A Review of Nutritional and Nutraceutical Components of Buckwheat

Roman Przybylski • Eliza Gruczyńska

ABSTRACT

Buckwheat, frequently classified as a pseudocereal, is one of the minor crops cultivated by ethnic groups in developed and developing countries which is an integral part of their diet and culture. When views on food components changed from only a source of basic nutrients into a resource of health promoting compounds, suddenly buckwheat was recognized as a food ingredient offering a variety of unique nutrients and nutraceuticals. The importance of buckwheat components is currently reflected by the large volume of research on nutritional and health aspects of this crop. In this paper we appraise recent findings in the macronutrients, nutraceuticals and unique components with astonishing properties present in buckwheat seed and plant.

Keywords: anthocyanins, chiro-inositol, diabetes, dietary fiber, fagopyritols, flavonoids, lignans, macronutrients, minerals, resistant starch

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INTRODUCTION

Buckwheat has been an important part of the human diet for centuries and it was introduced in Canada and the United States by European and Asian immigrants. Buckwheat has been grown for centuries in Eastern Europe and Asia but originated in the mountainous regions of southern China. There are many species of buckwheat; nevertheless only a few have agricultural significance: Fagopyrum esculentum Moench; Fagopyrum tataricum Gaertner; Fagopyrum giganteum Krotov; Fagopyrum cymosum Meissn.; Fago- pyrum suffruticosum Fr. Schmidt; and Fagopyrum ciliatum Jaegt. Among these species only F. esculentum (common buckwheat) and F. tataricum (tartary buckwheat) are cultivated for human consumption (Ikeda 2002).

Common buckwheat has been a crop of secondary importance in many developed countries and yet it has persisted through centuries of civilization in the agriculture of nearly every country where cereals were cultivated. Buckwheat is a broad-leaved herbaceous annual, which belongs to the Polygonaceae family. This family includes rhubarb and sorrel. Buckwheat seed structurally and chemically resembles cereal grains and it is usually handled and classified with cereals (Table 1). Buckwheat seed is a fruit, strictly an achene (Campbell 1997). The seed, covered by a hull (pericarp), has a triangular shape and its flour can be white, pink or yellow. The exact shape, size, and colour of the seed may vary depending on the species and variety. The hull may be glossy or dull and brown, black or gray in colour. The dehulled buckwheat seed is called the groat and resembles the cereal kernel in its gross chemical composition and structure (Table 1).

The first layer of the groat is a one-cell thick, light green coloured testa (seed coat). Under the testa, surrounding the starchy endosperm is a one-cell aleurone layer. The inner portion of the groat consists of a spermadern and an
Table 1 Proximate composition of buckwheat and other food grains (%).

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Common</th>
<th>Buckwheat</th>
<th>Wheat</th>
<th>Rye</th>
<th>Barley</th>
<th>Corn</th>
<th>Oat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>9.8</td>
<td>10.2</td>
<td>10.9</td>
<td>10.9</td>
<td>9.4</td>
<td>10.4</td>
<td>8.2</td>
</tr>
<tr>
<td>Energy</td>
<td>343</td>
<td>328</td>
<td>339</td>
<td>335</td>
<td>354</td>
<td>365</td>
<td>389</td>
</tr>
<tr>
<td>Protein</td>
<td>13.3</td>
<td>10.3</td>
<td>13.7</td>
<td>14.8</td>
<td>12.5</td>
<td>9.4</td>
<td>16.9</td>
</tr>
<tr>
<td>Lipids</td>
<td>3.4</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.3</td>
<td>4.7</td>
<td>6.9</td>
</tr>
<tr>
<td>Ash</td>
<td>2.1</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>2.3</td>
<td>1.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>71.5</td>
<td>74.3</td>
<td>71.1</td>
<td>69.8</td>
<td>73.5</td>
<td>74.3</td>
<td>66.3</td>
</tr>
<tr>
<td>Fiber</td>
<td>10.0</td>
<td>6.3</td>
<td>11.2</td>
<td>14.6</td>
<td>17.3</td>
<td>7.3</td>
<td>10.7</td>
</tr>
<tr>
<td>Protein in flour</td>
<td>19.0</td>
<td>18.9</td>
<td>10.3</td>
<td>14.3</td>
<td>10.5</td>
<td>6.9</td>
<td>14.7</td>
</tr>
</tbody>
</table>


endosperm; a large embryo and two cotyledons extending in the shape of letter “S” are embedded in the center of the endosperm. The endosperm fraction and the embryo represent 74 and 26% of the mature seed (groat), respectively.

Buckwheat seed tastes harsh for F. esculentum, and slight bitter for F. tataricum. The bitter components in F. tataricum can be removed by isoelectric precipitation (Kawakami 1994).

Buckwheat has gained an excellent reputation as a nutritious ingredient in the human diet (Kreft et al. 1998). Its renewed popularity stems from its many proven and much sought after beneficial nutraceutical components. The unique bioactive components in buckwheat seeds provide human health benefits akin to flavonoids, fagopyritols, phytosterols, and the thiamin-binding proteins. Buckwheat should be used more often in formulation of functional and nutraceutical foods to exploit its positive medical benefits.

MACRONUTRIENTS

Protein

The protein content in common and tertiary buckwheat varies from 7 to 21%, depending on the cultivar and environmental conditions during growth (Table 1). Currently grown cultivars yield seeds with 11-15% protein in a whole seed (Campbell 1997). The proteins in buckwheat are the best known source of high biological value protein in the plant kingdom, having 92.3% of the value of nonfat milk solids and 81.4% of the whole egg solids (Pomeranz and Robbins 1972). Buckwheat flour has the highest protein content among all cereals (Table 1). Flour produced from Canadian varieties of buckwheat verified high protein content and elevated contribution of fiber and ash (Table 2). The composition of essential amino acids in buckwheat protein is close to egg protein, the latter is used as reference (Table 3). Compared to other cereals, the amino acids in buckwheat proteins are well balanced and rich in lysine, methionine, histidine and tryptophan which are generally recognized as the limiting amino acids in wheat and barley (Pomeranz and Robbins 1972). Buckwheat flour protein has a score of biological value (BV) of 93, which is calculated from amino acid composition. BV is very close to egg protein, and much higher than for any other cereals (Table 3). Comparison of amino acid composition and amount of protein in different buckwheat seed parts and different types of buckwheat indicates that the germ is the main place where protein is concentrated. Amino acid compositions among different buckwheat seed parts and products show very small differences (Table 4).

Buckwheat protein consists of 18.2% albumin, 43.3% globulin, 0.8% prolamin, 22.7% glutelin, and 5.0% other nitrogen containing components (Javornik and Kreft 1984; Ikeda et al. 1991b; Ikeda and Asami 2000). Immunological studies showed little cross-reactivity between buckwheat proteins and wheat prolamins, the main culprit for celiac disease (Skerritt 1986; Friis 1988). In the absence of gluten type proteins, buckwheat flour can be an important ingredient in gluten-free diet for people suffering from the celiac disease. Since buckwheat groat and flour are rich in many nutrients and nutraceuticals this pseudocereal can also be an excellent ingredient in bread and cereal formulation, improving the nutritional value of these products (Li and Zhang 2001).

Despite the balanced amino acid composition, buckwheat contains anti-nutritional components, such as pro-

endosperm; a large embryo and two cotyledons extending in the shape of letter “S” are embedded in the center of the endosperm. The endosperm fraction and the embryo represent 74 and 26% of the mature seed (groat), respectively.

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Despite the balanced amino acid composition, buckwheat contains anti-nutritional components, such as pro-
trypsin inhibitors, phytic acid and tannins (Farrell 1978; Javornik et al. 1979; Ikeda et al. 1981; Ikeda et al. 1986). These factors lower buckwheat protein digestibility in humans and in animals although it is comparable with other cereals (Table 3). Buckwheat trypsin inhibitors are resistant to thermal processing and treatment with acids (Ikeda et al. 1993, 2002). On the other hand, given that obesity is one of the prominent health problems in North America and the World, the low digestibility of buckwheat protein may not necessarily be a negative property. “Resistant proteins”, resistant to enzymatic digestion in digestive tract, such as those in buckwheat, can also beneficially affect blood cholesterol levels by limiting its absorption (Kayashita et al. 1997). Buckwheat trypsin inhibitors (BPI) were sufficiently digested, absorbed and provided adequate amount of amino acids required for growing organisms and people with digestive tract problems, since the consumption of insufficiently cooked buckwheat products can lead to diarrhea (Ikeda et al. 1993, 2002). On the other hand, given that obesity is one of the prominent health problems in North America and the number of obese people is increasing in different parts of the World, the low digestibility of buckwheat protein may not necessarily be a negative property. “Resistant proteins”, resistant to enzymatic digestion in digestive tract, such as those in buckwheat, can also beneficially affect blood cholesterol levels by limiting its absorption (Kayashita et al. 1996; Iwami 1998; Tomotake et al. 2000, 2001; Metzger et al 2007). Kayashita et al. (1995a) reported that both plasma and hepatic cholesterol levels were significantly lowered in rats fed a diet containing buckwheat protein extract compared to soybean protein or casein diet. Metzger et al. (2007) reported that 0.1 to 0.4% of buckwheat proteins added to cell culture reduced cholesterol solubility by 40%; in the presence of buckwheat protein cholesterol uptake was reduced by 36 and 47% when compared to bovine albumin and casein, respectively. Carroll and Hamilton (1975) reported that the ratios of lysine to arginine and methionine to glycine are the main factors determining the cholesterol lowering properties of proteins, because these amino acids are involved in regulation of the hepatic low density lipoprotein (LDL) formation. In buckwheat, the ratios of these amino acids are lower than in the other plant proteins; nutritional studies have shown that buckwheat proteins have the highest cholesterol lowering properties among plant proteins (Huff and Carroll 1980). Moreover, high content of methionine in the diet negatively affects cholesterol level in serum, because methionine is a part of homocysteine catalysis which affects homocystine transferase (Carroll and Kurowska 1995).

Kayashita et al. (1997) reported that buckwheat protein isolate (BPI) was more efficient in cholesterol lowering than soybean protein isolate. The authors also showed that rats fed with BPI experienced the same body growth as casein-fed reference rats, suggesting that buckwheat proteins were sufficiently digested, absorbed and provided adequate amount of amino acids required for growing organisms. BPI was shown to be more effective in lowering LDL and very low density lipoprotein (VLDL), than any other plant and animal proteins (Sueki et al. 1990). BPI can

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Barley</th>
<th>Wheat</th>
<th>Corn</th>
<th>Buckwheat</th>
<th>Egg*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lysine</td>
<td>3.7</td>
<td>2.5</td>
<td>2.8</td>
<td>5.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Methionine</td>
<td>1.8</td>
<td>1.8</td>
<td>2.4</td>
<td>2.3</td>
<td>3.8</td>
</tr>
<tr>
<td>Cysteine</td>
<td>2.3</td>
<td>1.8</td>
<td>2.2</td>
<td>2.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Threonine</td>
<td>3.6</td>
<td>2.8</td>
<td>3.9</td>
<td>3.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Valine</td>
<td>5.3</td>
<td>4.5</td>
<td>5.0</td>
<td>4.7</td>
<td>7.2</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>3.7</td>
<td>3.4</td>
<td>3.8</td>
<td>3.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Leucine</td>
<td>7.1</td>
<td>6.8</td>
<td>10.5</td>
<td>6.1</td>
<td>8.4</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>4.9</td>
<td>4.4</td>
<td>4.5</td>
<td>4.3</td>
<td>6.1</td>
</tr>
<tr>
<td>Histidine</td>
<td>2.2</td>
<td>2.3</td>
<td>2.4</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>1.1</td>
<td>1.0</td>
<td>0.6</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>TD (%)</td>
<td>84.3</td>
<td>92.4</td>
<td>93.2</td>
<td>79.9</td>
<td>99</td>
</tr>
<tr>
<td>BV (%)</td>
<td>76.3</td>
<td>62.5</td>
<td>64.3</td>
<td>93.1</td>
<td>100</td>
</tr>
<tr>
<td>NPU (%)</td>
<td>64.3</td>
<td>57.8</td>
<td>59.9</td>
<td>74.4</td>
<td>94</td>
</tr>
<tr>
<td>UP (%)</td>
<td>73.3</td>
<td>80.0</td>
<td>77.6</td>
<td>62.7</td>
<td>12.2</td>
</tr>
</tbody>
</table>


| Amino acid composition of common and tartary buckwheat products (g/100 g protein). |
|-----------------------------------------------|----------|------|------|------|------|
| Amino acid                  | Common   | Bran | Flour | Tary  | Bran | Flour |
| Alanine                     | 4.4      | 4.6  | 4.3  | 4.7  | 4.5  | 3.6  |
| Arginine                    | 10.5     | 9.9  | 11.0 | 9.6  | 9.7  | 11.9 |
| Aspartic acid               | 10.3     | 10.2 | 10.1 | 10.3 | 11.3 | 10.9 |
| Cysteine                    | 2.1      | 2.7  | 2.6  | 2.7  | 1.6  | 2.2  |
| Glutamic acid               | 18.8     | 17.6 | 18.4 | 17.1 | 18.6 | 19.3 |
| Glycine                     | 6.1      | 6.1  | 6.0  | 5.9  | 6.3  | 6.0  |
| Histidine                   | 2.7      | 2.5  | 2.7  | 2.6  | 2.7  | 2.6  |
| Isoleucine                  | 3.8      | 3.9  | 4.0  | 4.2  | 3.8  | 3.5  |
| Leucine                     | 6.5      | 6.9  | 6.4  | 7.1  | 6.4  | 5.8  |
| Lysine                      | 5.5      | 5.8  | 5.9  | 6.2  | 6.1  | 5.6  |
| Methionine                  | 1.1      | 1.4  | 1.3  | 1.4  | 2.5  | 2.0  |
| Phenylalanine               | 4.5      | 4.6  | 4.5  | 4.7  | 4.8  | 4.7  |
| Proline                     | 4.0      | 4.5  | 4.1  | 4.5  | 3.8  | 3.8  |
| Serine                      | 3.2      | 5.0  | 5.2  | 5.2  | 4.7  | 5.0  |
| Threonine                   | 3.6      | 3.7  | 3.5  | 3.7  | 3.9  | 3.7  |
| Tyrosine                    | 2.7      | 2.7  | 2.9  | 2.9  | 2.1  | 2.8  |
| Protein (% DM)              | 4.3      | 19.0 | 4.1  | 18.9 | 13.8 | 55.9 |

Source: Adapted from Bonafaccia et al. (2003)

A – Pomeranz and Robbins (1972)
also be used as a functional food ingredient to treat hypertension, obesity, as well as constipation (Kayashita et al. 1995b). As an example of unusual specific bioactivity of buckwheat protein, a patent has been issued in Japan to produce a buckwheat protein isolate which has lowering activity of angiotensin converting enzyme (ACE) and directly controlling hypertension (Koyama et al. 1993).

Tomatoke et al. (2001) reported that high fat diets and obesity delay the start of the gut's backup system when buckwheat protein hydrolyzate was included in the diet. This protective effect was much weaker for soybean protein hydrolyzate. Mitsunaga et al. (1986) first reported the presence of thiamine-binding protein (TBP) in buckwheat seeds. Buckwheat TBP has a 1:1 binding stoichiometry with thiamin, offering protection for larger amounts of this vitamin (Mitsunaga et al. 1986). After ingestion, this complex is digested by proteases, and thiamine is released and absorbed. The protein moiety in the TBP complex improves the stability of thiamine during food storage, processing and enhances its bioavailability particularly for people who suffer thiamin deficiency and cannot store it (Watanabe et al. 1999).

Several epidemiological studies have shown that buckwheat proteins act like a dietary fibre and can retard mammary carcinogenesis (Kayashita et al. 1999) as well suppress the development of colon cancer (Cassidy et al. 1994; Lipkin et al. 1999). Absorption and blocking carcinogenic initiators in the colon may form a mechanism for anti-carcinogenic activity of buckwheat protein. Additionally, difficult to digest proteins may interact with resistant starch and form a prebiotic utilized by colon bacteria to produce short chain fatty acids that protect tissues and positively affect colon physiology (Scheppach et al. 1992; Morita et al. 1998). Among the unusual properties of buckwheat protein, evidence showing the potential to reduce the incidence of colonic adenocarcinomas by 47%. Further these proteins provide colon protection by reducing the proliferation and expression of carcinoma cells in colonic epithelium (Liu et al. 2001).

Carbohydrates

Starch is the major carbohydrate in buckwheat, and its amount in Canadian varieties of buckwheat may vary from 67 to 75% (Campbell 1997). The amylose content in buckwheat starch granules varies from 15 to 52% and its degree of polymerization fluctuates from 12 to 45 glucose units (Mazza 1993). The composition of starch isolated from different varieties of buckwheat grown in several countries in Table 5 is presented. In Polish varieties a significant amount of resistant starch were observed as components of buckwheat starch. Roasting of buckwheat seeds, which is used often before groats cooking, causes an increase in contribution of protein in starch and lowering the total amount of starch (Table 5). During roasting non-enzymatic browning is happening and proteins are bonded to carbohydrates (Christa et al. 2009). Raw buckwheat starch contains 17.1 to 26.1% of amylose and it contribution is dependent on variety and growing region, whereas amylopectin contents of majority of starch granules (Table 5). Data about starch composition for other varieties and growing regions are limited to contribution of amylose and amylopectin (Praznik et al. 1999; Qian et al. 1999). Buckwheat starch granules are polygonal or round in shape with a diameter ranging from 2 to 12 μm with flat areas due to the tide packing in the endosperm. The majority of granules are 2-6 μm in diameter and growing size defines the unusual properties and performance of buckwheat products during processing (Soral-Smieta et al. 1984; Acquistucci and Fornal 1997; Campbell 1997).

Lipids

In the whole buckwheat grain the total lipids content range from 1.5 to 4.8% and 1.2 to 4.3% for common and tartary buckwheat, respectively (Table 1). The content of lipids varies by seed part and is usually in: the embryo 9.6-19.7%, the endosperm 2.0-3.0% and the hulls 0.4-0.7% (Campbell 1997). Buckwheat oil contains 16-25% of saturated and 74-79% of unsaturated fatty acids (Table 6). Among these fatty acids palmitic, oleic and linoleic are dominant with contribution of 15-20, 30-45 and 31-41%, respectively (Campbell 1997). Other typical fatty acids for plant lipids were also detected although their contribution was below 10% (Table 6). Sterols, the main source of signalling and metabolic components, are found in the buckwheat embryo and endosperm at levels of 2.1 and 0.55 ppm, respectively (Campbell 1997). Among the unusual properties of buckwheat protein, evidence showing the potential to reduce the incidence of colonic adenocarcinomas by 47%. Further these proteins provide colon protection by reducing the proliferation and expression of carcinoma cells in colonic epithelium (Liu et al. 2001).

<table>
<thead>
<tr>
<th>Component</th>
<th>Native</th>
<th>Roasted</th>
<th>Seed¹</th>
<th>Different varieties²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>90.2</td>
<td>82.5</td>
<td>95.8</td>
<td></td>
</tr>
<tr>
<td>Amylose</td>
<td>17.1</td>
<td>12.4</td>
<td>24.0</td>
<td>21.3 - 26.4</td>
</tr>
<tr>
<td>Amylopectin</td>
<td>73.1</td>
<td>70.1</td>
<td>76.0</td>
<td>78.7 - 73.6</td>
</tr>
<tr>
<td>Resistant starch</td>
<td>5.1</td>
<td>5.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dietary fiber</td>
<td>5.6</td>
<td>4.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proteins</td>
<td>11.1</td>
<td>14.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Adapted from Praznik et al. (1999)
2 Starch from different buckwheat varieties and growing area. Adapted from Qian et al. (1999)

Dietary fiber

Dietary fiber is a part of a plant or analogous carbohydrates that is resistant to digestion and absorption in the human small intestine but is partially or completely fermented by microflora in the large intestine (AACC Report 2001). The amount of total dietary fiber (TDF) in buckwheat may be affected by both variety and environmental factors during growth. The major components of TDF are: cellulose, non-starch polysaccharides, resistant starch and lignins. These components are concentrated in the cell walls of the starchy endosperm, aleurone, seed coat, and hull. The content of TDF in groats may range from 5.0 to 11.0% (Yoshi and Rana 1995; Zheng et al. 1998; Steadman et al. 2001; Izydorczyk et al. 2004). Smaller groats have less endosperm and, therefore, relatively more seed coat, resulting in more dietary fiber. Bran fractions obtained by milling buckwheat were especially enriched in dietary fiber (15-22%) because the outer layer covering the seeds contains non-starch polysaccharides (Table 2). Hatcher et al. (2008) reported that dark flours from cross- and self-pollinating Canadian common buckwheat were richer in dietary fiber (15.2-22.0%)
than white flours containing mostly starch. However, the majority of TDF in dark flours was insoluble, whereas the dietary fiber associated with white flours were mainly water soluble (Hatcher et al. 2008). The amount of fiber in buckwheat flour is affected by the milling process and the number of fractions produced. The fiber is distributed among fractions and the amount in each fraction can be 1.7-8.5% as reported by Steadman et al. (2001).

From a functional point of view TDF is classified into soluble and insoluble dietary fiber. The insoluble part of dietary fiber (IDF) decreases transit time through the digestive tract and at the same time increases fecal mass, preventing or ameliorating constipation. Soluble dietary fiber (SDF), due to its absorption of large amounts of water and formation of high viscosity solution, slows gastric emptying, reduces and preventing absorption of nutrients. Among nutrients which are the most affected by this type of fiber are glucose and cholesterol. SDF is fermented by gut microflora producing short chain fatty acids, implicated with lowered glycemic index, which in turn positively affects blood glucose level. SDF is also used as functional ingredient in the formulation of food with lowered glycemic index, which in turn positively affects blood glucose level.

**Resistant starch**

Starch is a major component of buckwheat (Table 1). Although the majority of buckwheat starch is readily digestible, a small portion (4.0-7.0%) is resistant to enzymatic hydrolysis (Christa et al. 2009). The so-called resistant starch – including physically inaccessible starch, native granular starch, retrograded starch, and chemically and thermally modified starch – is another source of dietary fiber in buckwheat and may exhibit nutritionally advantageous effects similar to those of dietary fiber (Christa and Soral – Smietana 2008). There are indications that resistant starch is similarly fermented in the large intestine as soluble fiber, and similar metabolites with positive health effects are produced (Englyst et al. 1992). The factors influencing starch availability include its botanical origin, physical properties and form of starch, the ratio of amylase to amylpectin, and its interactions with other constituents. Raw buckwheat grain may contain 33-38% of resistant starch; however cooking reduces its content three-fold (Christa and Soral- Smietana 2008). Processing of buckwheat starch or foods-containing buckwheat by autoclaving, cooling cycles, extrusion, boiling, baking, increase the amount of resistant starch (Skrabanja and Kreft 1998; Skrabanja et al. 1998a). During storage, development of the retrograded amyllose in starches may result in limited accessibility to amylases (Berry 1986). Other components may interact with starch or inhibit starch degrading enzymes and thus reduce starch digestibility (Thompson and Gabon 1987). Consumption of boiled buckwheat groats or bread with 50% of buckwheat flour lower blood glucose and insulin responses compared with white wheat bread (Skrabanja et al. 2001). Thus, buckwheat has potential to be used as functional ingredient in the formulation of food with lowered glycemic index, which in turn positively affects blood glucose level.

**Fig. 1 Chemical structure of fagopyritols from B series.** Linkage between D-chiro-inositol and galactose molecules. Adapted from Horbowicz et al. (1998).
Table 7 Composition of vitamins in buckwheat and selected food grains (unit/100 g).

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Units</th>
<th>Rye</th>
<th>Buckwheat</th>
<th>Barley</th>
<th>Corn</th>
<th>Wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin C</td>
<td>mg</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Thiamin</td>
<td>mg</td>
<td>0.32</td>
<td>0.42</td>
<td>0.65</td>
<td>0.39</td>
<td>0.51</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>mg</td>
<td>0.25</td>
<td>0.19</td>
<td>0.29</td>
<td>0.21</td>
<td>0.11</td>
</tr>
<tr>
<td>Niacin</td>
<td>mg</td>
<td>4.27</td>
<td>6.15</td>
<td>4.61</td>
<td>3.63</td>
<td>5.71</td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>mg</td>
<td>1.46</td>
<td>0.44</td>
<td>0.28</td>
<td>0.42</td>
<td>0.94</td>
</tr>
<tr>
<td>Vitamin B-6</td>
<td>mg</td>
<td>0.29</td>
<td>0.58</td>
<td>0.32</td>
<td>0.62</td>
<td>0.34</td>
</tr>
<tr>
<td>Folate</td>
<td>μg</td>
<td>60</td>
<td>54</td>
<td>19</td>
<td>19</td>
<td>43</td>
</tr>
<tr>
<td>Choline, total</td>
<td>mg</td>
<td>30.4</td>
<td>54.2</td>
<td>37.8</td>
<td>21.6</td>
<td>31.2</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>IU</td>
<td>11</td>
<td>0</td>
<td>22</td>
<td>214</td>
<td>9</td>
</tr>
<tr>
<td>Lutein + zeaxanthin</td>
<td>mg</td>
<td>0.21</td>
<td>0.22</td>
<td>0.16</td>
<td>1.36</td>
<td>0.22</td>
</tr>
<tr>
<td>Vitamin E</td>
<td>mg</td>
<td>1.3</td>
<td>0.32</td>
<td>0.57</td>
<td>0.49</td>
<td>1.01</td>
</tr>
<tr>
<td>Vitamin K</td>
<td>μg</td>
<td>5.9</td>
<td>7.0</td>
<td>2.2</td>
<td>0.3</td>
<td>1.9</td>
</tr>
</tbody>
</table>


Fagopyritols and other soluble carbohydrates

Fagopyritols are specific carbohydrates formed by joining D-chiro-inositol with galactose, where series B have 2-1 while A series 3-1 α-galactosyl bond, firstly identified in buckwheat and named after the Latin name of this crop (Fig. 1). Fagopyritols are mono-, di-, and tri-galactosyl derivatives of D-chiro-inositol that accumulate specifically in the embryo and the aleurone tissues of buckwheat. These components hold water, preventing desiccation of seed. Among plant sources, buckwheat is the richest in these carbohydrates (Horbowicz et al. 1998; Obendorf et al. 2000).

Buckwheat embryos usually have two mono-galactosyl chiro-inositol isomers (Fagopyritol B1 and Fagopyritol A1), two di-galactosyl chiro-inositol isomers (Fagopyritol B2 and Fagopyritol A2) and small amounts of tri-galactosyl chiro-inositol (Fagopyritol B3). In buckwheat embryos the amount of fagopyritol B1 [O-α-D-galactopyranosyl-(1→2)-D-chiro-inositol] was at 40% whereas sucrose accounted for 42% of all soluble carbohydrates, indicating importance of these sugars to it function and survivalability (Horbowicz et al. 1998). Other soluble carbohydrates found in buckwheat embryos include D-chiro-inositol, myo-inositol, galactitol, raffinose and stachyose. The latter two oligosaccharides contribution was below 1% of the total soluble components in buckwheat embryos (Horbowicz et al. 1998).

Bran fractions contain the highest amount of fagopyritols among all milling fractions, reflecting the high amount of embryo and aleurone tissues. It has been reported that the bran milling fractions may contain 2.6 g of fagopyritols per 100 g of dry weight, whereas dark and light buckwheat flours contain 0.7 g and 0.3 g/100 g, respectively (Steadman et al. 2000). Dark flour is formed by milling embryo, aleurone tissue and hull from buckwheat seed and it contains the highest amounts of fagopyritols and D-chiro-inositol (Table 2).

Buckwheat contains the highest amounts of fagopyritols and D-chiro-inositol could positively affect the blood glucose level and insulin activity (Ortmeyer et al. 1993; Fonteles et al. 2000). Work done at the University of Manitoba has shown that buckwheat extract was equally efficient in lowering blood glucose level and activating insulin as synthetic D-chiro-inositol (Kawa et al. 2003). Further work by this group showed that single dose of buckwheat extract can keep blood glucose level lowered by 20% for extended period of time. However, this effect was not related to the content of either D-chiro-inositol or fagopyritols, indicating that buckwheat contains other components that can replace insulin and regulate glucose level. There is also evidence that D-chiro-inositol may obstruct development of polycystic ovary (Nestler et al. 1999). The digestion of fagopyritols in the human digestive system and the amounts required for consumption to achieve beneficial effects remain unknown and necessitate further investigation.

Vitamins

Buckwheat is unique from other cereals in its content of minerals and vitamins, each is discussed separately. Buckwheat contains various vitamins with content comparable to other grains (Pomeranz 1983). However, buckwheat contains higher levels of niacin, B6 vitamin K and choline. The latter is an important component of the neurotransmitter acetylcholine and body can synthesize choline from methionine; however this amino acid is often in short supply in our diet (Clemens et al. 2009). On the other hand buckwheat does not contain vitamin A while carotenoids such as lutein and zeaxanthin are present in similar amounts as in other cereals (Table 7).

Minerals

The ash content of buckwheat varies from 2.0-2.2%, depending upon the variety and conditions during growth (Campbell 1997). Different parts of the buckwheat seed contains different amounts of minerals; hull, aleurone tissues and embryo are the main locations of the most of the minerals (Tables 2, 8) (Sokolov et al. 1981; Ikeda et al. 1995). Buckwheat seeds are a good source of many essential minerals; whereas the amounts are similar to other cereals (Table 8).

The mineral content in buckwheat seeds and their morphological fractions reach: 2.0-2.5% in the whole grains, 1.8-2.0% in the kernel, 2.2-3.5% in the dehulled grains, 0.8-0.9% in flour, and 3.4-4.2% in the hulls (Li and Zhang 2001). In comparison with rice, wheat, corn flour, buckwheat contains the highest amounts of zinc, copper, and manganese. Trace elements, e.g. selenium or chromium, are also present in buckwheat, however at very low levels. As in other plant material, mineral content is highly influenced by the presence of these elements in soil where the crop was produced (Ikeda et al. 1991a, 1998; Steadman et al. 2001). Minerals are cofactors in antioxidative enzymes. Activity of the following enzymes is maintained by: superoxide dismutase on zinc, copper and manganese; glutathione peroxidase and thioredoxin reductase on selenium; and catalase on iron (Fardet et al. 2008).

The bioavailability of zinc, copper and potassium from buckwheat is especially high (Ikeda et al. 1990). It has been reported that 100 g of buckwheat flour can provide approximately 13-89% of the daily recommended dietary allowance (RDA) for zinc, copper, magnesium, and manganese. However, the phytic acid, mainly located in bran fractions, may reduce minerals bioavailability by forming undigestible salts (Thompson 1993). Folic acid makes buckwheat grains a rich source of dietary selenium and a useful raw material to enrich food products (Stibilj et al. 2004; Smrkolj et al. 2006; Ozbolt et al. 2008). Buckwheat accumulates selenium predominantly as organic compounds including high levels of selenium (Stibilj et al. 2004; Smrkolj et al. 2006; Ozbolt et al. 2008). Buckwheat accumulates selenium predominantly as organic compounds including
seleno-methionine, methyl-selenocysteine and γ-glutamyl-
methyl-selenocysteine. These compounds are part of an
antioxidative system and may reduce the risk of cancer
development (Ip et al. 2000; Nomura et al. 2000; Burke
et al. 2003; Kitaguchi et al. 2008).

Flavonoids

Flavonoids and anthocyanins are phenolics, a large group of
components produced mainly by plants. Oomah and Mazza
(1996) reported the amount of phenolics in buckwheat at
0.7% in the hulls and 0.8% in the groats. Phenolics content
and composition in buckwheat seeds is affected by specie,
growing phase, growing conditions. New varieties with
high levels of these compounds were developed in Canada,
Japan and Germany (Ohsawa et al. 1995; Oomah et al.
1996; Jiang et al. 2007; Olschlager et al. 2008; C. Campbell,
pers. comm.). The average total flavonoids contents were
significantly different for the buckwheat species, 2.04% in
F. tataricum, 0.35% in F. homotropicum, and 0.04% in F.
esculentum (Jiang et al. 2007). Many different flavonoids
have been isolated and identified in buckwheat grains
including rutin, orientin, vitexin, quercetin, isovitexin, querc-
cetrin and isoorientin in the hull, and rutin and small
amounts of isovitexin in the groats (Table 9). Rutin, the
main buckwheat flavonoid, is a quercetin aglycon attached
to rutinose and the chemical structure of rutin, quercetin
(quercetin with rhamnose) and aglycon quercetin are pre-
sented in Fig. 2. Rutin attributed 54, 29, and 82% of the
total flavonoid content in F. esculentum, F. homotropicum,
and F. tataricum, respectively (Oomah and Mazza 1996; Li
and Zhang 2001; Jiang et al. 2007). In the flowers, leaves
and stems of F. tataricum the content of flavonoids can ex-
ceed 10% of wet plant weight (Park et al. 2000). New
Canadian varieties, selected for plant flavonoids production
achieved up to 18% of rutin in fresh plant tissues (C. Camp-
bell, private communication). The average rutin seed con-
tent differs significantly depending on the buckwheat spe-
cies, and was found 1.7% in F. tataricum, 0.1% in F.
homeotropicum, and 0.02% in F. esculentum (Jiang et al
2007).

Table 8 Comparison of minerals composition in buckwheat and food grains (mg/100 g).

| Mineral   | Corn | Barley | Rye | Wheat | Seed | Hull | Flour
|-----------|------|--------|-----|-------|------|------|-------
| Calcium   | 7    | 33     | 33  | 25    | 18   | 33.3 | 41
| Iron      | 2.7  | 3.6     | 2.7 | 3.6   | 2.2  | 6    | 4.1
| Magnesium | 127  | 133     | 121 | 124   | 231  | 5991 | 251
| Phosphorus | 210  | 264     | 374 | 340   | 332  | 347  | 337
| Potassium | 287  | 452     | 264 | 340   | 460  | 1416 | 577
| Sodium    | 35   | 12      | 6   | 2     | 1    | 46   | 11
| Zinc      | 2.2  | 2.8     | 3.7 | 2.8   | 2.4  | 7.3  | 3.1
| Copper    | 0.3  | 0.5     | 0.5 | 0.4   | 1.1  | 1    | 0.5
| Manganese | 0.5  | 1.9     | 2.7 | 4.1   | 1.3  | 4.6  | 2.1
| Selenium  | 15.5 | 37.7    | 35.3| 70.7  | 8.3  | 6.8  | 5.7

A – Flour from whole groats.


Table 9 Composition and content of flavonoids and catechins in buck-
wheat (μg/g DM).

<table>
<thead>
<tr>
<th>Flavonoids</th>
<th>Groat</th>
<th>Hull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isoorientin</td>
<td>8.5</td>
<td>8.4</td>
</tr>
<tr>
<td>Orientin</td>
<td>8.6</td>
<td>14.3</td>
</tr>
<tr>
<td>Vitexin</td>
<td>17.8</td>
<td>30.4</td>
</tr>
<tr>
<td>Rutin</td>
<td>176.5</td>
<td>33.1</td>
</tr>
<tr>
<td>Isovitexin</td>
<td>21.6</td>
<td>20.4</td>
</tr>
<tr>
<td>Total</td>
<td>233.0</td>
<td>106.5</td>
</tr>
</tbody>
</table>

Flavanols

| Catechin | 31.3 |
| Epicatechin | 203.5 |
| Epicatechin gallate | 12.3 |

Source: Adapted from Zielinska et al. (2007), Danila et al. (2007)
Steadman et al. (2001) reported that the tartary buckwheat hull contained a similar amounts of rutin (4.4 g/kg) as the hull of common buckwheat, but the rutin level was much higher in groats of tartary buckwheat (81 g/kg) than in common buckwheat (0.2 g/kg). Fabjan et al. (2003) reported that content of rutin in seeds of three Tertiary buckwheat cultivars were at 0.8-1.7% while at 0.01% in common buckwheat seeds (Minami et al. 1992). The uses of rutin derived from buckwheat, were reported to be in the range of 180-350 mg, when 10 g of fresh buckwheat leaves were consumed (Dietrich-Szostak and Oleszek 1999). To exploit the variety and content of different nutraceuticals, particularly flavonoids, the buckwheat plant is utilized in some countries as a vegetable and often parts of buckwheat plants are collected a few times during the growing season (Lipkin et al. 1999; Li and Zhang 2001; Kim et al. 2004).

Biofunctionality displayed by rutin includes anti-inflammatory, antiutamigenic, antitumor, anticarcinogenic, smooth muscle relaxation, and estrogen receptor binding (Pisha and Pezzuto 1994; Ushida et al. 2008). It has been established that rutin can positively affect the activity of angiotensin I, enzyme involved in the controlling of blood pressure (Kawakami et al. 1995). The amount of rutin present in buckwheat groats is usually increased, effective in ameliorating blood cholesterol level, high blood pressure, keeping capillaries and arteries strong and flexible, arteriosclerosis and assisting in prevention of brain and lung hemorrhage (Yildzogle-Ari et al. 1991; Santos et al. 1999; Li and Zhang 2001; Gao et al. 2003). Flavonoids also act as strong antioxidants protecting lipids, DNA, proteins and lipoproteins (Noroosi 1998; Przybylski et al. 1998; Cao et al. 2008). Due to higher content of flavonoids in tartary buckwheat, this crop is more effective in antioxidant activity (Cao et al. 2008). However newer varieties of common buckwheat offer even higher content of rutin as typical tartary buckwheat (Campbell 2001) reported that the tartary buckwheat and the last two in tartary buckwheat sprouts. Rutin content of tartary buckwheat and common buckwheat was found in sprouts at the level of 0.2 mg/g and 5.5 to 6.6 mg/g DM, respectively. The amount of these components is highly affected by the intensity and type of drying forming higher levels under dry conditions (Kretk et al. 2002; Jovanovici et al. 2006; Kim et al. 2007). Formation of more anthocyanins is related to the protective properties of these compounds against radiation and oxidative stress, suggesting that these compounds are strong antioxidants and radiation protectants. Pigmentation of plants is not the only function of anthocyanins, it has been established that components from this group have bioactivity similar to the flavonoids discussed above, including strong antioxidative capacity and activation of resistant insulin (Kim et al. 2007; Zhang et al. 2009).

**Lignans**

Lignans are the most researched group of nutraceuticals with the diverse activity proven by nutritional testing. They are metabolites of plant lignans in the gut bacteria, and have been found in many plants (Setchell 1995). These components act in mammalians as hormone-like phytostrogens, affecting many metabolic processes. Human gut microflora in large intestine is converting them into active compounds such as enterodiol (ED) and enterolactone (EL) (Thompson et al. 1991). The concentration of plant lignans acting as precursors of mammalian lignans are measured by subjecting a particular food ingredient to fermentation by intestinal microorganism and by measuring the released amount of ED and EL (Setchell 1995). In animals, the excretion of ED and EL measured in the urine indicates the amount of consumed plant lignan components (Rickard and Thompson 2000). The pathway of plant lignans transformation into mammalian lignans by bacteria is presented in Fig. 3. Flaxseed is one of the richest sources of plant lignans, and it contains 75-800 times more that other oilseeds, cereals, legumes, fruits and vegetables. Buckwheat is placed as the fourth highest in the amount of excreted ED and EL lignans among cereals and oilseeds (Fig. 4). The main plant lignans found in buckwheat are secoisolariciresinol diglycoside (SDG) and matairesinol (MAT) (Thompson et al. 1991; Kurzer et al. 1995). Mammalian lignans are often called enterolignans and are also found as converted and active forms in cereals, oilseeds and nuts (Smeds et al. 2007). Significant efforts are considered to prevent and control some forms of cancer, particularly ones where hormones play a role (Thompson 1993). It was established that the urinary excretion of ED and EL was significantly lower in omnivore patients with breast cancer than in vegetarians who have a lower risk of cancer development due to the higher consumption of lignans (Adlercreutz et al. 1986). Also lignans reduced mammary tumor size by 50% and the number of tumors by 37% when compared to experimental rats (Setchell 1995; Rickard and Thompson 2000). Furthermore, it has been suggested that lignans have antiinflammatory, antitumorogenic, antiviral, antibacterial, and antifungal properties (Setchell et al. 1995; Thompson et al. 1995, 1996; Rickard and Thompson 2000). Epidemiological studies show that a high serum level of EL is associated with a reduced risk of coronary heart disease (Ayres 1990; Vanhaecke et al. 1999). Lignans and their metabolites also display antioxidant activity towards different lipids, however low antioxidative activity was observed for components of the genetic system (Kitts et al. 1999; Pool-Zobel et al. 2000).

**Food uses**

Buckwheat has favorable composition in terms of high biological value of proteins, variety of nutraceutical compo-
Nutrients and nutraceuticals in buckwheat. Przybylski and Gruczeńska

Buckwheat flour and groats are used for a wide variety of dishes. In Asia they are consumed as noodles, dumplings and as unleavened chapattis. The buckwheat flour, called 'sobako', is mixed with wheat flour for the production of buckwheat noodles called 'soba noodles' in Japan. The buckwheat flour content ranges from 50 to 80% depending on the type of noodle produced. The Japanese Food Agency stipulates that a minimum of 35% buckwheat must be present for noodles to be called 'soba'. Some handmade 'soba noodles', available only in selected restaurants, are made with 100% buckwheat flour. In addition to their unique taste, buckwheat noodles have a superior protein makeup, high lysine level, contain an abundance of vitamins B1, B2, minerals and dietary fibre (Fu 2008). ‘Soba noodles’ prepared with 60% of dark buckwheat flour contain conside-

Fig. 3 Formation of mammalian lignans and their plant precursors. Adapted from Thomson (1993).

Fig. 4 Total excretion of mammalian lignans in the urine of rats after diet supplementation with various foods. Sources: Compiled from Smeds et al. (2007), Thompson (1993, 1995).
rably higher amounts of minerals, proteins, dietary fibre, fagopyritols and flavonoids than noodles prepared with white flour, the potential health benefits of dark buckwheat noodles may be substantially greater (Hatcher et al. 2008). In the Japanese market, there are many kinds of buckwheat products presently available including: buckwheat wine, buckwheat sauce, and buckwheat lotus confectionery.

The buckwheat flower itself is one of the most important honey-producing plants. It is available for bees in time when other plants are deficient and very important for the survival of honeybees (Krkosková and Mrázová 2005). Honey produced from buckwheat flowers, usually contains high amounts of flavonoids and other phenolic components, protects human blood lipoproteins against oxidation more effectively than sucrose analogues (Gheldof et al. 2003). In Japan, buckwheat inflorescences are utilized as a functional food, due to their rich rutin content. Rutin-rich herb tea and green buckwheat flour are the most commonly used buckwheat herb products (Fabjan et al. 2003). Green flour obtained by milling the dried flowering buckwheat plants is added as a natural food colorant to pasta, ice cream, and other products in Japan and South Korea (Kim et al. 2001).

In the early 2000s, buckwheat sprouts were introduced as functional vegetables because of their beneficial nutritive value, including amino acids, fibre, minerals, and protein (Kim et al. 2001). However, compared to the sprouts of common buckwheat, those of ‘tartary buckwheat’ (F. tataricum) have received greater attention as a functional food given their two fold higher content of rutin known to strengthen blood vessels (Mukoda et al. 2001). In Europe, particularly Eastern Europe, roasted, hulled buckwheat kernels, usually cracked into coarse, medium, or fine granules, also known as ‘kasha’ are used in dishes ranging from pilafs to mixtures with meat and as a basic ingredient used in the preparation of porridges and soups. In North America, the main use has been in pancakes, however, utilization of buckwheat has been increasing in the form of noodles, cereals and various ethnic dishes. The functional properties of buckwheat also create an opportunity for developing a new puffed snack product and buckwheat grit cakes (Im et al. 2003). Buckwheat is also used in pastries and as a meat extender.

In Europe and North America, buckwheat has been blended with other grains to produce multigrain pasta, energy bars, waffles, cereal flakes, bagels, and bread. Buckwheat, which is added to bread as a supplement, can provide beneficial health effects and prevent bread from oxidative degradation during processing and storage (Lin et al. 2009). The investigations of the effect of buckwheat ingestion in a rat model showed an increase of aerobic, mesophilic and lactic acid bacteria content in rats’ intestines, concurrently significant decrease in pathogenic bacteria was also observed (Prestamo et al. 2003). Thus, buckwheat products could be considered as potential prebiotics for human gastrointestinal tract.

As discussed above buckwheat is very rich source of a variety of nutraceutical components which can directly improve our diet and through it, positively affect our health and well being. Every coming year offers more data specifying new bioactive components found in buckwheat seed and plant. The crop stands apart from other cereals or plant sources as it contains immensely more nutraceuticals usable in our food supply that can ameliorate many chronic and civilization based health problems.

FUTURE PERSPECTIVES

Buckwheat is the rich source of nutraceutical and functional food ingredients; however, years of neglect and treating it as marginal crop caused that considerable development is required to utilize those components for food and drugs. The main challenge for buckwheat is keeping continues production of good quality seeds to provide food industry with source of unusual food ingredients to allow development of new products.

The current technologies used for cereals processing need adaptation to accommodate buckwheat seed and to protect nutraceutical components present in it. Many novel techniques are required to improve traditional buckwheat products and to produce new with improved amount of functional and nutraceutical components. For buckwheat processing low temperature technologies need to be developed to protect functional components. Extrusion often used in cereals processing requires modification to accommodate unique buckwheat starch properties and to protect health impacting compounds.

Progress need to be made in the utilization of buckwheat seed and plant for new nutraceutical and mainstream food products for everyday consumption. Many components of buckwheat plant and seed are rich in nutrients and nutraceuticals. Flowers and green parts of plant can produce large amounts of flavonoids; newly developed varieties can produce up to 18% of rutin in plant tissues. To utilize this component new technologies have to be developed to transfer it from plant to supplement and/or food ingredient.

Buckwheat is gluten-free and can be an important ingredient in celiac food formulations where considerable economical impact can be made for producers and processors. Example of the new applications of buckwheat is in the production of gluten-free malt, beer and novel functional drinks, where major modifications to processing were required to obtain proper quality product.

In the area of breeding, new varieties of buckwheat containing higher amounts of already know nutraceuticals are currently under development. Dr. Campbell developed new varieties of buckwheat seed which produce multiple amounts of fagopyritols compared to standard crop; however its utilization is lacking. It is expected that new health impacting compounds will be found in this crop and new variety containing higher amounts of specific component or multitude of compounds needs to be developed. However, breeding of new varieties of buckwheat is hampered by minimal food market interest.

Buckwheat has to be treated as potential source of drugs, especially for chronic and resistant diseases such as cardiovascular and diabetes. Many buckwheat components posses mysterious health activity, for example controlling insulin activity and type II diabetes, nevertheless further research is needed to establish bioactivity of compounds present in buckwheat.

In summary, to fully utilize generous amounts of bioactive components present in buckwheat seed and plant, substantial advancement in breeding, production, processing and health assessment is needed in the near future.

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