes of selected secondary metabolites in potatoes and buckwheat caused by UV, gamma- and microwave irradiation. Rostlinna Vyroba. 2001;47(11):493-500

[135] Hossen Z. Light emitting diodes increase phenolics of buckwheat (*Fagopyrum esculentum*) sprouts. Journal of Plant Interactions. 2007;2:71-78. DOI: 10.1080/17429140701288228

[136] Tabaković M, Simić M, Stanisavljević R, Sečanski M, Lj Ž, Štrbanović R. Buckwheat seed quality during the five-year storage in various packing materials. Plant, Soil and Environment. 2019;65(7):349-354. DOI: 10.17221/237/2019-PSE