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BUCKWHEAT AS A HIGH-QUALITY RAW MATERIAL: NUTRITIONAL AND TECHNOLOGICAL PROPERTIES UNDER DIFFERENT STORAGE CONDITIONS

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Abstract: Buckwheat (*Fagopyrum esculentum*) is a pseudocereal with extremely beneficial nutritional composition. High content of quality proteins, dietary fibers, polyphenolic compounds (especially rutin), as well as the absence of gluten, makes it very common in human and animal nutrition since ancient times. Thanks to its low glycemic index, content of resistant starch and fiber, as well as the presence of bioactive compounds that affect enzymes involved in carbohydrate metabolism, buckwheat shows a favorable effect on the glycemic response. The aim of this work was to examine the chemical composition and content of biologically active compounds in buckwheat seeds, as well as the effects of storage conditions on changes in the quality of buckwheat. The results showed an extremely high content of gallic and *p*-coumaric acids, as well as epicatechin (91, 102.4 and 95.7 µg/g DW, respectively). Storage conditions did not significantly affect the content of gallic and p-coumaric acids, while the content of epicatechin decreased with longer storage time. Also, the content of total phenols, as well as antioxidant activity decreased with increasing storage time compared to the native sample. The results of this research contribute to the promotion of buckwheat and buckwheat flour as an extremely important raw material and the possibility of its application in the modern food industry.

Keywords: Buckwheat, Nutrients, Polyphenols, Antioxidants, Storage conditions, Functional food

IINTRODUCTION

Buckwheat (*Fagopyrum esculentum*), a traditional annual pseudocereal, is valued for the high nutritional quality of its seeds used in human and animal diets. It does not require special growing conditions, and due to its short growing season, it is often grown as a cover crop after early spring crops (Jha et al., 2024). Buckwheat seeds are usually consumed as cereal after removing the husk and processed into flour. Buckwheat flour is used as raw material to make buckwheat-enriched food products such as bread, noodles, pasta, cakes, biscuits, and some valuable fermented products like wine, beer, and vinegar (Suzuki et al., 2020). The leaves of buckwheat can also be used as a tea and the flowers provide an excellent source of honey production due to their attractive colour and texture. During its flowering phase, it can produce up to 2000 flowers per plant, very rich in nectar. The grains have an exceptionally beneficial nutritional profile, as their proteins include all essential amino acids necessary for human health. Moreover, the uniqueness of buckwheat stems from its complex biochemical composition - high contents of phenolic acids, bioflavonoids, especially rutin, minerals, vitamins, as well as dietary fibres. The lack of the allergenic protein gluten, makes it ideal for individuals with celiac disease as well as those with non-celiac gluten sensitivity (Salejda et al., 2022; Pisinov et al., 2024). Furthermore, an increasing body of scientific evidence highlights the multiple health-promoting effects of buckwheat, particularly its role in glycemic regulation, lipid metabolism, and the maintenance of digestive health.

Due to its favourable nutritional profile and bioactive compound content, it has also been associated with the prevention and mitigation of various chronic diseases, particullary cardiovascular disorders, hypertension, and obesity (Huda et al., 2021).

Recent research on buckwheat, both in vivo and in vitro, confirms its potential health benefits, including antitumor, anti-inflammatory, antioxidant, and hepatoprotective effects (Huda et al., 2021; Zhu, 2016). Buckwheat's bioactive components may help prevent several illnesses, including diabetes, high blood pressure, cancer, glycemic disorders, and more (Huda et al., 2021). It is a crop recognized for its exceptional nutritional profile and high concentration of bioactive compounds, which contribute to its functional and health-promoting properties (Wieslander et al., 2020).

Due to its high content of polyphenolic compounds that exhibit antioxidant activity, the use of buckwheat as an additive in bakery products is widespread. In addition to its use in the production of bread and pastries, buckwheat flour can be processed into various non-bakery products, such as noodles or pasta (Bojňanská et al., 2022).

In recent decades, buckwheat has also found application in the meat industry. Thanks to its water-binding properties, adding a small amount of buckwheat flour to semi-smoked sausage samples increases the moisture-binding capacity by 1.1-1.8%. Also, introducing hydrated buckwheat flour into minced meat up to 6% of the mass of raw meat raw material has a positive effect on the physicochemical, functional-technological, structural-mechanical and organoleptic parameters of semi-smoked sausages (Yessengaziyeva et al., 2023).

In order to be used throughout the year, buckwheat must be adequately stored, which is one of the most important segments in the production chain, as it directly affects its quality, safety and economic value. Buckwheat, as a food raw material, remains subject to numerous biological, physical and chemical changes after harvest that can lead to spoilage, weight loss and a decrease in nutritional value. Therefore, its proper preparation and storage are considered a key step in ensuring stable and safe supplies for the needs of various users of this grain (Jose and Selvan, 2024). Like other grains, buckwheat can be sensitive to moisture, temperature, and attack by pests and diseases during storage.

This research focused on evaluating the nutritional properties, antioxidant potential, and biochemical profile of buckwheat. A significant aspect of the study involves exploring the changes in color and nutritional value of buckwheat during various storage durations, with the purpose of incorporating buckwheat into the development of functional foods.

MATERIAL AND METHODS

Buckwheat variety Novosadska was used for examination of nutrition and biochemical composition, as well as influence of storage conditions. Buckwheat was harvested at the moment of technological maturity of the seeds, and 2 kg of raw material was equally divided into eight samples. Six samples were stored for 3, 6, and 9 months in a drying oven at a temperature of 40 ± 2 °C with controlled thermoregulation and a relative humidity of 50%. After each storage period, samples were ground in a laboratory mill and stored in a refrigerator until analysis. All chemicals, reagents, and standard solutions used in the experiments were of minimum purity p.a. or higher. The chemical and nutritional properties of buckwheat were determined using standard international methods:

1) moisture content was determined gravimetrically, according to ISO 712 (2009),
2) total protein content, according to ISO 20483 (2013),
3) total lipid content according to NMKL 160 (1998),
4) total carbohydrate content according to AOAC 986.25 (1988),
5) starch content according to ISO 10520 (1997),
6) β-glucan (dietary fiber) content according to AOAC 995.16 (1995).

Extraction of buckwheat flour was performed according to a previously optimized method (Đurović et al., 2018). Total phenol content (TPC), ferric reducing/antioxidant power (FRAP), and radical-scavenging activity (DPPH) were determined spectrophotometrically, and the polyphenol profile was determined by reverse-phase liquid chromatography (HPLC), all according to a previously established method (Pisinov et al., 2024). For each parameter, analyses were conducted in triplicate and results were expressed as mean value ± SD.

RESULTS AND DISCUSSION

The results of the chemical and nutritional properties of buckwheat are shown in Table 1.

Table 1. Influence of storage period on chemical and nutritional properties of buckwheat variety Novosadska

Parameters, % (w/w)	Storage period			
	Freshly harvested grains	3 months	6 months	9 months
Moisture content	10.21 ± 0.006^{d}	9.09 ± 0.020^{c}	7.89 ± 0.066^{b}	6.02 ± 0.021^{a}
Total protein content	13.46 ± 0.344^{b}	12.62 ± 0.590^{ab}	12.25 ± 0.336^{a}	11.57 ± 0.448^{a}
Total lipid content	3.44 ± 0.152^{b}	2.99 ± 0.303^{ab}	2.64 ± 0.235^{a}	2.99 ± 0.050^{ab}
Carbohydrates content	81.13 ± 0.510^{a}	82.38 ± 0.676^{ab}	83.17 ± 0.465^{b}	83.48 ± 0.370^{b}
Strach content	62.55 ± 0.105^{c}	49.12 ± 0.315^{a}	47.67 ± 0.737^{a}	52.12 ± 1.342^{b}
β-glucan content	0.050 ± 0.0013^{b}	0.030 ± 0.0012^{a}	0.100 ± 0.0028^{c}	0.120 ± 0.0027^{d}

[a,b,c,d] Means within the same row with different superscripts differ significantly ($p<0.05$); nd -not detected; d.w. - dry weight

There was a significant difference ($p<0.05$) in moisture content across all treatments. Total protein, total lipid, and carbohydrate content showed significant differences at 6 months, although this was not the case thereafter. Freshly harvested seeds exhibited the highest levels of moisture, total protein, and total lipid, while after 9 months, they decreased by 41, 14, and 23%, respectively. In contrast, carbohydrate content increased to its highest level in 9 months, increasing by 3% from freshly harvested seeds. Nutritional parameters of buckwheat flour changed over time, with a significant decrease ($p<0.05$) in starch and an increase in β-glucan content. Statistically significant differences in β-glucan were noted across treatments, while differences in starch were significant at 3 months and continued thereafter. Our results on the Novosadska variety align with Dapčević et al. (2011), showing moisture, protein, and lipid contents of approximately 9.76, 13.40, and 3.08%, respectively

Antioxidant activity of buckwheat analyzed by conducting TPC, FRAP, and DPPH assays is shown in Table 2. Storage period led to significant decreases in TPC, FRAP, and DPPH. Compared to freshly harvested grain, which had the highest TPC and FRAP, the lowest values were recorded after 9 months, showing a 1.3- and 2.9-fold decrease, respectively. The highest DPPH value was noted after 3 months, with a 2.4-fold decrease by 9 months.

Table 2. Influence of storage period on antioxidant activity of buckwheat variety Novosadska, by three different assays

Parameters	Storage period			
	Freshly harvested grains	3 months	6 months	9 months
TPC, mg GAE/g d.w.	7.28 ± 0.194^{c}	6.97 ± 0.115^{c}	6.04 ± 0.121^{b}	5.57 ± 0.122^{a}
DPPH, µmol TE/g d.w.	19.47 ± 0.907^{c}	19.66 ± 0.333^{c}	25.32 ± 0.445^{b}	22.20 ± 0.440^{a}
FRAP, µmol Fe^{2+}/g d.w.	63.45 ± 1.520^{d}	28.68 ± 0.476^{c}	2.64 ± 0.235^{a}	2.99 ± 0.050^{ab}

^{a,b,c,d} Means within the same row with different superscripts differ significantly ($p<0.05$); nd -not detected; d.w. - dry weight

In the Novosadska variety of buckwheat, 15 polyphenolic compounds, nine polyphenolic acids, and six bioflavonoids were examined (Table 3). An example of a chromatogram of a mixed standard of examined polyphenolic compounds, with a concentration of 200 µg/ml, monitored at two wavelengths of 280 nm and 325 nm, is shown in Figure 1.

Only one compound, hesperetic acid, was not detected in any of the samples. In all samples, p-coumaric acid was the most abundant, followed by gallic and trans-cinnamic acid, and storage period did not lead to statistically significant changes in their content. A significant decrease in chlorogenic acid content was observed during storage ($p < 0.05$) up to the sixth month, and thereafter there were no statistically significant losses. Changes in dihydrocaffeic and phloretinic acids were also significant but showed irregular patterns. Among bioflavonoids, daidzein, quercetin, and naringin increased significantly during storage, while epicatechin decreased significantly. There were no significant changes for catechin or naringenin.

Table 3. Influence of storage period on polyphenole profile of buckwheat variety Novosadska

Parameters, µg/g d.w.	Storage period			
	Freshly harvested grains	3 months	6 months	9 months
Gallic acid	91.0 ± 8.44	92.7 ± 6.97	94.1 ± 6.88	93.6 ± 7.53
Dihydrocaffeic acid	18.7 ± 1.93^{b}	11.5 ± 1.16^{a}	19.1 ± 1.95^{b}	15.5 ± 1.52^{ab}
Chlorogenic acid	14.4 ± 1.29^{c}	11.1 ± 1.10^{b}	7.6 ± 0.74^{a}	7.1 ± 0.72^{a}
Caffeic acid	38.2 ± 3.83	37.6 ± 3.97	39.2 ± 3.78	38.3 ± 3.87
Phloretic acid	25.8 ± 2.44^{a}	46.5 ± 4.11^{b}	31.4 ± 3.04^{a}	29.1 ± 2.65^{a}
p-Coumaric acid	102.4 ± 7.52	101.9 ± 7.57	97.8 ± 6.14	95.9 ± 6.90
Ferulic acid	56.5 ± 3.79	57.0 ± 3.56	57.4 ± 4.00	56.5 ± 3.80
Hesperetic acid	nd	nd	nd	nd
trans-Cinnamic acid	90.0 ± 4.76	89.9 ± 4.53	89.5 ± 4.27	87.9 ± 4.60
Catechin	49.1 ± 4.12	52.2 ± 4.28	49.9 ± 4.12	49.3 ± 4.20
Epicatechin	95.7 ± 7.87^{c}	78.5 ± 6.31^{b}	77.0 ± 6.46^{b}	59.8 ± 5.08^{a}
Daidzein	57.0 ± 4.25^{a}	59.3 ± 4.25^{ab}	56.1 ± 3.84^{a}	69.3 ± 4.98^{b}
Quercetin	9.8 ± 0.93^{a}	12.5 ± 1.27^{ab}	16.6 ± 1.69^{b}	47.1 ± 3.95^{c}
Naringin	nd	42.7 ± 2.91^{a}	54.9 ± 4.22^{b}	51.9 ± 3.70^{b}
Naringenin	38.4 ± 2.78	37.8 ± 2.33	38.7 ± 2.24	38.3 ± 2.33

[a,b,c] Means within the same row with different superscripts differ significantly ($p<0.05$); nd -not detected; d.w. - dry weight

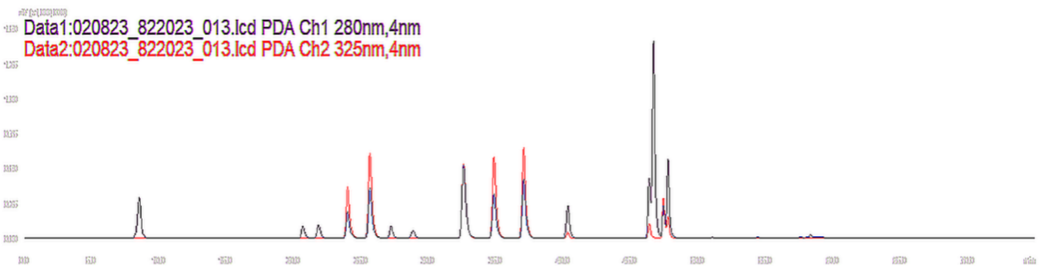

Figure 1. Chromatogram of a mixed standard of 15 polyphenolic compounds, with a concentration of 200 µg/ml, monitored at two wavelengths of 280 nm and 325 nm. The order of polyphenolic compounds is as follows: Gallic acid, Catechin, Dihydrocaffeic acid, Chlorogenic acid, Caffeic acid, Epicatechin, Phloretic acid, p-Coumaric acid, Ferulic acid, Hesperetic acid, Naringin, Daidzein, trans Cinnamic acid, Quercetin and Naringenin.

To the best of the author's knowledge, dihydrocaffeic and phloretinic acid, as well as daidzein, naringin, and naringenin, have been quantified for the first time in buckwheat flour of Novosadska variety, although there are a large number of studies in which several dozen different polyphenolic compounds were detected, both in different buckwheat varieties and in different parts of the plant (grain, stem, leaf), but also in products such as pollen and honey obtained from buckwheat (Kiprovski et al., 2015; Nešović et al., 2021; Yang et al., 2022). Furthermore, the research findings showed that storage does not lead to statistically significant changes in most of the parameters examined. This insight may be useful for the promotion and popularization of this variety, both among producers and consumers.

CONCLUSION

Buckwheat (*Fagopyrum esculentum*) is recognized as a highly valuable raw material for the formulation of functional foods, attributed to its favorable nutritional profile, significant content of bioactive compounds, and absence of gluten. Its diverse applications encompass a wide array of products, including gluten-free baked goods, fermented beverages, instant porridge, and energy bars. The advancement of novel processing technologies, alongside the synergistic combination of buckwheat with other natural ingredients, further enhances its applicability within the modern food industry.

In light of the growing consumer demand for natural and health-oriented food products, buckwheat holds considerable promise as a key ingredient in the development of functional foods in the forthcoming decades. Its unique attributes position it favorably within the health food sector, suggesting its potential to significantly impact dietary habits and nutritional patterns.

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