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# The Contribution of Buckwheat Genetic Resources to Health and Dietary Diversity

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**Abstract:** Despite several reports on the beneficial effects of buckwheat in prevention of human diseases, little attention has been devoted to the variability of biochemical and physiological traits in different buckwheat genetic resources. This review describes the biochemical evaluation of buckwheat genetic resources and the identification of elite genotypes for plant breeding and exploitation. The various types of bioactive compounds present in different varieties provide basic background information needed for the efficient production of buckwheat foods with added value. In this review, we will provide an integrated view of the biochemistry of bioactive compounds of buckwheat plants of different origin, especially of fagopyrin, proteins and amino acids, as well as of other phenolic compounds including rutin and chlorogenic acid. In addition to the genetic background, the effect of different growth conditions is discussed. The health effects of fagopyrin, phenolic acids, specific proteins and rutin are also presented.

**Keywords:** Buckwheat, Chlorogenic acid, Rutin, Fagopyrin, Phenolic acid, Phenols, Gluten, Protein, Aminoacids.

## 1. INTRODUCTION

Common buckwheat (*Fagopyrum esculemntum* Moench), a traditional crop of the *Polygonaceae* family, is widely used as a food and medicinal plant. Buckwheat's beneficial effects are due to the broad spectrum of flavonoids which are biologically active phytonutrients possessing health benefits, including reduction of cholesterol [1], inhibition of tumors [2], regulation of hypertension [3], as well as control of inflammation, carcinogenesis and diabetes [4]. The numerous uses of buckwheat in making noodles, pancakes, and muffins have made it one of the most widely consumed products in many countries, including India, China, Japan, Nepal, Canada and Ukraine. In Korea, Japan, Italy, and China, buckwheat is mainly consumed in the form of noodles. The largest producers of buckwheat are China, The Russian Federation, Ukraine and Kazakhstan. In eastern European countries, such as Ukraine, Poland and Russia, buckwheat is eaten mainly in the form of grains. However, no buckwheat cultivation exists in many EU countries. Compared to rice and wheat, buckwheat seeds are richer in protein and antioxidants, such as phenolic compounds [5]. In experiments, D-chiro-inositol, fagopyritols (galactosyl derivatives of D-chiro-inositol), resistant starch, and buckwheat protein, all present in buckwheat, had positive health effects on rats, but further studies should be undertaken to establish their effects on humans [6].

To date, there is no clear understanding of the evolution of the genus *Fagopyrum*. However, it appears that there is great differentiation among *Fagopyrum* species. For example, *F. esculentum* is a heterostylous and crosspollinating annual species while *F. homotropicum* is a homostylous self-pollinating species. Perennial species such as *F. cymosum, F. statis* and *F. urophyllum* also exist with distinct achene morphologies. Polyploidy has occurred twice, in *F. cymosum* and in *F. gracilipes* resulting in loss of heterostyly and a shift from self-incompatible to selfcompatible pollination in the latter species. In general, buckwheat can be classified into three kinds of species, the so called common buckwheat (*Fagopyrum esculentum*), tataricum buckwheat (*F. tataricum*) and cymosum buckwheat (*F. cymosum*). Among these species, *F. esculentum* Moench (common/sweet buckwheat) and *F. tataricum* (L.) Gaertn. (tartary/bitter buckwheat) are used as food by humans. Although common buckwheat is eaten widely in the world and its chemical and nutritional aspects have been well-studied, food usage of tataricum buckwheat, common in the Himalayan region, is less well-studied [7].

There are two very well-known and widely cultivated buckwheat species: *F. esculentum* Moench (common/sweet buckwheat) and *F. tataricum* (L.) Gaertn. (tartary/bitter buckwheat) [8].

Neupane *et al.*, 2011 recorded differences in the yield of sweet buckwheat (*F. esculentum*) and bitter buckwheat (*F.

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*tataricum*) [9]. Information about the nutritional characteristics of other buckwheat species is not currently available. Neutraceutical compounds exist not only in the buckwheat seeds but also in its vegetative mass [10].

In many cases, the genotypes selected from local populations are cultivated in traditional regions of buckwheat production. This can be considered to be a great advantage, as it creates preconditions for a rich and diverse germplasm of this species. On the other hand, buckwheat represents a minor crop and, hence, the main goals of the previous and recent breeding programs were on the increase of yield [11] or high protein content [12]. The idea of producing functional food using buckwheat seeds and plants [13] sets new breeding targets such as high levels of bioactive compounds. To meet this target, additional genetic resources need to be involved.

Despite numerous biochemical studies providing information on locally cultivated genotypes, there is still a lack of comprehensive information regarding the comparison of species and genotypes of different origin. Therefore, the aim of this review is to provide the complementary research analysis of buckwheat's genetic diversity regarding bioactive compounds, including those located in other useful parts of the plant. We focused also on the healthy nutritional effects of the bioactive components, which may help to identify the main biochemical targets for future crop improvement. Thus, although this review is primarily intended for experts in conventional and molecular breeding, it may also be of interest to people searching for plant resources useful for production of functional and healthy foods.

## 2. AMINO ACID COMPOSITION AND PROTEIN CONTENT IN BUCKWHEAT PLANTS

Compare to other cereals proteins of buckwheat have a higher biological value because of their high lysine content with score 100 in an amino acid score [14]. The buckwheat plants got higher protein content than other cereals (for example, wheat, rice, maize and sorghum). However, the digestibility of these proteins is low (79,9%) due to anti-nutritional factors including tannins and protease inhibitors and tannins [9, 15-17]. The absence of gluten in buckwheat flour determines its potential use in gluten-free diets, a market of tremendous growth in recent years [9, 18].

Buckwheat achene's contain mostly carbohydrate, especially starch (55.8%) [19]. In buckwheat, the starch content is 55.8% in grains, 40.7% in bran and 78.4% in flour. The protein content of buckwheat grains is 11. 7% while in bran it is 21.6% and in flour 10.6% [19]. The protein content in different buckwheat species is between 11-15%.

Approximately half (55%) the protein content in a buckwheat kernel is located in the embryo, 35% in the endosperm, and the rest in the hull [20]. In contrast, cereals have a different allocation of protein content in kernels. Specifically, cereals have 10-20% of the protein in the embryo and most of the protein (80-90%) in the endosperm.

A comparative study of the chemical composition and protein quality of two buckwheat varieties found that the protein content in buckwheat is approximately 12% which is comparable to that in wheat. The high protein quality found in these two varieties had biological values above 90% probably due to the high concentration of essential amino acids and sulphur-containing amino acids. The fat content in buckwheat is near 3%. At the same time the high concentration of crude fiber of two experimental buckwheat (12.7 and 17.8%) varieties has been found. The high fiber content caused by a small content of soluble carbohydrates. Both buckwheat varieties got 1.76 and 1.54% of tannin content what is high. The high quality of buckwheat protein with biological values raised 90% what can be explained by a high concentration of most essential amino acids, especially lysine, tryptophan, threonine and the sulphur-containing amino acids. The high tannin (1.54%-1.76) and crude fiber content of the buckwheat varieties resulted in less than 80% digestibility of the true protein [21].

Compared to cereals, the amino acid composition of buckwheat is characterized by higher amounts of aspartic acid, lysine and arginine and less glutamic acid and proline. Lysine is the first limiting amino acid from buckwheat protein source and important parameter of high nutritional value which makes buckwheat more promising than other cereals. The lysine content decreased from albumin > glutelin > globulin > prolamin. Another tendency compared to the lysine have threonine. The threonine content decreased from prolamin > glutelin > albumin > globulin in the protein from kernels of common buckwheat varieties (*F. esculentum*) and tartary buckwheat varieties (*F. tataricum*) (Japanese) [22].

In buckwheat groats, the large increase in weight was accompanied by a decrease in protein concentration. During the maturation period, the groat's contents of arginine increase while the contents of lysine, proline, alanine, and isoleucine decrease. The amino acid composition of maturing buckwheat is relatively stable compared observed changes in the amino acids compositions of cereals and legumes during maturation period. Changes in buckwheat are intermediate between true cereals and legumes for amino acids of storage proteins such as glutamic acid and for limiting amino acids such as lysine [23].

The data regarding amino acid composition and content in buckwheat *F. esculentum* grains show varietal differences in the content of the amino acids depending on their origin (Table **1**). Nowadays information about amino acid composition in bitter buckwheat (*F. tataricum*) is not readily available. It should be noted however that the Korean cultivar "Dasanmaemil" is a developed buckwheat variety with high content of amino acids and protein. It was found that in the buckwheat sprouts the total amino acid content higher than in the seeds of buckwheat on 28-38%. In sprout tissue were identified fourteen kinds of amino acids, including lysine, glutamic acid and aspartic acid and their contents were notably increased. However, arginine and cysteine (sulfur containing amino acid) levels were decreased [24].

In four buckwheat cultivars (*F. esculentum* Moench, *F. tataricum* Gaertn., *F. kashmirianum* Munshi and *F. sagittatum* Gilib.) has been undertaken comparative study of the chemical composition of grains. Based on this analysis the relatively low fat, free sugar and protein content, also the lowest content of phenolics but a higher starch content compared to the other three cultivars had grains of *F. esculentum*. *F. esculentum* had a higher content of residual insoluble

**Table 1. Amino acids composition in the groats of cultivars *Fagopyrum esculentum* Moench with different origin (g/100 g protein).**

| Aminoacids | *F.esculentum* Cultivated in China | *F. esculentum* Cultivated in China | *F.esculentum* Cultivated in Japan | *F. esculentum* New Developed Cultivar `Dasanmaemil' Cultivated in Korea |
|---|---|---|---|---|
| Arginine | 11.16 | 10.6 | 7.4 | 73.0 |
| Histidine | 2.52 | 3.9 | 2.3 | 3.7 |
| Aspartic acid | 9.54 | * | 19.3 | 24.7 |
| Glutamic acid | 19.38 | * | 11.1 | 58.8 |
| Serine | 4.61 | 4.5 | 4.0 | 10.3 |
| Threonine | 3.5 | 3.3 | 3.9 | 12.4 |
| Proline | 7.93 | 3.6 | 3.2 | 2.9 |
| Glycine | 5.66 | 4.0 | 5.7 | * |
| Alanine | 3.89 | 3.5 | 5.9 | 8.1 |
| Valine | 4.26 | 5.1 | 5.7 | 26.3 |
| Isoleucine | 3.12 | 3.7 | 4.3 | 9.6 |
| Leucine | 5.94 | 6.3 | 7.0 | 6.8 |
| Lysine | 5.68 | 5.6 | 7.2 | 7.0 |
| Methionine | 2.3 | 1.4 | 2.9 | 3.7 |
| Tyrosine | 3.03 | 3.4 | 2.2 | 4.9 |
| Phenylalanine | 4.3 | 5.3 | 4.4 | 3.7 |
| Tryptophane | 2.0 | * | * | * |
| | *Tomotake et al. (2006)* | *Tang et al. (2009)* | *Pomeranz et al. 1975* | *Kim et al., 2004* |

*- not determined.

proteins and lower globulin, albumin, and glutelin content. Each of the four cultivars has been characterized by low content of prolamins. The low phenolics content in the groat of *F. esculentum* is considered more acceptable compared to other three cultivars with higher phenolics content what can cause an bitter taste of flour [25].

Bitter buckwheat (*F. tataricum*) is very wholesome. Bitter buckwheat contains 11.66% of protein. It is significant higher than in rice on 38.2% 30.5% higher than corn, 20.2% higher than in common buckwheat and on 3.9% higher than wheat. In the bitter buckwheat has been identified 18 kinds of amino acids among which found especially high contents of lysine and 8 essential amino acids. It was confiremed that bean protein is similar to protein composition of bitter buckwheat. Protein composition of bitter buckwheat is also close to the protein composition of eggs [26].

The use of buckwheat to promote health benefits has been a subject of intensive study in recent decades. For example, in flour mixes, buckwheat has been shown to significantly increase antioxidant activity (AA) when 15% of wheat flour in white bread preparations is replaced by buckwheat – without altering consumer perception [27]. Additionally, comparison of consumption of white wheat bread and boiled buckwheat groats or bread baked using flour of buckwheat has been revealed reduced post-prandial blood glucose and insulin responses after buckwheat consumption [28]. The positive effects of buckwheat consumption also extend to animal feeding. For example, it has been recently shown that buckwheat bran can successfully replace 30% of a corn-soy-based diet in laying hens, resulting in an increase in egg production and without changes in egg quality [29].

For improving the nutritional and technological quality of bread the effect of the substitution of buckwheat flour for 10%, 20%, 30% and 40% of a gluten-free formulation was studied. The specific volume of bread loaf is increasing with advancing addition of buckwheat flour. It is established decreasing in whiteness and higher redness and yellowness of crumb compared with the control sample. Decrease of crumb hardness during storage is caused by increased amount of buckwheat flour during backing process of gluten-free bread. This is connected with decreased gelatinization enthalpy in the starch and with the increased quantity of buckwheat flour in the gluten-free formula in comparison with the control sample. Buckwheat flour can be integrated into the gluten-free formula for delaying bread staling and with a positive effect on bread texture [30].

The gliadin and glutenin are main components of gluten. These two compounds is dedicated with starch in the endosperm of different crop-related grains. The grains pseudocereals with buckwheat among them, amaranth and quinoa has a nutrient profile which is characterized as gluten-free. Contrary to the proteins of most common crop plants grains, in the proteins of buckwheat, amaranth and quinoa are presented mainly albumins and globulins. Discussed proteins contains very low level of storage prolamin proteins, which are the main storage proteins in cereals. It is known that prolamins are toxic proteins in coeliac (name for celiac disease in the United States) [31, 32]. The amino acid composition of globulins and albumins differs significantly to that of prolamins, which has implications in relation to their nutritional quality. Globulins and albumins contain less glutamic acid and proline than prolamins, and more essential amino acids such as lysine [32]. In the protein fraction of albumin of four experimental buckwheat cultivars the sequence of amini acids content was next from high to low - glutamic acid>aspartic acid>lysine>arginine>glycine>valine. The globulin protein fractions is characterized next sequence from high to low - glutamic acid>arginine>aspartic acid> glycine>histidine. The contents of all amino acids in globulin were significantly lower than in albumin. The leucine content was 0.43% which is close to the average content. The prolamin fraction of protein got the highest glutamic acid content among all identified amino acids but content of other amino acids was less compared to the content of amino acids in the albumin and globulin fractions [22].

Basically coeliac disease can appear only rarely in childhood. But nowadays coeliac disease may be diagnosed at any age. 0.3–1.2% of this disease have been estimated after serologic screening in unselected North American, European, Indian and South American populations [33, 34]. The wheat gliadins and other prolamins are factors responsible for the primary life-long intolerance in genetically minded persons. It is hordein in barley, secalin in rye and can be avenin in oats [35]. The presence of gastrointestinal symptoms is main clinical evidence of coeliac disease. With such diagnosis to follow a life-long gluten-free diet is only one appropriate way of treatment. Gluten-free products are often poor in minerals, vitamins and proteins. To improve nutrition quality of gluten-free formulation in food products for diet was used incorporation of buckwheat flour and studied effect of it on the micro elements, protein content and size-related parameters. It was estimated that buckwheat flour have positive effect on the technological quality of bread (size of loaf and index of specific volume of bread). 10-40% increasing of buckwheat flour concentration in bread influenced the rising manganese and copper content together with proportional enhancement in proteins [36].

Processing of gluten-free products can can also affect protein quality. For example, thermal treatment of whole seeds could not significantly affect protein content, but roasting will significantly decrease the total protein content of groats. It was confirmed with deterioration of protein quality via formation of maillard reaction products (MRPs) after the thermal treatment of whole seeds and groats. A significant degradation in natural antioxidants due to thermal processing was observed [37]. Heating caused conformational changes in the buckwheat protein, especially in the globulin. Variations in the texture profile of buckwheat flour-water dough were observed during heating. Ikeda *et al.*, 1990 suggest that the protein of buckwheat flour may be closely associated with the texture of buckwheat dough [38].

The protein product from flour of tartary buckwheat prepared by isoelectric precipitation and alkali extraction gave a 45.8% protein content and amino acid composition similar to that of the common buckwheat protein product. In rats fed cholesterol, the consumption of protein product from common buckwheat and tartary buckwheat product at 20% net protein level for 2 weeks resulted in a 32% and 25% reduction in serum cholesterol. Longer consumption of buckwheat protein product and tartary buckwheat product resulted in 62% and 43% reductions of lithogenic index, respectively. The results of the study suggested that the two protein products could potentially be used as functional food ingredients [39].

## 3. NUTRITIONAL CHARACTERISTICS OF BUCKWHEAT SPROUTS

Several studies have showed that buckwheat (*Fagopyrum sp.*) flour may be a basis for producing healthy foods, due to the antioxidant properties attributed to its high content of phenolic compounds like rutin and quercetin. Two species of buckwheat are mainly used, common buckwheat (*F. esculentum*) and tartary buckwheat (*F. tataricum*), in which the broad composition of crude protein, fiber and fat are essentially the same. However, tartary buckwheat seems to contain more flavonoids than the common species. Recently, buckwheat sprouts have been introduced as a new raw material for the production of functional foods. Young parts, especially leaves of buckwheat are eaten in some countries as a vegetable. Green flour, obtained by milling of the dried plants, is used as a natural food colorant [40]. Indeed, buckwheat sprouts provide an abundance of such nutritional factors as protein, amino acids, minerals (Fe, Zn, Mn, Mg, Cu, Ca), crude fiber and rutin. The free sugars in both the buckwheat seed and the early stages of the seedling were mainly sucrose and maltose, but its composition gradually changed into glucose and fructose as the seedlings grew. The lysine content of the buckwheat sprouts was notably higher than that of the buckwheat seeds and cereals. Rutin (vitamin P), one of a group of flavonoids with the beneficial function of reducing vascular diseases and diabetes etc., was found to be abundant in buckwheat sprouts and its contents increased to about 27 times that of rutin in buckwheat seeds. *In vivo* activities of buckwheat sprouts shown advancement in lipid metabolism which occurs antidiabetic effects in type 2 diabetic mice. The diet with buckwheat sprouts is stimulate excretion of bile acids in feces, than supports farther contribution of suppression cholesterol concentration in the plasma and liver tissues of mice [41]. Buckwheat sprouts have a slightly crispy texture, balmy and mild flavor. Buckwheat sprouts have a very good-looking fragrance. At the same time sprouts of buckwheat do not have a flavor same to the sprouts of soybean. Such parameters makes buckwheat sprouts useful as a salad, fresh vegetable and as plant-source for preparation of fresh natural vegetable juice [24]. The buckwheat sprouts have bright-light hypocotyl and bright-yellow cotyledons, so their appearance is very similar to that of soybean sprouts.

Sprouts of buckwheat cultivated for 1 week were rich in dietary phenols with the highest total phenols in buckwheat sprouts at day 6. The highest content of rutin was estimated in buckwheat sprouts at 20 h after germination. The buckwheat sprouts contained five major phenols. At 3 day the highest contents of orientin, isoorientin, vitexin and isovitexin were measured [42].

The dried sprouts of tartary buckwheat have the highest antioxidant capacity and content of total phenolics higher than the dried sprouts of common buckwheat. Dried tartary sprouts were milled to obtain a flour to be used for the production of "spaghetti "containing 30% of dried sprouts and 70% of durum wheat flour. The effect of making and cooking spaghetti on total polyphenol content and antioxidant properties was studied comparing pasta prepared with buckwheat seed flour, with buckwheat sprout flour and with only durum wheat flour. Spaghetti made with buckwheat sprout flour exhibited significantly higher levels of total phenolic content (3.7±1.0 mg/g GAE) than those made with buckwheat seed flour and with only durum wheat (2.2± 0.6 mg/g GAE and 0.3±0.5 mg/g GAE respectively). However, total phenolic content in spaghetti made with buckwheat sprouts was 60% of the original content after cooking. The results of the study indicate that pasta made with sprout flour has a higher antioxidant capacity compared to the product derived by milled seeds [43].

Another area of investigation is the accumulation and distribution of selenium (Se) in the sprouts of tartary buckwheat. Selenium accumulation in different plant parts was shown to decrease in the order: radicle > husk >hypocotyl > cotyledon. Selenium in buckwheat proteins was primarily found as albumin-bound Se and glutelin-bound Se [44].

The characterization of hydrolysates from common buckwheat (*F. esculentum* Moench) in relation to physiochemical and antioxidant properties showed high antioxidant capacities, including DPPH radical scavenging activity, reducing the power and ability to suppress linoleic acid peroxidation. The antioxidant activities of buckwheat hydrolysates were closely related to their content of total phenolics. The hydrolysis derived in a decrease in the proteins, especially globulins aggregates and collateral increase in peptide fragments [45].

The content of rutin in the sprouts of Korean buckwheat cultivar Hokkai T 9 (value 21.8 mg $g^{-1}$ DW at 6–10 DAS) was 2 times higher than that in non-germinated/germinated seeds, but less than that in 6–8 DAS etiolated seed sprouts (27–29 mg $g^{-1}$ DW) [46]. Furthermore, in the sprouts of tartary buckwheat which were growth under natural light conditions, content of rutin was up to 5.0% DW whereas, in sprouts of common buckwheat, it was half that (2.6% DW) at 6 DAS [47]. In another study tartary buckwheat sprouts were 5 times higher in rutin than common buckwheat sprouts [27].

Rutin is the main flavonoid in the sprouts of common buckwheat (*F. esculentum* Moench) and tartary buckwheat (*F. tataricum* (L.) Gaertn.). Pasta made with sprout flour from tartary buckwheat sprouts had 5 times more rutin compared to common buckwheat sprouts. A compariative characteristics of common buckwheat (*F. esculentum* Moench) and tartary buckwheat (*F. tataricum* (L.) Gaertn.) has shown that the ethanol extracts of tartary buckwheat sprouts had higher free radical scavenging activity, reducing power, and superoxide anion scavenging activity than those of common buckwheat sprouts. The tartary buckwheat sprouts and common buckwheat sprouts has strong antioxidant effects which supports decreasing of intracellular peroxide production and removing of the intracellular superoxide anions in HepG2 cells; but tartary buckwheat sprouts decreased the cellular oxidative stress more effectively than common buckwheat sprouts, possibly because of its higher rutin (and quercetin) content [27].

## 4. BUCKWHEAT CULTIVATED UNDER DIFFERENT GROWTH CONDITIONS

Phenolic compounds have been described to have numerous biological effects among them one is antioxidant activity. Phenolic compounds can be present in edible and non-edible plants. The flavonoids concentration can vary in accordance with qualitative adjustments in circumstance light [48]. Conditions of day length together with solar radiation expanded the accumulation of rutin in common buckwheat (*F. esculentum*) [49, 50]. In addition, late buckwheat cultivars with late flowering period have higher content of rutin than cultivars of early flowering period [51]. Kitabayashi *et al.* (1995) also specified that varied differences and level of rutin content in common buckwheat have been connected to the geographic origin of the seed and also to the environmental conditions of seeds growth [52]. It was estimated that light emitting diodes increase the content of phenolics (orientin, homoorientin, vitexin, isovitexin and rutin) of sprouts of common buckwheat (*F. esculentum*) [53].

The content of total phenols in the different anatomical parts (leaves, stems, inflorescences and seeds) of 6 cultivars of common buckwheat was evaluated in the growth phase formation of buds, in the phase beginning of flowering, in the full blossoming phase and in phase of full ripeness. The maximal increase in content of total phenolics was found for each buckwheat cultivar at the end of the vegetation period (phase of full ripeness). The inflorescences contained the highest content of total phenolics compared to the leaves, stems or seeds of common buckwheat experimental cultivars from the Slovak collection [54]. The highest content of total phenolics was estimated for inflorescences of common buckwheat of the Ukrainian cultivar in the phase of the beginning of flowering. It was estimated that content of total phenolic in the leaves and stems of the buckwheat plant changed according to the vegetation period and plant organ [55]. The total phenolic content increased after 2% CCC treatment in phase formation of buds in the stems and in phase beginning of flowering in the leaves and then inflorescences respectively [55].

The growth conditions of *Agrobacterium rhizogenes* which favour the creation of hairy root culture could be an effective system for phenolic production for *F. tataricum* and *F.esculentum* [56-58]. The hairy roots culture, hairy leaves and stems cultures of common buckwheat have shown the highest phenolic acids content and antioxidant activity compared to the wild type cultures (Gabr *et al.*, 2012). It was shown that production of phenolics by various morphological phenotypes and in hairy root cultures of *F. tataricum* Gaertn is differ. The hairy roots culture is advertised two morphological phenotypes when cultivated on hormone-free medium was containing Murashige-Skoog salts and vitamins – thin and thick phenotypes. The thin phenotype have been characterized higher growth parameters compared to the thick phenotype. Thin phenotype have been produced almost two times higher content of (-)-epigallocatechin. The thin phenotype has been characterized by increased content of caffeic acid more than 2 times, content of chlorogenic acid on 65%, and level of rutin on 40% compared to the thick phenotype after 21 days of cultivation [59].

Tartary buckwheat is regularly cultivated under conditions with special light attitude (intensive UV radiation), when the environment is not suitable for growth of rice or other major crops [60]. Experimental work with growth conditions under the higher UV-B radiation that simulate 17% ozone depletion for common buckwheat and buckwheat tataricum has shown specific induction of quercetin concentration in the shoot in UV-B-treated common buckwheat. In parallel it were no specific responses for flavonoid metabolism in tartary buckwheat. It was found that arbuscular mycorrhizal fungal colonization can significantly reduce concentration of catechin in the roots of common buckwheat; it can also stimulate increasing concentration of rutin in the roots of tartary buckwheat, but did not affect phenolics content in the shoots [61].

The shoots of common buckwheat can easily accumulate up to 4.20 mg g-1 of Pb [62]. Foliar treatment of common buckwheat seedlings with different Ni concentrations affect development of the lipid peroxidation process and induce changes in content of phenolic acids [63]. Common buckwheat (*F. esculentum*) is an Al-tolerant species and can accumulate Al to levels as high as 15,000 ppm in leaves, when grown on acidic soils, without displaying symptoms of Al toxicity [64]. Physiological studies have demonstrated that common buckwheat secretes oxalate to detoxify Al externally and utilizes oxalate to chelate and sequester Al in the vacuoles of both roots and shoots for internal detoxification [65]. The Kyoto Encyclopedia of Genes and Genomes and Gene Ontology enrichment analysis presented that expression of genes involved in the defense of cell wall toxicity and oxidative stress was preferentially induced by Al stress. Tartary buckwheat is also, like common buckwheat, an Al-accumulating species [66]. But tartary buckwheat is self-pollinating compared to common buckwheat, which makes it easier to assemble transcripts and to conduct further gene function analysis. Two citrate transporter genes that were highly induced by Al and potentially involved in the release of citrate into the xylem were identified in tartary buckwheat.

## 5. ANTIOXIDANT ACTIVITY OF BUCKWHEAT EXTRACTS

The buckwheat water extract among the cereal grain water extracts exhibited antioxidant activity. The experimental results of changes in the antioxidant activity from highest to the lowest was contributed for 80% methanolic extracts of whole grains: buckwheat > barley > oat > wheat > rye. The antioxidant activity of buckwheat hulls, oat and barley hulls was next: buckwheat > oat > barley [67].

The parameters of the extracting solvents can significant affect the antioxidant activity, content of total phenolics and yield of buckwheat extract. The antioxidant activities of common buckwheat extracts has been assessed and compared with butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA) and tertiary butylhydroquinone (TBHQ) using a a DPPH assay, a $\beta$-carotene bleaching assay, and the Rancimat method. Extraction of buckwheat was done by solvents of different polarities. The methanol extract of buckwheat revealed longest induction time with use Rancimat method and the highest antioxidant activity by the $\beta$-carotene bleaching method. The highest scavenging activity by the DPPH method and highest content of total phenolics showed acetone extract [68].

The food processing effect on functional and nutritional compounds in buckwheat flour was studied. Buckwheat flour extracts were carried out before and after extrusion or roasting. Food processing of buckwheat did not cause any change in the content of total phenolics in buckwheat flour. An increase in non-polar and polar compounds was presented in the roasted (200 °C, 10 min) dark buckwheat flour. For same type of dark buckwheat flour extrusion exhibited an increase only in polar compounds. An DPPH antioxidant activity test showed that roasting at 200 °C for 10 min slightly decreased the antioxidant activity. At the same time it was revealed no changes in the antioxidant activity under processing (170 °C). The obtained results suggest that processing conditions can be optimized to keep the health promoting compounds in buckwheat products [69].

The 4 years research experiment at different locations in western Canada where grown buckwheat plants has shown that the location of plant cultivation is the main factor of variation for rutin and flavonoid contents of the seed. Although significant influence on the content of flavonoids of the hulls had the growing season. The factor of cultivar together with environment effect have been affected the variation in antioxidative activities. In the buckwheat samples was observed strong correlation of flavonoid content with rutin content. Flavonoid content was weakly associated with antioxidative activities, although content of rutin was not correlated to antioxidative activities [70].

## 6. PHENOLIC CONPOUNDS OF BUCKWHEAT EXTRACTS

Polyphenols contribute to about 20% of the total AA in common buckwheat, whereas in tartary buckwheat they are responsible for 85-90% of the total AA [71]. Flavonoids have been shown to vary in content and composition according to genotypes and the developmental phase of the plant [9]. Although, information on flavonoid and phenolic composition of several buckwheat varieties can be found, information on phenolic acids is lacking.

The variation in phenolic content and composition of tartary and common buckwheat collected from China, Japan and Korea has been investigated. The varieties of common and tartary buckwheat from each country were cultivated using a vermiculite and nutrient solution. Phenolics such as rutin, quercetin, chlorogenic acid, such C-glycosylflavones like orientin, isoorientin, vitexin, and isovitexin were identified using HPLC analysis at 17, 29, 44, 58, and 72 days after sowing (DAS). The cultivars from China and Korea at 17 DAS has higher rutin content than that at 29 and 44 DAS. Furthermore, two Japanese varieties at 44 DAS were characterized to have maximum level of rutin. The highest amount of rutin among all investigated cultivars found in cultivar "Hokkai T10" at 44 DAS (58.36 mg g –1 DW). The content of rutin in the stems and leaves at 72 DAS were higher than at 58 DAS. The total phenolics and rutin contents in the plants anatomical parts were higher in the order: influorescences>leaves,>stems and flowers. The orientin, isoorientin, vitexin, and isovitexin contents in common buckwheat was higher than those in tartary buckwheat. At the same time the rutin content which assumed for >90% of the total phenolics was higher in tartary buckwheat. The highest amounts of chlorogenic acid and quercetin were measured in the influorescnces of chinese cultivar “Xiqiao No.2” [72]. The phenolic compounds in buckwheat sprouts has superoxide anion radical-scavenging activities. The rutin, isoorientin, and orientin devoted mainly to the superoxide anion radical-scavenging activity of the extract from sprouts of buckwheat. Contrary, the cyaniding-3O-rutinoside contribution was considerably lower than that of flavonoids [73].

Rutin, quercetin, orientin, vitexin, isovitexin, and isoorientin have been isolated and identified in the grains of buckwheat (Table **2**). In the buckwheat seeds the flavonoids were presented only by rutin and isovitexin but the buckwheat hulls contain also quercetin, orientin, vitexin, The total flavonoid concentration was 18.8mg (in the seeds) and 74mg (in the hulls) per 100 g of dry matter. De-hulling the grain by using various temperature regimes resulted to the significant decreasing of the total flavonoid concentration in the grain on 75% compared to the control. In the hulls of buckwheat under the same treatments conditions found smaller but significant (15−20%) reduction [74]. The flavonoids orientin, isoorientin rutin, quercetin, vitexin, isovitexinwere found in the hulls of five varieties of Polish buckwheat (Emka, Hruszowska, Kora, Luba, Panda). The antioxidant activity (AA) analyzed flavonoids and synthetic antioxidant BHT (buthyl-hydroxytoluen) could be sequenced in a following way: vitexin < isovitexin < orientin < isoorientin < rutin < quercetin < BHT [75].

In the hulls of buckwheat next antioxidant compounds – rutin, quercetin, hyperin, protocatechuic acid, and 3,4-dihydroxybenzaldehyde were estimated. The content of these antioxidants in the hulls of buckwheat were from highest to lowest in order: protocatechuic acid >3,4-dihydroxybenzaldehyde (>hyperin > rutin >quercetin. The content of rutin and quercetin was 4.3 mg/100 g and 2.5 mg/100 g, respectively. Among the identified compounds vitexin and isovitexin in the extract did not showed peroxyl radical-scavenging activity [76].

## 7. RUTIN

Rutin is a flavonoid with high antioxidative power. It is present in many plants, but only buckwheat plant and few other nutritionally important species contain high amount of rutin. The buckwheat leaves and inflorescences can have about 2- 10% of rutin per dry weight [77] and much less can have grains and flour [13, 78]. The concentration of rutin in grains and flour is up to 0.01% which is low. Although in human nutrition such flavonoids content can represent an important part of daily intake [79]. Antioxidant activity *in vitro* and *in vivo* were shown for rutin and quercetin. Rutin presented high DPPH radical scavenging activity. The ascorbic acid, butylated hydroxytoluene and rutin (concentration of 0.05 mg $ml^{-1}$) revealed 92.8%, 58.8%, and 90.4% inhibition, respectively. Inhibition of lipid peroxidation was observed by rutin [80]. Together with antioxidant activity rutin also possesses additional pharmacological effects [79].

A statistically significant relationship between rutin, total phenolic content and antioxidant activity of buckwheat extracts was investigated [81]. Rutin, a flavonol glycoside compound is used medicinally to treat edema, hemorrhagic diseases and for stabilizing high blood pressure because it controls blood vessel elasticity. The content of rutin in buckwheat depends on the plant organ and on the stage of vegetation period. Amount of rutin is higher in the younger leaves than in the older ones. Rutin content is also vary among buckwheat species. Cultivars such as *F. esculentum* and *F. tataricum* also differ in their rutin content. Hagels *et al.* (1995) reported that during the first blossoming phase and phase of young fruit development in the buckwheat was estimated high amountof rutin (near 5-7% of dry wieght). Furthermore, the sowing time and density and also nitrogen fertilization were factors which influenced level of rutin [82]. The rutin content in sprouts of buckwheat was 27 times higher than that in seeds of buckwheat. Furthermore, the content of rutin was increased gradually during growth of seedlings [24].

In order to create a scientific background for the management and production of high quality buckwheat experiment with many buckwheat cultivars of different locations in China was done. During this study of buckwheat genotypes with high rutin content in grains under the effects of temperature, sowing date, seeding density, fertilization and planting district has been confirmed genotypic variation of the rutin content in grain of buckwheat. The significant difference in the grains among different cultivars within the same category in the content of rutin and protein components was estimated. A wide range of variation from 0.63% to 2.03% of rutin content in grains of different cultivars of tartary buckwheat was observed. The rutin content in the 22 cultivars of common buckwheat varied from 0.0051% to 0.0301%, which was lower than in the cultivars of tartary buckwheat. The content of rutin in 47% cultivars of tartary buckwheat varied between 1.15% and 1.5%. The content of rutin in grain of 50% cultivars of common buckwheat changed from 0.0051% to 0.013%. The average content of total protein in grains of tartary buckwheat was higher than that in common buckwheat. The albumin content was the highest and prolamin content was lowest among protein components in the investigated buckwheat cultivars. The range of albumin content variation was the widest than prolamin [83].

Analyses of high rutin content in various buckwheat species and cultivars, such as *F. esculentum* Moench (Cultivars Lileya, Bilshovik, Rubra), *F. tataricum* G. (ssp. rotundatum (Bab) Krot. and ssp. tuberculatum Krot.), *F. cymosum* Meissn., and *F. giganteum* Krot. have indicated that color visual assessment of the vegetative organs of buckwheat plants is a marker for selection of buckwheat cultivars with high anthocyanin and rutin content. The presence of anthocyanin content in the vegetative organs of buckwheat can be a reliable genetic marker for screening plants with a high content of rutin. In the third generation of the selection process with this selection method, a genetic line of Rubra cultivar with a high rutin content in the vegetative mass has been

**Table 2. Comparable characteristics identified phenolic compounds in the different organs of common and tartary buckwheat.**

| | *Stems* | | *Leaves* | | *Flowers* | | *Grain* | | *Hulls* | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Flavonoids** | **CB** | **TB** | **CB** | **TB** | **CB** | **TB** | **CB** | **TB** | **CB** | **TB** |
| **Orientin** | - | - | + | - | - | - | + | a | + | a |
| **Rutin** | + | + | + | + | + | + | + | + | a | + |
| **Quercetin** | + | + | + | + | + | + | a | + | + | + |
| **Quercitin** | a | a | a | a | a | a | a | + | a | a |
| **Isovitexin** | + | - | + | - | + | - | + | a | a | a |
| **Isoorientin** | - | - | + | - | - | - | + | a | a | a |
| **Vitexin** | - | - | + | - | - | - | + | a | a | a |
| **Hyperin** | a | a | a | a | a | a | a | a | + | a |
| **Protocatechuic acid** | a | a | a | a | a | a | a | a | + | a |
| **3,4-dihydroxy-benzaldehyde** | a | a | a | a | a | a | a | a | + | a |
| | *Seo et al., 2013* | *Seo et al., 2013, Kim et al., 2009* | *Seo et al., 2013, Koyama et al., 2011* | *Seo et al., 2013, Kim et al., 2009* | *Seo et al., 2013, Koyama et al., 2011* | *Seo et al., 2013, Kim et al., 2009* | *Dietrych-Szostak and Oleszek, 1999* | *Fabjan et al., 2003* | *Watanabe et al., 1997* | *Steadman et al., 2001* |

a-not determined Common buckwheat – **CB**, Tartary buckwheat – **TB.**

obtained. The method of selection based on the color visual assessment of the plant parts of buckwheat is correlated with anthocyanin contents [84].

Seeds evaluation of 11 cultivars of three buckwheat species *F. esculentum, F. tataricum* and *F. homotropicum* revealed dependence on kind of the species regarding rutin and total flavonoids content. The contents of rutin and total flavonoids were 0.02% and 0.04% in *F. esculentum*, 0.10% and 0.35% in *F. homotropicum*, and 1.67% and 2.04% in *F. tataricum*, respectively. A dose–response effect in inhibiting low-density lipoprotein peroxidation was shown for all experimental buckwheat species. The antioxidant activity was from highest to lowest in the order: *F. tataricum* > *F. homotropicum* > *F. esculentum*. Linear regression analysis estimated a correlation between antioxidant activity and total flavonoids content (R2=0.77) or content of rutin (R2 = 0.98) in all investigated buckwheat cultivars [85].

Tang Yu *et al.*, 2007 have confirmed also that quantity of rutin in the leaves, stems, inflorescences and seeds of tartary buckwheat was higher than that in *F. cymosum* and *F. esculentum*. The content of rutin in the plant parts of *F. tatricum, F.esculentum* and *F.cymosum* species was higher with the order of inflorescences > leaves> seeds> stems> roots. In *F.tataricum* the level of rutin was higher about 3.2 times in the inflorescences, about 3.1 times in the stems, and near 65 times in the seeds compared to *F. esculentum* [86]. The content of rutin was different between cultivars of *F.esculentum* and *F.tataricum* and not depended from hull-on or hull-free kinds of cultivars. For example, in the germinated seeds of cultivar Hokkai T9 (*F. tataricum*) rutin content was 51-times higher than in hull-free Kitawase (*F. esculentum*). The content of rutin at 49-times was higher in non-germinated seeds of cultivar Hokkai T9 (*F. tataricum*) than in hull-on Kitawase (*F. esculentum*) seeds. The enzymic glycosylation of quercetin to quercetin 3-rutinoside (rutin) during seed germination process in tartary buckwheat sprouts is less active than in common buckwheat sprouts [87, 88]. Fabjan *et al.* (2003) have showed the rutin content in tartary buckwheat seeds (0.8–1.7% DW) to be greater than that in common buckwheat seeds (0.01% DW) [89]. An interesting fact was that rutin content in seeds colored differently was higher with the order of dark gray>black>brown. Rutin content in seeds shaped differently was higher with the order of slender> notched> round. At the same time the rutin content in plant parts of cultivated strains was higher than in those of wild strains [86].

At the same time the literature data analysis presented in (Table **3**) shows that highest content of rutin was found in seeds of *F. cymosum*. Inflorescences of *F. esculentum* had the highest content of rutin. It is important to note that the place of growth and the cultivar included in the experiment can also affect the content of rutin for each buckwheat species. Buckwheat leaves are also a promising source of rutin. The distribution of such antioxidants as vitamin E, squalene, rutin, and epicatechin within buckwheat plants and changes in their content during the vegetation season, were estimated by HPLC and GC-MS analyses. In all parts of the buckwheat plant the main component of vitamin E was $\alpha$-tocopherol. The epicatechin and squalene were also identified in all parts of the buckwheat plants. As an antioxidant source the most suitable parts of buckwheat plants for consumption in human

**Table 3. Rutin content in the vegetative organs of buckwheat species from the full-bloom stage and seeds (Mean of percent dry weight).**

| Species | Stem | Leaves | Inflorescences | Seeds | |
|---|---|---|---|---|---|
| ***F. esculentum*** | 0.9 | 6.46 | 8.9 | 0.022 | *Sytar et al., 2014, Jiang et al. 2007, Tang et al., 2007* |
| ***F. tataricum*** | 0.85 | 4.95 | 5.45 | 1.32 | *Sytar et al., 2014, Jiang et al. 2007, Tang et al., 2007* |
| ***F. homotropicum*** | * | 1.12 | * | 0.101 | *Jiang et al. 2007, Kim et al., 2002* |
| ***F. cymosum*** | 1.1 | 2.5 | 6.4 | 1.85 | *Sytar et al., 2014, Park et al., 2004* |
| ***F. giganteum*** | 1.0 | 2.8 | 6.6 | * | *Sytar et al., 2014* |
| ***F. gracilipes*** | * | * | * | 0.78 | *Tang et al., 2007* |
| ***F. urophyllum*** | * | * | * | 1.06 | *Tang et al., 2007* |

diet can be leaves and inflorescences at the phase of full flowering because the high amounts of epicatechin and rutin. The content of $\alpha$-tocopherol correlates positively with solar radiation period, drought and temperature. Furthermore exists differences among the varieties of buckwheat regarding studied antioxidants contents, especially in the contents of rutin and squalene [90].

The *F. cymosum* complex is a group of wild perennial buckwheats which includes the diploid species *F. megaspartanium* Q. F. Chen and *F. pilus* Q. F. Chen as well as the allotetraploid species *F. cymosum* (Trev.) Meisn. The flavonoid content in leaves and inflorescences of the accessions of the *F. cymosum* complex native to Guizhou, Yunnan, Sichuan, Hunan, Hubei, and Tibet has been studied by means of spectrophotometry and high-performance liquid chromatography. Among different species, accessions and plants found significant differences of flavonoid content. The leaves of *F. megaspartanium* has average flavonoid content higher than leaves of *F. cymosum* and of *F. pilus*. The average flavonoid content of inflorescences of *F. megaspartanium* is higher than that of *F. pilus*. The content of flavonoids in inflorescences was significantly higher than that in leaves, and that they have positive relationships to each other. There is a significant difference in rutin content between leaves and inflorescences, but there is no significant relationship to each other. There is also no significant relationship between flavonoid and rutin contents in the leaves, but there is a significant positive correlation between flavonoid and rutin contents in the inflorescences [91].

## 8. BUCKWHEAT AS A SOURCE OF CHLOROGENIC ACID AND OTHER PHENOLIC ACIDS

Chlorogenic acid is a naturally occurring hydroxycinnamic acid. It is an important biosynthetic intermediate [92]. The polyphenolic caffeic acid and cyclitol (-)-quinic acid are esters in biosynthesis of chlorogenic acid [93]. Chlorogenic acid known as potent functional inhibitor of the microsomal glucose-6-phosphate translocase (G6PT) which possess cancer chemopreventive properties. It is also important cinnamic acid derivative for biosynthesis of other compounds [97, 98]. It is also a promising precursor compound for the development of drugs against AIDS virus HIV [99].

A main known source of chlorogenic acid in the human diet is coffee. Other nutritional sources of chlorogenic acid include berries, aubergines, apples, pears and artichokes [94]. It is also one of the phenols found in black tea [95], in bamboo *Phyllostachys edulis* [95], and in buckwheat plants [96], as well as in many other plants.

A high content of chlorogenic acid can be found in buckwheat seedlings [97] In buckwheat, chlorogenic acid concentration is affected by different Ni concentrations [63] and it os high in the hairy root culture of buckwheat plants [56]. In China, buckwheat tea (as an organic product) which is made using buckwheat grains, is used to prevent hypertension, hyperglycemia and hyperlipidemia. Making use of buckwheat inflorescences in organic tea is a new way of promoting buckwheat plants [100] and could be developed also in the EU market. This in turn could create a new use for buckwheat as an additive for the production of functional food.

The different biological capacities of phenolic compounds, which includes UV protection, antimicrobial activity, insect resistance and pollen tube growth are important for the plant [101, 102]. The phenolic acids such as *p*-coumaric and transcinnamic acids are precursors for more complex compounds including flavonoids, anthocyanins, tannins and lignins [102]. The derivatives of trolox, caffeic acid and rosmarinic acid which are natural phenolic acids with recognized antioxidant capacities. These phenolic acids derivatives have been conjugated with choline to account for the recognition by acetylcholinesterase. The molecular modeling studies found that these synthesized hybrid compounds have a good antioxidant properties, also acetylcholinesterase inhibitory capacity and effects on human neuroblastoma cells [103].

As a cultivar-distinguishing factor total phenolic content might be useful for all the plant materials, but it can be distinguishing factor for only some buckwheat varieties. For example, some varieties and cultivars were best presented by the syringic acid. The revers proportions of syringic and vanillic acids to the total phenolics content has been observed. A positive correlation between ferulic and syringic acid was estimated. Furthermore, significant correlation between ferulic and vanilic acid and content of protein in plant material was noted [104].

Treatment of buckwheat (*F.esculentum*) seeds with 2% of CCC resulted in increased total phenolics content in the leaves, stems and inflorescences. On analyzing the different parts of buckwheat plants, 9 different phenolic acids – vanilic acid, ferulic acid, chlorogenic acid, *trans*-ferulic acid, salycilic acid, cinamic acid, *p*-anisic acid, *p*-coumaric acid, methoxycinamic acid and catechins were identified. The levels of the identified phenolic acids varied not only significantly among the plant organs but also between the early stages of the vegetation period. The same changes as in the contents of chlorogenic acid, ferulic acid, trans-ferulic acid were found for the content of salycilic acid. The content of these phenolic acids significantly increased under the effect of 2% CCC treatment at phase formation of buds and in the stems, leaves and inflorescences at phase beginning of flowering. The content of catechins as potential buckwheat antioxidants increased at the early stages of the vegetation period after treatment with 2% CCC. It is possible that effect of CCC on the phenolic composition can be a result of the different mechanisms of CCC uptake, transformation in the seedlings of buckwheat [55].

The comparative analysis of total phenolic and phenolic acid composition together with parameters of antioxidant activities was studied in the inflorescences of three varieties of buckwheat (*F. esculentum*, *F. esculentum*, green-flower form and *F. tataricum*). The antioxidant activity of extracts of these buckwheat varieties has been found to be high and at the same time extracts of inflorescences of green flower buckwheat have been characterized by the highest total phenolic content. Eight phenolic acids (ferulic acid, vanillic acid, chlorogenic acid, p-coumaric acid, trans-ferulic acid, p-anisic acid, salicylic acid and methoxycinnamic acid) were found in the investigated buckwheat inflorescences with HPLC analysis. Inflorescences of *F. esculentum*, green-flower form have a high content of chlorogenic acid and p-anisic acid. Among the investigated buckwheat inflorescences, the highest content of vanillic acid, transferulic acid, chlorogenic acid and *p*-anisic acid were detected in *F. tataricum* and *F. esculentum* which have been found to contain the highest content of salicylic acid and methoxycinnamic acid) [105].

It is confirmed that more influence on the antioxidant capacities and individual phenolics will make growing conditions and the interaction between variety and environment than just parameter of selection some plant variety or cultivar [106]. For example, higher altitudes as environmental factor may increase the level of some phenolic acids and rutin in tartary buckwheat. Experiment on the antioxidant activity and phenolic content of tartary buckwheat of different growth locations has confirmed this suggestion. Increasing content of ferulic, 4-hydroxybenzoic, caffeic, vanillic, syringic and protocatechuic acids were detected in the grains of *F. tataricum* [107]. At the same time content of free flavonoids is higher than content of bound flavonoids in the samples of tartary buckwheat what is different from the flavonoid distribution in common buckwheat [108], rice, wheat, oat and corn [109], where content of bound flavonoids was higher than the free flavonoids.

## 9. FAGOPYRIN

Fagopyrin is a naphthodianthrone which has anticarcinogenic effect. For the first time fagopyrin was isolated from the blossoms of the red flowering variety of *F. esculentum* in 1943. The fagopyrin structure is mostly the same to hypericin from St. John's wort (*Hypericum perforatum* L.). Both hypericin and fagopyrin have a light-dependent activity. Such capacity makes them used for medicine in photodynamic therapy [110].

Samel and Witte (1994) suggested that fagopyrin is a potent inhibitor of protein tyrosine kinase (PTK) which can control proliferative process of cancer cells and therefore possesses a high anticarcinogenic effect [111]. Nowadays, there exist not many data about the accumulation of fagopyrin in some part of buckwheat [112, 113]. In the inflorescences of common buckwheat was found highest content of fagopyrin (0.08% FW) and in the leaves a smaller amount (0.05% FW) [60]. Ozbolt *et al.*, 2008 estimated that leaves of common buckwheat (*F. esculentum*) have about a 2-3 times higher fagopyrin content compared to the stems [114].

The rutin, quercetin and fagopyrin content of different plant part samples from 10 different samples of common (*F. esculentum*), 2 samples of tartary (*F. tataricum*), and 5 samples of cymosum buckwheat (*F. cymosum*) were detected via HPLC analysis [115]. The experiment included different parts of the buckwheat plant for each cultivar of experimental species but did not permit the comparison of the fagopyrin content between experimental cultivars. For example the leaves of the *F. cymosum* cultivar from China had a content of fagopyrin 936 $\mu g\ g^{-1}$ of product, the leaves of the *F. cymosum* cultivar from Slovenia had 947 $\mu g\ g^{-1}$ of product but the leaves and thin stems of the cultivar from Korea had 1930 $\mu g\ g^{-1}$ of product which was 2 times highercompared to the fagopyrin content in the leaves of the cultivar from China and the cultivar from Slovenia. In this case it is important to know for comparative purposes which was the main source of the fagopyrin content in the cultivar from Korea - the leaves or the thin stems. *F. cymosum* flowers cultivated in Slovenia have the highest content of fagopyrin of all of the investigated samples. The leaves from common buckwheat and from tea bags got a high contents of fagopyrin (322–2300 $\mu g\ g^{-1}$) while even higher levels were found in the flowers. Buckwheat tea bags with leaves which were produced in Germany and Austria had a higher content of fagopyrin compared to the tea bags produced in the Czech Republic, suggesting that cultivation conditions can affect the fagopyrin content in buckwheat leaves. *F. tataricum* leaves and seeds, which growth in Sichuan, Xichan region, China had the lowest content of fagopyrin among the investigated species. Two cymosum samples had a high proportion of fagopyrin relative to rutin (~200 $\mu g$ fagopyrin $mg^{-1}$ rutin), whereas this proportion was lower (15–90 $\mu g$ fagopyrin $mg^{-1}$ rutin) in other samples [115]. This provides evidence of a correlation between content of rutin and antioxidant activity. In 2005 Hinneburg and Neuber developed methodology to obtain the buckwheat extract with antioxidants such as fagopyrin, rutin and chlorogenic acid. It was studied effect of three extraction parameters - extraction time, concentration of ethanol and temperature [116].

Investigation of the impact of different growing conditions and the development phase on the phenolics and fagopyrin contents in the seedlings of buckwheat has found that fagopyrin and flavonoids were located almost exclusively in cotyledons of buckwheat. Based on a comparison to hypericin toxicity, the recommendable intake of buckwheat sprouts was estimated to be less than 40 g per day as optimal for fagopyrin content [117].

UV-B radiation is a factor which stimulate flavonoids synthesis in buckwheat, however highly intensive UV-B radiation may have harmful effect on plants which will decrease flavonoids concentration [118]. It was found that tolerance of plants to intensive UV-B radiation can be increased by selenium [119]. A detailed investigation by Nowak, Kaklewski, and Ligocki (2004) suggested that applied selenium has effect of stimulation on the oxidoreductase enzymes activity in plants [120].

## PERSPECTIVE AND CONCLUSION

It is generally accepted that not only the seeds, but also the other parts of buckwheat plants are rich in compounds with a high biological value. The seeds used for food contain proteins which have high lysine levels and specific amino acid content, giving them a high nutritional value. The absence of gluten in buckwheat flour determines its potential use in gluten-free diets but quality of protein and the antioxidants composition of different varieties of buckwheat can vary - this is important to know for flour production. The other valuable bioactive compounds in seeds are resistant starch, dietary fibre, rutin and other polyphenols, which have healthy effects. The vegetative mass of buckwheat plants has a higher content of biologically active compounds such as phytosterols, flavonoids, fagopyrins, phenolic acids, lignans and vitamins. The high content of these compounds should become the major goal in the future selection of genetic resources and breeding aimed at nutritional effects. Based on recent knowledge, the most valuable sources of fagopyrin, orientin, rutin, isovitexin, quercetin are the vegetative mass of common buckwheat (*F.esculentum*). At the same time the seeds of *F. cymosum* and *F.tataricum* have the highest rutin content among the investigated buckwheat species. Other important bioactive compounds are phenolic acids which are abundant mainly in the leaves and inflorescences of buckwheat plants but their content varies depending on genotype. A detailed experimental analysis of different buckwheat species regarding phenolic acids composition is lacking.

Apart from the genotypic variation of the total content of bioactive compounds in buckwheat the environment plays a crucial role. The characterization of existing buckwheat varieties and the introduction of buckwheat-based products from elite varieties into the modern food chain are needed to fill the current gap. In this review, we have presented the high diversity of bioactive compounds in buckwheat varieties, which could be broadly exploited for food and medicinal use.

## LIST OF ABBREVIATIONS

CCC = Chlorcholinechloride

TBP = Tartary buckwheat protein product

BWP = Common buckwheat protein product

GAE = Gallic acid equivalents

AAC = Antioxidant activity coefficient

DPPH = 2,2-diphenyl- $\beta$ -picrylhydrazyl assay

AA = Antioxidant activity

DAS = Days after sowing

SOD = Superoxide dismutase

BHT = Butylated hydroxytoluene

AIDS = Acquired immune deficiency syndrome

## CONFLICT OF INTEREST

The author(s) confirm that this article content has no conflict of interest.

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