REVIEW

Buckwheat

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ABSTRACT

Buckwheat has major potential as food ingredient, especially for the functional food industry. Buckwheat, a pseudo-cereal, contains protein of high nutritional value, dietary fiber, resistant starch, rutin, D-*chiro*-inositol, vitamins, and minerals. D-*Chiro*-inositol, fagopyritols (galactosyl derivatives of D-*chiro*-inositol), resistant starch, and buckwheat protein product exhibited positive health effects on rats, but more studies should be undertaken to establish effects on humans. Rutin and quercetin are the main antioxidants in buckwheat and have been mentioned in the treatment of chronic venous insufficiency. The main nutritional value of buckwheat groats (dehulled seeds) is similar to that of cereals. Starch and fiber are present in similar amounts, and buckwheat also contains a high level of polyunsaturated essential fatty acids such as linoleic acid. Several vitamins (B1, C, and E) are present, whereas minerals are present in abundance. In comparison to cereals, buckwheat protein is of high nutritional quality due to its relatively high level of lysine. On the other hand, a low digestibility has been recorded, possibly due to tannins, phytic acid, and protease inhibitors. Some protease inhibitors can also cause allergic reactions in humans. Malting may enhance the nutritional and functional properties of buckwheat by increasing protein digestibility and the level of nutritional and functional components.

Buckwheat is a traditional crop in Asia and Central and Eastern Europe. Over the last 40 years, China has been the largest producer of buckwheat. In 2004, China produced 1,500,000 Mt, followed by Russia and the Ukraine which produced 649,560 Mt and 293,400 Mt, respectively (FAO 2004). The cultivation of buckwheat has decreased over the last century. The main reason for this decline was self-incompatability, which lead to breeding difficulties. In addition, buckwheat showed a poor response to fertilizer applications compared with other crops (Marshall and Pomeranz 1982; Pomeranz 1983). In recent years, interest in buckwheat has been renewed as an alternative crop for organic cultivation and as a health food (Li and Zhang 2001; Biacs et al 2002). Buckwheat contains several compounds that may have potential in reducing risk of certain diseases (Mazza and Oomah 2005). Common buckwheat (*Fagopyrum esculentum* Moench) is the most commonly grown species, while two other species of buckwheat (*F. tataricum* Gaertner and *F. emarginatum*) have been cultivated on a small scale (Marshall and Pomeranz 1982; Mazza and Oomah 2005). Buckwheat belongs to the family of *Polygonaceae* and not to the cereal family (*Poaceae*). Buckwheat is categorized as a pseudo-cereal in that it shows both differences and similarities with cereals (Aufhammer 2000). The main structural difference is that buckwheat is a dicotyledonic plant in contrast to the monocotyledonic cereals. The embryo in a buckwheat seed is located in the center of the endosperm and possesses two cotyledons (Fig. 1). The hull (pericarp) has a hard fibrous structure and surrounds the seed coat, endosperm, and embryo tightly. The endosperm cells have thin cell walls and consist mainly of starch (Pomeranz 1983; Steadman et al 2001a). Cereals also contain starchy endosperms, which is one of the main similarities between cereals and buckwheat. In addition, both cereal grains and buckwheat seeds are edible and have a nonstarchy aleurone layer (Aufhammer 2000; Bonafaccia et al 2003b). Although other parts of the buckwheat plant can be used for human consumption and animal feed, buckwheat is now mainly grown for the production of seeds (Biacs et al 2002; Mazza and Oomah 2005). Buckwheat seeds are usually processed into flour. Buckwheat seeds are dehulled before milling or the flour is sieved afterward. Dehulled seeds are called groats (Marshall and Pomeranz 1982; Ikeda 2002). The composition of buckwheat groats is shown in Table I. This article reviews chemical and nutritional characteristics of buckwheat groats and seeds.

CARBOHYDRATES

Starch

Buckwheat groats showed a total carbohydrate percentage of 67.8–70.1% (Li and Zhang 2001; Steadman et al 2001a), of which 54.5% was found to be starch (Steadman et al 2001a). Buckwheat seeds exhibited a higher carbohydrate percentage of 73.3% due to the presence of the pericarp but had a similar starch percentage (55.8%). The percentage of starch (57.4 ± 0.12%) in tartary buck-

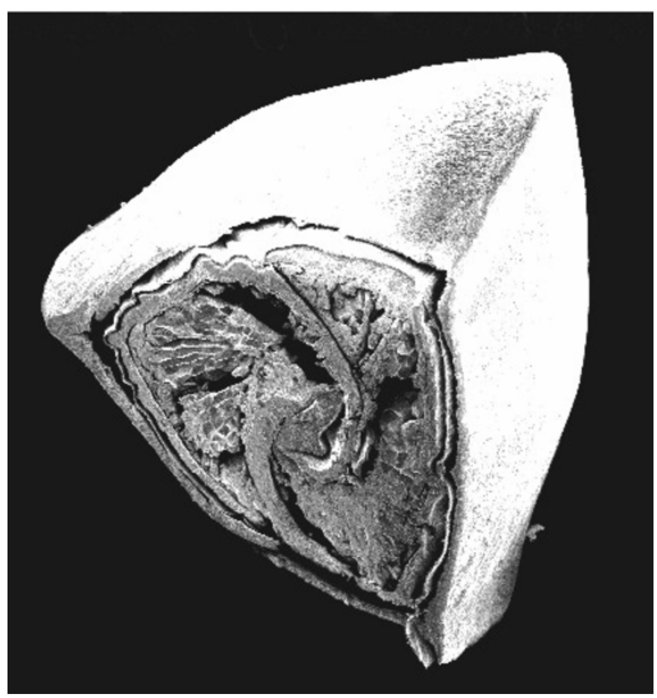

Fig. 1. Scanning electron micrograph of a buckwheat kernel germinated for three days (magnification 25×).

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wheat was slightly higher than in common buckwheat but this could be due to the cultivar analyzed in this particular study (Bonafaccia et al 2003b). An apparent amylose content as high as 46.6% has been determined (Qian et al 1998) but lower apparent amylose contents of 21.1–27.4% were reported in later publications (Noda et al 1998; Qian and Kuhn 1999b; Yoshimoto et al 2004). These ranges agree with amylose percentages found in cereals (Qian and Kuhn 1999b). No consistent differences existed between apparent amylose percentages of common and tartary buckwheat (Li et al 1997).

The presence of amylose-lipid complexes has been suggested because iodine affinity increases when buckwheat starches are defatted (Yoshimoto et al 2004). This assumption is supported by Qian et al (1998). Buckwheat starch has a high level of crude fat and amylose. Also, a second melting transition peak temperature of 84.5°C has been observed by differential scanning calorimetry analysis. Both results may point to the presence of amylose lipid-complexes. The formation of amylose-lipid complexes could lead to the restriction of swelling power and solubility (Qian et al 1998).

Yoshimoto et al (2004) determined a big difference between the actual amylose content (15.6–17.9%) and the apparent amylose content (25.5–26.5%). This difference indicates the presence of a large amount of longer chain amylopectins that have tendency to complex with iodine (Yoshimoto et al 2004). The presence of long chain branched molecules was confirmed by Praznik et al (1999) and Noda et al (1998). The degree of polymerization (DP) of amylopectin depended on the botanical origin and, hence, varied between buckwheat starches but <4% of amylopectin demonstrated a DP of 6 and 7 and >40% of the amylopectin showed a DP of 10–12 (Noda et al 1998). This indicates that amylopectins of buckwheat contain a higher level of long chains than cereal amylopectins. In addition, the weight average DP of buckwheat starch was 94,900, which was closer to values of waxy maize starch than starches isolated from other cereals or pseudo-cereals. This implies the presence of a relatively higher level of super molecular glucan structures that can affect viscosity. During gelatinization, super molecular glucan structures can be disintegrated but they tend to reconstitute during cooling (Praznik et al 1999). In general, buckwheat starch exhibited higher peak viscosities than cereal starches and more resembled pasting behavior of root and tuber starches (Qian et al 1998; Qian and Kuhn 1999a; Yoshimoto et al 2004). Besides super molecular glucan structures, these high viscosity values can be explained by the fact that buckwheat starches exhibited a higher granule swelling and gelling tendency than cereal starches (Yoshimoto et al 2004). Peak gelatinization temperatures differed slightly by buckwheat cultivar. Noda et al (1998) reported peak gelatinization temperatures of buckwheat starches ranging from 57.2 to 66.7°C, but most peak gelatinization temperatures have been described within a range of 63.7–70.8°C (Li et al 1997; Qian et al 1998; Qian and Kuhn 1999a; Yoshimoto et al 2004). It is important to note that the equipment applied to determine gelatinization properties can affect gelatinization curves. For instance, different onset temperatures of gelatinization (60, 70, and 80°C) have been reported with differential scanning calorimetry analysis, rapid viscoanalysis, and Brabender viscoamylography, respectively (Qian and Kuhn 1999a).

The water-binding capacity of buckwheat starch was 109.9%, which is higher than that of wheat and corn starch. This high value can be explained by the small size (and hence a bigger surface area) of buckwheat starch granules (Qian et al 1998). Buckwheat starch granule sizes are 2.9–9.3 μm with a mean size of 5.8 μm and are round or polygonical shaped (Qian and Kuhn 1999b). The appearance of a buckwheat starch granule is smooth with a few pores, possibly caused by enzymatic attack (Qian and Kuhn 1999b). Due to the presence of pores and the small starch granule size, buckwheat starch is more susceptible to porcine α-amylase than are corn and wheat starch (Qian et al 1998).

In general, it can be said that buckwheat starch has its own unique characteristics; some properties correspond to tuber starches (high viscosity values) and others correspond more with cereal starches (shape and composition).

TABLE I
General Composition of Common Buckwheat Groats[a]

Parameter	Level (% w/w)
Moisture (wb%)[a]	11.8
Starch (db%)[b]	54.5
Protein	12.3
Dietary fiber	7.0
Lipids	3.8
Minerals	2.4
Soluble carbohydrates	1.6
Other compounds	18.4

[a] Steadman et al (2001a).

Resistant Starch

Starch can be divided into three groups depending on the rate and extent of digestion in vitro: rapidly digestible starch, slowly digestible starch, and resistant starch (RS). RS can again be divided into three groups: physically inaccessible starch, native granular starch, and retrograded starch (Englyst et al 1992). Undigested starch may result in positive nutritional effects that are similar to effects observed with fiber (Skrabanja and Kreft 1998). Various factors such as physical form of starch, extent of retrogradation, amylose-to-amylopectin ratio, and nonstarchy inhibitory components affect the digestibility of starch (Skrabanja et al 1998). In raw buckwheat groats with a total starch content of 73.5%, 33.5% was RS (Skrabanja and Kreft 1998). Processing can affect RS. For instance, autoclaving decreased RS from 33.5% to 7.5%. In contrast, the level of retrograded starch can be increased by either autoclaving or boiling from 1% to 4–7% (Skrabanja and Kreft 1998; Skrabanja et al 1998, 2001). Rats excreted ≈0% starch of native buckwheat groats compared with 1.0–1.6% of hydrothermally processed buckwheat starch. Hence it was suggested that rats (and possibly humans) can completely digest native buckwheat starch, but not if buckwheat starch was hydrothermally processed (Skrabanja et al 1998). Therefore, buckwheat is suggested when designing low GI foods. Low GI foods are important in improving diabetic control and can be ranked according to their blood glucose raising potential (glycemic index) (Jenkins et al 1981). Foods with higher levels of resistant starch usually have a low GI and are generally advantageous for most healthy adults (Skrabanja et al 2001). In comparison to white wheat bread (100 GI), a 61.2 GI in boiled buckwheat groats has been recorded and a 66.2 GI in buckwheat bread baked with 50% buckwheat groats (Skrabanja et al 2001). Buckwheat flour extract contains compounds such as tannins, phytic acid, and proteinaceous inhibitors that can act against human saliva amylase (Ikeda et al 1994; Skrabanja et al 2001) and affect the level of digestible starch. It would be interesting to know what the relative contribution of these various factors on the digestibility of starch is, when designing low GI products.

Fiber

Dietary fiber (DF) has been mentioned in many reports as potentially protective against certain diseases (Roberfroid 1993). DF can be divided in insoluble fiber (IDF) and soluble fiber (SDF). IDF generally includes lignin and cellulose, while SDF includes pectin and gums (Roberfroid 1993; Steadman et al 2001a). SDF especially may contribute positively to human health by reducing levels of blood cholesterol (Roberfroid 1993). In addition, DF can also have a negative role as it may bind proteins and minerals, inhibit digestive enzymes, and thereby lower digestibility or absorption (Ikeda and Kusano 1983; Steadman et al 2001a). Bonafaccia et al (2003b) reported a DF of 27.38% in buckwheat seeds.

DF is mainly present in outer seed coverings such as the seed coat and hull, which explains the much lower DF percentage of ≈7% in buckwheat groats (Steadman et al 2001a; Bonafaccia et al 2003b). IDF and SDF of buckwheat groats are similar to cereals such as oats and wheat. An IDF of 2.2 ± 0.2% has been determined in buckwheat groats and an SDF of 4.8% (7.0–2.2) can be calculated. Indigestible oligosaccharides such as fagopyritols are not measured in SDF assays because they are dissolved in the solvents used. If total α-galactosides were included in the assay, SDF would be increased by 20–30% (Steadman et al 2001a).

D-Chiro-Inositol

D-Chiro-inositol is an inositol isomer that occurs in relatively high levels in buckwheat seeds (Fig. 2) (Steadman et al 2000). Chemically synthesized D-*chiro*-inositol has lowered elevated plasma glucose in spontaneously insulin-resistant rhesus monkeys, streptozotocin-treated hyperglycaemic rats, and normal rats when D-*chiro*-inositol was administered either intravenously or orally (Ortmeyer et al 1993, 1995). Because a relatively high level of D-*chiro*-inositol was found in buckwheat, administering doses of 10 and 20 mg of D-*chiro*-inositol in the form of natural buckwheat concentrate decreased serum glucose concentrations by 12–19% in streptozotocin-diabetic rats. Although no study of the effect of D-*chiro*-inositol on humans has been reported, buckwheat concentrate has been suggested as a natural product in helping to treat diabetes (Kawa et al 2003). Steadman et al (2000) advocates a free level of D-*chiro*-inositol in buckwheat groats that ranges from 20.7 to 41.7 mg 100/g, dwb, but most D-*chiro*-inositol in buckwheat is present in the form of fagopyritols (Horbowicz et al 1998). Fagopyritols are galactosyl derivatives of D-*chiro*-inositol that can accumulate in seeds of some species. Buckwheat embryos are unique because they accumulate galactosyl cyclitols and not raffinose oligosaccharides (Horbowicz et al 1998). The structures of D-*chiro*-inositol, fagopyritol B1, B2, and B3 are shown in Fig. 2. Fagopyritols are, besides other soluble carbohydrates such as sucrose, mainly localized in buckwheat embryos (71.4%). Fagopyritol B1 is the most abundant fagopyritol in buckwheat seeds and represents 41.16 %/g, dwb, of soluble carbohydrates in embryos. In addition to B1, four other fagopyritols have been identified in embryos from common buckwheat seeds: two digalactosyls and two trigalactosyls (Steadman et al 2001c). They were present in levels of ≤2 mg/g, dwb, of total soluble carbohydrates (Horbowicz et al 1998). Tartary buckwheat contained 50% of the level of fagopyritols present in common buckwheat. Tartary buckwheat contained another soluble carbohydrate that was not identified in common buckwheat cultivars. This compound was possibly rhamnosyl glucoside and was present at a level of 31% (Steadman et al 2000). Malting is one possibility to increase fagopyritol levels. Germinating at 18°C raised amounts of fagopyritol B1, while germinating at 25°C increased the levels of both A2 and B2 (Horbowicz et al 1998). The effects of D-*chiro*-inositol and fagopyritols in natural buckwheat concentrate on plasma glucose levels in humans should be investigated. These compounds may have positive effects for patients with diabetes and products may be designed accordingly.

PROTEIN

Storage Proteins

All proteins can be divided in four groups by their solubility: 1, albumins (soluble in water and dilute buffers at neutral pH); 2, globulins (soluble in salt solutions but insoluble in water); 3, glutelins (soluble in dilute acid or alkali solutions); and 4, prolamins (soluble in aqueous alcohols of 70–90%) (Bewley and Black 1985).

In cereals, prolamins are the major storage proteins, while globulins are mainly found in buckwheat. According to Ikeda et al (1991), common buckwheat seeds consist of 64.5% globulin, 12.5% albumin, 8.0% glutelin, and a small percentage of prolamins (2.9%). Similar ranges have been reported by Radovic et al (1999). The major storage proteins, globulins, consist of two major families that differ in molecular weight (MW) and sediment with different sedimentation coefficients (S values) of ≈7 (average 7–8) and 11 (11–13) during ultracentrifugation. Both are composed of regularly assembled subunits (Bewley and Black 1985). In buckwheat, 13S globulin and 8S globulin have been identified. The MW of 13S globulin is 280,000. It is a legumin–like storage protein composed of nonidentical subunits consisting of one acidic and one basic polypeptide linked by disulfide bonds. 13S globulin contributes to 33% of total seed proteins in buckwheat and is a major storage protein (Radovic et al 1996). The smaller 8S globulin is a trimer. It is composed of subunits with MW 57,000 to 58,000 and is similar to vicilin-like storage proteins. The 8S globulin contributes to ±7% of total seed proteins in buckwheat (Milisavljevic et al 2004). In addition to globulins, 2S albumins are identified in buckwheat. These water-soluble proteins were single-chain polypeptides with MW 8,000 to 16,000 (Radovic et al 1999). Most of the protein in buckwheat is localized in protein bodies. Protein bodies are special cellular organelles with average diameters of 1–10 μm and are bound by a single membrane (Elpidina et al 1990). The 13S protein was only found in the cotyledons, while 8S globulin was found in both cotyledons and the endosperm (Radovic et al 1996).

Amino Acids

Buckwheat does not belong to the cereal family and contains very little or no prolamins. This is the reason why Coeliac sufferers can consume buckwheat (Fasano and Catassi 2001). In cereal grains, where the percentage of prolamins is high, lysine is limiting, tryptophan is low, and threonine levels are nutritionally inadequate. The majority of buckwheat proteins consist of globulins and albumins; buckwheat protein contains a wide range of various amino acids. Pomeranz and Robbins (1972) analyzed the amino acid composition of 10 samples of buckwheat seeds from various origins (Table II). A mean percentage of 13.7% protein has been found and 17 amino acids have been identified. The first nine amino acids in Table II are essential and have to be taken in, as the body is not able to produce them (Insel et al 2004). In comparison to cereal grains, buckwheat protein shows a high level of

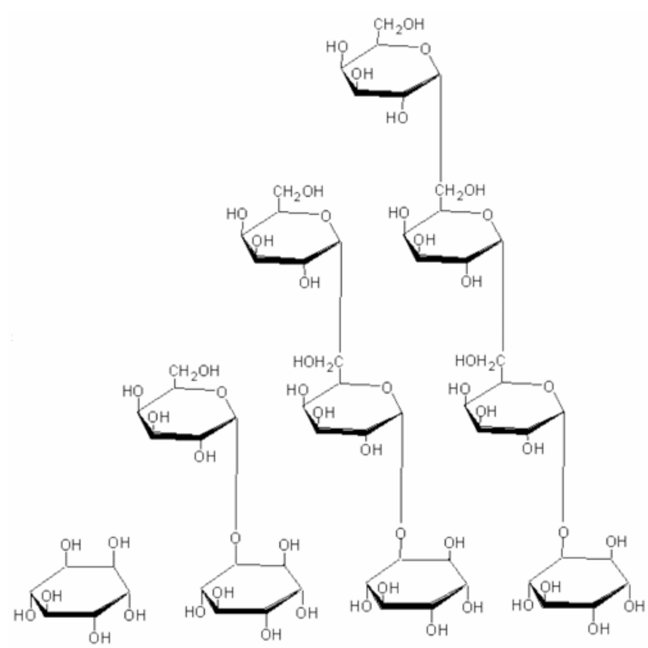

Fig. 2. Molecular structure (left to right) of D-*chiro*-inositol, fagopyritol B1, fagopyritol B2, and fagopyritol B3.

lysine (6.1% of 100 g of amino acid recovered). In addition, buckwheat contains high levels of arginine (9.7%) and aspartic acid (11.3%), and low levels of proline (3.9%) and glutamic acid (18.6%), when compared with cereals (Pomeranz and Robbins 1972). Similar results have been reported by Javornik et al (1981) and Eggum et al (1981). A relatively low level of proline and glutamic acid can be explained by the fact that prolamins, which are high in proline and glutamine, are present in very low amounts in buckwheat (Ikeda et al 1991). The amino acid composition was similar in all parts of the buckwheat kernel. The only difference in amino acid composition of the buckwheat seed was observed in buckwheat hulls (Pomeranz and Robbins 1972).

Nutritional Quality

Nutritional quality of protein reflects the essential amino acid content of the food protein, digestibility of the protein, and bioavailability of amino acids in the specific food (FAO 1990). The formula for calculating the protein digestibility-corrected amino acid score is (mg of limiting amino acid per g of test protein/mg of same amino acid per g of reference protein) × fecal true digestibilty (%) × 100% (Schaafsma 2000). The amount of limiting amino acid per g of test protein is the first limiting essential amino acid. In buckwheat, in contrast to cereals, leucine is sometimes limiting instead of lysine (Chung and Pomeranz 1985). The reference protein is based on the requirement of amino acids of a preschool-age child (Table III). When excluding the requirements of infants, during the preschool age, children require the maximum amount of essential amino acids. By using these requirements, requirements of all children (except infants) and adults would be met (FAO 1990). When the values of buckwheat protein of Pomeranz and Robbins (1972) are applied, the only limiting amino acid is leucine (Table III). This amino acid is present in a level of 64 mg/g of protein, when it should contain levels of 66 mg/g of protein, based on the requirement of amino acids of a preschool-age child. The amino acid score would then be (64/66) × 100% = 97%. Eggum et al (1981) reported a high amino acid score of buckwheat protein as well, although it is not clear how this value was calculated. They verified an amino acid score of 93.1 and 90.5% for two different buckwheat cultivars. When buckwheat was fed to rats, a true digestibility of 79.9 and 78.8% was analyzed for these buckwheat cultivars (Eggum et al 1981). This is a low value when compared with cereals (FAO 1990). The results are in agreement with data from Javornik et al (1981), who demonstrated a true protein digestibility of 79.9 and 77.6% in common and tartary buckwheat, respectively. When transferred into the amino acid score formula, 97 × 79% results in a protein digestibility-corrected amino acid score of 77%. A similar value (74.4%) of net protein utilization of whole buckwheat seeds has been reported. Buckwheat groats showed a higher net protein utilization (81.3%) and tartary buckwheat a lower net protein utilization of 63.1% (Javornik et al 1981). Protein digestibility-corrected amino acid scores of buckwheat are high when compared with other cereals such as wheat and oats that have protein digestibility-corrected amino acid scores of 42 and 57%, respectively (FAO 1990). The lower values of oats and wheat are not due to low digestibility but to a relatively low level of lysine.

TABLE II
Values and Standard Deviations for Crude Protein and Amino Acid Composition of 10 Buckwheat Samples[a]

	Protein Values (% db of buckwheat kernels)			
Parameter[b]	**Maximum**	**Minimum**	**Mean**	**SD**
Protein	15.4	12.6	13.7	0.851
Lysine (Lys)	7.0	5.0	6.1	0.460
Histidine (His)	3.1	2.3	2.7	0.164
Threonine (Thr)	4.1	3.6	3.9	0.138
Valine (Val)	5.4	4.8	5.1	0.166
Methionine (Met)	3.0	1.8	2.5	0.344
Isoleucine (Ile)	4.0	3.6	3.8	0.098
Leucine (Leu)	6.6	6.1	6.4	0.156
Tryptophane	nd	nd	2.4[c]	nd
Phenylalanine (Phe)	5.0	4.6	4.8	0.127
Ammonia (NH_3)	2.3	1.7	2.1	0.164
Arginine (Arg)	11.6	8.5	9.7	0.837
Aspartic acid (Asp)	12.1	10.8	11.3	0.331
Serine (Ser)	5.2	4.5	4.7	0.198
Glutamic acid (Glu)	19.4	17.8	18.6	0.404
Proline (Pro)	4.3	3.2	3.9	0.353
Half cystine (Cys)	1.8	1.2	1.6	0.162
Glycine (Gly)	6.5	5.9	6.3	0.186
Alanine (Ala)	4.7	4.2	4.5	0.133
Tyrosine (Tyr)	2.5	1.8	2.1	0.235

[a] Pomeranz and Robbins (1972).
[b] Amino acids (in italics) are essential; the remaining amino acids are nonessential.
[c] Tkachuk and Irvine (1969).

Proteolysis

During germination, storage material of protein bodies is degraded and the embryonic axis is supplied with amino acids, phosphorous compounds, and inorganic cations. The breakdown of 13S storage globulin consists of two stages. The first stage can proceed without the presence of the embryonic axis. Dunaevsky and Belozersky (1993) reported that the absence of the embryonic axis has no effect on the presence and hydrolytic activity of the enzyme that starts the initial transformations of 13S globulin. This enzyme is already present in ungerminated buckwheat seeds (Elpidina et al 1990; Dunaevsky and Belozersky 1993) and regulates the first phase of proteolysis. It is a metalloproteinase, which is believed to be located entirely in the protein bodies (Elpidina et al 1991). The isolated metalloproteinase contains a Zn^{2+} ion (1.2 g-atom) per molecule of the proteinase and the enzyme had MW 34,000. This metalloproteinase exhibited maximum activity at pH 8.0–8.2 when using 13S globulin as a substrate. The enzyme degrades 13S globulin from buckwheat seed and 11S globulin from soybean better than it degrades haemoglobin and BSA (Belozersky et al 1990). During the first two days of seedling growth, metalloproteinase inhibitor activity is reduced and the metalloproteinase activity doubles. Thereafter, the enzyme activity drops to a lower level than the initial activity. Elpidina et al (1991) suggested that metalloproteinase is activated by divalent cations such as Mg^{2+} ions. It has been proved that the presence of Mg^{2+} ions increases proteolytic activity. The Mg^{2+} cations compete with Zn^{2+}, which is located in the enzyme molecule, for binding to the active site of the metalloproteinase inhibitor. Thereby, the enzyme-inhibitor complex can be destabilized and the metalloproteinase is activated. The metalloproteinase then hydrolyzes 1.5% of the

TABLE III
Amino Acid (mg/g of crude protein) Requirement Patterns and Levels in Buckwheat

Essential Amino Acid	**Requirement for Preschool-Age Child[a]**	**Level in Buckwheat[b]**
Ile	28	38
Leu[c]	66	64
Lys	58	61
Total sulphur amino acids (Met and Cys)	25	41
Total aromatic aminoacids (Tyr, Phe, Trp)	63	93
Thr	34	39
Trp	11	24
Val	35	51
Total	320	411

[a] Based on amino acid requirements of preschool-age child (mg/g of crude protein) (Schaafsma 2000).
[b] Amino acid pattern present in buckwheat (mg/g of crude protein) (Pomeranz and Robbins 1972).
[c] Amino acid leucine (in italics) is the first limiting amino acid in buckwheat.

peptide bonds (Müntz et al 2001). After initial cleavage of globulin 13S by metalloproteinase, the storage protein undergoes conformational change (Müntz et al 2001). Hence, 13S globulin can only be attacked by other proteases when it has dealt with metalloproteinase. The second stage of proteolysis is performed by de novo enzymes, mainly by cysteine proteinase. The optimum pH of cysteine protease is acidic in contrast to the basic optimum of the metalloproteinase (Dunaevsky and Belozersky 1989). During the second stage, the phytohormone abscisic acid comes into play. When the level of abscisic acid is reduced to 0.1–1.0 μM, proteases necessary for complete degradation of 13S globulin are synthesized (Dunaevsky and Belozersky 1993). Consequently, the level of cysteine proteinase increases during seedling growth (Dunaevsky and Belozersky 1989). Cysteine proteinase is feedback inhibited, which means that it is inhibited by its own products. The presence of the embryonic axis is therefore essential during the second stage, since it seems to regulate the efflux of proteolysis products to the growing part of the buckwheat plant. When proteolysis products such as amino acids and peptides are accumulated in the cotyledons, proteolysis is inhibited (Dunaevsky and Belozersky 1993). Furthermore, cysteine proteinase, carboxypeptidase, and aspartic proteinase have been isolated and localized in buckwheat cotyledons (Elpidina et al 1990). Carboxypeptidase and aspartyl proteinase are involved during last steps of protein hydrolysis and facilitate its completion (Belozersky and Dunaevsky 1999). In intact seeds, globulin 13S was completely degraded after four days of germination (Dunaevsky and Belozersky 1993). In summary, activities of proteases are under control by a number of factors: protein inhibitors, concentration of bivalent metal ions, pH, concentration of products of proteolysis, and abscisic acid (Belozersky and Dunaevsky 1999) (Fig. 3).

Inhibitors

As mentioned above, a low digestibility of buckwheat protein has been noted. Studies by Ikeda et al (1991) concluded that poor digestibility of buckwheat protein is due to two factors: various susceptibility of proteolytic action of buckwheat fractions, and antinutritional components such as tannins and inhibitors.

The presence of proteinase inhibitors in seeds is not completely understood but can include three functions. 1) Storage. In some cereals, trypsin inhibitors can contribute 5–10% of water-soluble proteins. 2) Control of endogenous enzymes. Some authors believe inhibitors control activity of proteolytic enzymes. 3) Protection or dissuasion. Proteinase inhibitors might inhibit proteolytic digestive enzymes of invading insects or secretive proteinases of microorganisms (Bewley and Black 1985).

Several inhibitors were identified in buckwheat seeds by various authors. They can be separated into two main groups, anionic and cationic inhibitors, based on their behavior in ion-exchange chromatography. In addition, they can be categorized by MW values. Kiyohara and Iwasaki (1985) isolated seven main inhibitors. In Belozersky and Dunaevsky's review, seven inhibitors are mentioned as well, but it remains unclear if they are similar to the seven found by Kiyohara and Iwasaki (1985). Belozerksy and Dunaevsky (1999) isolated three anionic (BWI-1a, BWI-2a, BWI-4a) and two cationic inhibitors (BWI-2c and BWI-4c) in buckwheat seeds. All of these inhibitors are small proteins inactivated by pepsin at pH 2.2. The anionic inhibitors had MW 7,700 to 9,200, while cationic inhibitors had MW ≈6,000. The identified inhibitors showed action against several proteases such as bovine trypsin, crab trypsin, and trypsin-like proteases from the fungi *Alternaria alternata* and *Fusarium oxysporum* (Dunaevsky et al 1998; Belozersky and Dunaevsky 1999). Tsybina et al (2004) identified four cationic trypsin-inhibitors, which they named BWI-1c, BWI-2c, BWI-3c, and BWI-4c. In addition to activity against proteases from bacterial and animal origin, these inhibitors showed activity against exo-proteases from some filamentous fungi. Because researchers have been giving inhibitors different names and have been using various methods of isolation, it remains unclear as to the exact number of protease inhibitors present in buckwheat seed. Besides protease inhibitors, an α-amylase inhibitor has been identified in buckwheat. This compound exhibits inhibitory activity against α-amylase from human saliva and α-amylase from porcine pancreas, but not against α-amylase from *Bacilius subtilis* and β-amylase from sweet potato (Ikeda et al 1994; Skrabanja et al 2001). One possibility of increasing biological availability of amino acids by reducing inhibitory activity may be germination. Trypsin-inhibitory activity in buckwheat seeds rapidly decreases during germination. On the fourth day of germination, seedlings have little or no detectable amount of trypsin inhibitor left. During germination, the level of total nitrogen remains unchanged, while the amino acid composition alters and the level of TCA-soluble proteins is increased 4× (Ikeda et al 1984).

Buckwheat Allergy

Other than the fact that protease inhibitors can affect protein digestibility, some inhibitors show IgE binding activity. To evaluate allergenic properties of protease inhibitors, Park et al (1997) characterized two protease inhibitors and tested their allergenic reactivity. Both inhibitors (BWI-1 and BWI-2b) showed a low binding activity with IgE, which suggests that they may be minor allergenic proteins in buckwheat seeds.

Buckwheat allergy can sometimes cause severe reactions that are similar to those caused by soybean or peanut. The reaction is an IgE-mediated immediate type reaction (Wieslander 1996). Most known cases are in young children in Japan. In a screening

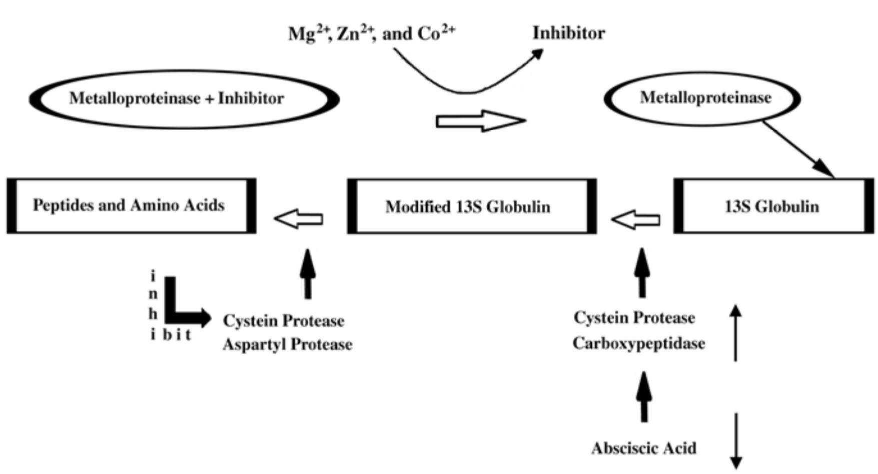

Fig. 3. Proteolysis in buckwheat seeds. Adapted from Belozersky and Dunaevsky (1999).

of 92,680 children, 0.22% had a buckwheat allergy. Symptoms are asthma, urticaria, wheezing, and anaphalytic shock. In addition, people who are daily in contact with buckwheat or buckwheat products are likely to become allergic to buckwheat. It has been reported that health shop workers, bakers using buckwheat flour, and buckwheat noodle makers showed allergic symptoms when handling buckwheat. Besides asthmatic symptoms, buckwheat is the cause of various skin disorders (Wieslander and Norbäck 2001). Because buckwheat is a food often consumed by coeliac patients, the incidence of buckwheat allergy among coeliac sufferers has been established. Patients with coeliac disease combined with other food allergies have an increased buckwheat intolerance of 30%. Normal coeliac sufferers show a buckwheat allergy of 1% (Wieslander and Norbäck 2001). Park et al (2000) reported that buckwheat-allergic patients often complain about urticaria (nettle rash), dyspnea (difficulty with breathing), facial angioedema, and gastrointestinal symptoms such as vomiting and abdominal pain. They mentioned proteinaceous compounds with MW 9,000, 16,000, 24,000, and 29,000, which are proven to be potential major allergens. All isolated allergens reported have been proteinaceous. Yano et al (1989) isolated three allergenic proteins in buckwheat seeds. One of these proteins was a trypsin inhibitor. The MW of each protein varies between 8,000 and 9,000. The protein inhibitors were still reactive after heating for 60 min at 100°C (Yano et al 1989). Matsumoto et al (2004) identified an allergenic protein with MW 10,000 belonging to the 2S albumin family. It has been suggested that more attention should be drawn to albumins because this protein group is known to contain major allergens in walnuts and peanut allergy as well (Matsumoto et al 2004).

Functional Properties

It has been reported that buckwheat protein product (BWP) has various potential functional properties. BWP is composed of 65.8% w/w protein, 22.0% w/w lipids, 5.9% w/w nonfiber carbohydrates, and 3.1% w/w water. Defatted BWP is not suitable for utilization as a functional ingredient because food intake in rats fed with defatted BWP was significantly lower than in rats fed BWP (Tomotake et al 2002). BWP has been claimed to exhibit several functional properties such as hypocholesterolemic activity in rats fed with a high cholesterol diet (Kayashita et al 1995), suppression of body fat in rats (Kayashita et al 1996), and suppression of induced colon carcinogenesis in rats (Liu et al 2001). BWP is soluble over a wide pH range and might therefore be used in functional beverages (Tomotake et al 2002).

LIPIDS

In general, lipids comprise a small part of cereals and pseudocereals, but they have an important physiological role (Chapkin 2000). Lipids also play a role in food quality as they may cause deterioration of stored seeds or flours. In both common and tartary buckwheat, lipids are concentrated in the embryo. The embryo contains an average of 6.5% oil, while the endosperm contains <0.4% oil (Dorrell 1971). In buckwheat flour, the embryo is generally included (mostly in bran farctions), so the risk of deterioration by lipids is particularly important (Taira et al 1986).

Contents of free, neutral, and polar lipids are shown in Table IV (Mazza 1988). These results have been confirmed by Bonafaccia et al (2003b), but Kim et al (2002) and Dorrell (1971) have detected lower total lipid levels in common buckwheat varying from 1.9 to 2.4%. Generally, the level of lipids in buckwheat groats can vary per cultivar. The differences between lipid contents may be due to various seeding times. Early seeding cultivars in Japan exhibit higher lipid contents than late seeding cultivars (Taira et al 1986). Buckwheat also holds lipase activity. Most lipase activity, like the lipid itself is localized in the embryo. The lipase is a triacylglycerol lipase, which shows an optimal temperature of 30°C. It consists of two isozymes: LIP I that holds a lower activity (0.108 μmol of fatty acid released/min/mg of protein at 30°C using triolein as substrate) than LIP II (0.727 μmol of fatty acid released/min/mg of protein at 30°C using triolein as substrate) (Suzuki et al 2004). Eighteen fatty acids have been identified in buckwheat, of which 14 appear in all seed tissues. The eight main acids (oleic, linoleic, palmitic, linolenic, lignoceric, stearic, behenic, and arachidic) represent 93% of total fatty acids (Dorrell 1971). The fatty acid composition of common and tartary buckwheat is shown in Table V. Similar fatty acid compositions have been observed in amaranth oil and cotton seed oil (Jahaniaval et al 2000). The embryo contains most of the unsaturated fatty acids, while the hull has a high level of saturated fatty acids (Dorrell, 1971). Some fatty acids (linoleic acid and linolenic acid) are polyunsaturated and cannot be produced by the human body (essential fatty acids) (Chapkin 2000). One of these essential fatty acids (linoleic acid), is the major fatty acid present in buckwheat; the level of linoleic acid is particularly high in the seedcoat (Dorrell 1971; Taira et al 1986; Mazza 1988). Differences in the presence of levels of the various fatty acids have been reported (Tsuzuki et al 1991; Jahaniaval et al 2000; Bonafaccia et al 2003b). These differences may be due to variety in cultivars, growth locations, and seeding time (Tsuzuki et al 1991). Levels of some fatty acids can be increased by germination. The fatty acid level of the sprouts from germinated buckwheat seeds were analyzed. The level of linoleic acid and linolenic acid increased from 36.8 to 51% and from 2.7 to 19%, respectively (Kim et al 2004).

TABLE V
Fatty Acid Composition in Common and Tartary Buckwheat[a]

Fatty Acid	Level in Common Buckwheat (%)	Level in Tartary Buckwheat (%)
Myristic (C14:0)	0.0	0.0
Palmitic (C16:0)	15.6	19.7
Palmitoleic (C16:1)	0.0	0.0
Stearic (C18:0)	2.0	3.0
Oleic (C18:1)	37.0	35.2
Linoleic (C18:2)	39.0	36.6
Linolenic (C18:3)	1.0	0.7
Arachidonic (C20:0)	1.8	1.8
Eicosaenoic (20:1)	2.3	2.0
Behenic (C22:0)	1.1	0.8
Saturated	20.5	25.3
Unsaturated	79.3	74.5
Unsaturated/saturated	3.87	2.94

[a] Bonafaccia et al (2003).

TABLE IV
Lipids (% db) in Common Buckwheat[a]

Cultivar	Total Lipids	Free Lipids	Neutral Lipids	Polar Lipids	
				Glycolipids	Phospholipids
Mancan	3.2	2.6	2.6	0.15	0.33
Mancan (stored for 25 months)	2.9	2.4	2.4	0.13	0.22
Manor	2.6	2.2	2.2	0.09	0.27
Tokyo	2.9	2.1	2.5	0.13	0.32

[a] Mazza (1988).

MINERALS

Minerals are important for various physiological functions in the human body. The human body requires more than 100 mg per day of each major mineral (Na, Mg, K, Ca, P, S, and Cl) and less than 100 mg per day of trace elements (Cr, Mn, Fe, Co, Cu, Zn, Se, Mo, and I) (Insel et al 2004). The mineral composition of buckwheat groats is shown in Table VI. Variations in mineral composition between cultivars and growth locations have been reported (Ikeda and Yamashita 1994; Bonafaccia et al 2003a). Buckwheat is a richer mineral source (except for Ca) than many cereals such as rice, sorghum, millet, and maize. Especially, the levels of Mg, Zn, K, P, Cu, and Mn are high when compared with other cereals (Mazza 1988; Steadman et al 2001b). Mg, Zn, K, P, and Co are mainly stored as phytate in protein bodies (Elpidina et al 1991; Steadman 2001b). During germination, phytin is hydrolyzed and metal ions are dissolved (Bewley and Black 1985). Buckwheat contains 10.0 mg/g of phytic acid and the enzyme phytase that liberates 2.17 μmol of inorganic phosphate/min/g (Egli et al 2003). Protein bodies (and therefore Mg, Zn, K, P, and Co) are generally present in embryo tissues and the aleurone layer (Steadman 2001b). Minerals such as Fe, Zn, Mn, Cu, Mo, Ni, and Al are primarily localized in both hull and seed coat. Ca and B are present in hull fractions (Steadman et al 2001a,b; Bonafaccia et al 2003a; Skrabanja et al 2004). One possibility to increase mineral levels of buckwheat seeds is to germinate them in solutions with elevated mineral levels (Lintschinger et al 1997).

VITAMINS

Vitamins are a group of organic compounds that are essential in very small amounts for the normal functioning of the human body. They vary widely in their chemical and physiological functions and are broadly distributed in natural food sources (Ball 1998). Vitamin content of common buckwheat groats is shown in Table VII. Thiamine (vitamin B1) is known to be strongly adhered to thiamine-binding proteins in buckwheat seeds (Mitsunaga et al 1986; Rapala-Kozik et al 1999) and its bioavailability is uncertain. In general, tartary buckwheat has higher levels of vitamin B than in common buckwheat (Pomeranz 1983; Bonafaccia et al 2003a).

Levels of vitamin C and the sum of vitamin B1 and B6 can be increased by germinating buckwheat. The level of vitamin C can increase up to 25 mg/100 g in buckwheat sprouts (Lintschinger et al 1997; Kim et al 2004). Vitamin E includes all naturally occurring tocopherols and tocotrienols (Zielinski et al 2001). No tocotrienols have been detected in buckwheat (Zielinski et al 2001). Tocopherols are naturally occurring antioxidants (Dietrych-Szostak and Oleszek 1999) and exist in α-, β- γ- and δ- form (Burton and Traber 1990). Of wheat, barley, oat, rye, and buckwheat, buckwheat groats exhibit a maximum amount of 5.46 mg/100 g of tocopherols. Zielinski et al (2001) and Kim et al (2002) reported γ-tocopherol as the main tocopherol, while Przybilski et al (1998) detected α-tocopherol (the most potent biological and antioxidant form of the vitamin [Burton and Traber 1990]) to be the major tocopherol present. Differences have been attributed to different cultivars of common buckwheat (Przybylski et al 1998; Zielinski et al 2001; Kim et al 2002). Tartary buckwheat contains higer levels of tocopherols than common buckwheat (Kim et al 2002).

TABLE VI
Ash[a] and Mineral Composition of Common Buckwheat

Element[b]	Mineral Composition (mg/100 g, db)
1st Cluster	
K	565
P	490
Mg	267
Ca	19.7
2nd Cluster	
Fe	3.03
Zn	2.92
Mn	1.64
Cu	0.71
Mo	0.09
Co	0.01
Cr	0
3rd Cluster	
B	0.67
Al	0.36
Ni	0.24
Cd	0

[a] Steadman et al (2001b). Amount of ash (g/kg, db) is 24 ± 1.
[b] First cluster of minerals contains major minerals for humans; the second cluster contains trace elements; the third cluster contains remaining minerals.

PHYTOCHEMICALS

Flavonoids

Phytochemicals are plant substances that may promote good health but are not essential for life (Insel et al 2004). Oxidative stress, which releases free oxygen radicals in the body, has been implicated in a number of disorders including cardiovascular malfunction, cataracts, cancers, and rheumatism. Phytochemicals present in fruits and vegetables can act as antioxidants by scavenging free radicals and saving the cell (Kaur and Kapoor 2001). Widely known antioxidants are vitamins A, C, and E. More recently, polyphenolic compounds such as flavonoids have received interest due to their antioxidant effect (Rice-Evans et al 1997). Flavonoids are ubiquitous in most plants and usually exist in glycosidic forms (Rice-Evans et al 1997). It has been reported that flavonoids in regularly consumed foods such as tea, apples, and onions may have reduced the risk of death from coronary heart disease in elderly men (Hertog et al 1993). Another well known case is the French paradox: residents of southern France have a low incidence of coronary heart disease despite a high fat diet and smoking tendencies (Renaud and Lorgeril 1992). This may be due due to their Mediterranean diet.

In many cases, flavonoids show a greater efficacy as antioxidants in food systems on a mole-to-mole basis than the antioxidants vitamin C, vitamin E, and β-carotene (Table VIII) (Rice-Evans et al 1997). Rutin and quercetin are the main polyphenols with antioxidant activity present in buckwheat (Oomah and Mazza 1996; Kreft et al 1999; Steadman et al 2001b). In Table VIII, it can be seen that quercetin shows a higher antioxidant activity than rutin, which is a glycoside of quercetin (Fig. 4). It is generally known that glycolization reduces antioxidant activities (Rice-Evans et al 1997). Rutin and quercetin levels in buckwheat depend greatly on growth location and cultivar (Oomah and Mazza 1996; Steadman et al 2001b). In common buckwheat groats, levels of rutin and quercetin are ≈0.20 mg/g and 0.001 mg/g,

TABLE VII
Vitamin Levels in Common Buckwheat

Vitamin	Level (mg/100 g)
A (carotenoids)[a]	0.21
B1 (thiamine)[b]	0.46
B2 (riboflavin)[b]	0.14
B3 (niacin)[c]	1.80
B5 (pantothenic acid)[a]	1.05
B6 (pyridoxine)[b]	0.73
C (ascorbic acid)[d]	5.00
E (tocopherols)[e]	5.46

[a] Gabrovská et al (2002).
[b] Bonafaccia et al (2003).
[c] Aufhammer (2000).
[d] Lintschinger et al (1997).
[e] Zielinski et al (2001).

respectively. Buckwheat hulls contained higher levels of rutin (0.84–4.41 mg/g) and quercetin (0.009–0.029 mg/g) (Oomah and Mazza 1996). Tartary buckwheat is an excellent source of rutin because groats of tartary buckwheat showed levels of rutin at 80.94 mg/g. Besides rutin and quercetin, Watanabe (1998) isolated four catechins with antioxidant activity from ethanol extracts from buckwheat groats (*F. esculentum* Moench cv Iwate zairai): epicatechin, catechin 7-*O*-β-D-glucopyranoside, epicatechin 3-*O*-*p*-hydroxybenzoate, and epicatchin 3-*O*-(3,4-di-*O*-methyl)-gallate. Catechins show a higher antioxidant activity than rutin (Watanabe 1998). But both rutin and quercetin have another advantage in addition to their antioxidant activity: they can help with treatment of chronic venous insufficiency (Erlund et al 2000).

Processing

When buckwheat is processed, flavonoid levels and, therefore, antioxidant activity can be affected. When buckwheat is heated to 150°C, the flavonoid concentration is reduced. A reduction of flavonoid concentration of 20% has been determined when buckwheat is heated for 10 min at 150°C, and a reduction of 40% has been determined when buckwheat is heated for more than 1 hr and 10 min at 150°C. The concentration of flavonoid content in hulls is also affected, but to a much lesser degree than the concentration in groats (Dietrych-Szostak and Oleszek 1999). Flavonoid contents can be increased by producing buckwheat sprouts. Rutin and quercetin contents in seeds were 0.63 and 0.35 mg/g, respectively. Seven days after seeding, rutin and quercetin content in buckwheat sprouts were increased to a maximum of 22.36 and 23.12 mg/g, respectively (Kim et al 2004).

Comparison with Other Cereals

Several solvents and methods can be used to prepare extracts of phenolics. The amount of phenolics extracted will depend on solvent (water, ethanol, or methanol), time, and temperature used (Zieliński and Kozlowska 2000). In addition, several methods to determine antioxidant activity can be applied. These include β-carotene bleaching method, AAPH induced peroxidation method (liposome system), ABTS-(radical cation)-scavenging technique, and DPPH radical scavenging method (Zieliński and Kozlowska 2000; Sun and Ho 2005). Results measured with ABTS-(radical cation)-scavenging technique showed a higher activity of extract prepared from buckwheat than results measured by the liposome system. When various cereal grains were extracted with water, only the extract prepared from the whole seed of buckwheat showed antioxidant activity. The remaining extracts from the whole grains of wheat, barley, rye, and oats exhibited a pro-oxidant effect (Zieliński and Kozlowska 2000). In 80% methanol extraction, total phenolics correlated with total antioxidant activity. Buckwheat extract again showed the highest antioxidant activity in the order buckwheat > oats > barley > wheat > rye. But when corrected to similar phenolic concentrations, the highest antioxidant activity has been found in oats (Zieliński and Kozlowska 2000).

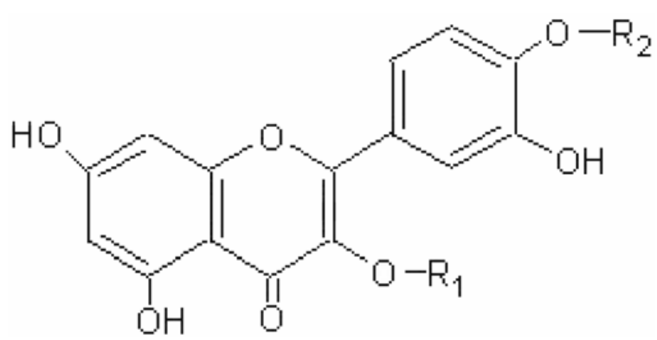

Fig. 4. Structure of quercetin (R_1 = H, R_2 = H), quercetin-4'-*O*-glucoside, (R_1 = H, R_2 = glucose), and rutin (R_1 = rutinose, R_2 = H).

Effect of Buckwheat Flavonoids

Flavonoid glycosides are usually hydrolyzed by intestinal microorganisms (Rice-Evans et al 1997). *Eubacterium ramulus* is a gut bacterium that has been proved to degrade flavonoids from buckwheat. Dietary flavonoids from buckwheat leaves act as a better substrate for *E. ramulus* than pure rutin (Simmering et al 2002). Several glucuronides have been identified as quercetin me tabolites in human blood. These potentially active glucuronides are identical regardless of the type of quercetin glycosides administered (Graefe et al 2001). Buckwheat plant extract showed better effects than pure rutin: the level of potentially bioactive quercetin metabolites in plasma was 1.33 times higher when buckwheat plant extract was administered to humans (Graefe et al 2001). Boyle et al (2000) revealed that by supplementing quercetin, total quercetin levels in plasma of humans were elevated but the antioxidant status of the blood plasma was not affected. On the other hand, serum antioxidant capacity increased significantly (by 7%) when 25 healthy men were administered with buckwheat honey, a natural product of buckwheat (Gheldof et al 2003).

Toxic Polyphenols

Fagopyrin is a complex polyphenol present in buckwheat. It can cause photosensitization, or so-called fagopyrism, in light-skinned animals exposed to sunlight. Seeds contain very few fagopyrins but the whole plant, either dried or green, can cause serious problems in livestock (Johnson 1983; Cheeke and Shull 1985).

CONCLUSIONS

Overall, buckwheat has major potential as food ingredient, especially for the functional and clinical food industry. Buckwheat (a pseudo-cereal) contains protein of high nutritional value, dietary fiber, resistant starch, rutin, fagopyritols, minerals, and vitamins. In general, more studies should be undertaken of the actual effect of buckwheat and its products on humans. Most studies on the effects of D-*chiro*-inositol, fagopyritols (galactosyl derivatives of D-*chiro*-inositol), resistant starch, and buckwheat protein product exhibited positive effects on rats. D-*Chiro*-inositol and fagopyritols reduced plasma glucose levels in rats and may be a possibility in helping to treat diabetes patients. Resistant starch may have similar effects as fiber. There have been claims that buckwheat protein product exhibits several functional properties in rats, such as hypocholesterolemic activity in rats fed with a high cholesterol diet, suppression of body fat, and suppression of induced colon carcinogenesis. Few studies have been conducted on quercetin and rutin (a glycoside of quercetin), the two major

TABLE VIII
Antioxidant Activities of Various Compounds from Different Sources[a]

Antioxidant	Source	Antioxidant Activity[b]
Vitamins		
C	Fruit and vegetables	1.0 ± 0.02
E	Grains nuts and oils	1.0 ± 0.03
Flavon-3ols		
Quercetin	Onion, apple skin, berries, balck grapes, tea, broccoli, buckwheat	4.7 ± 0.10
Kaempferol	Endive, leek, broccoli, grapefruit and tea	1.3 ± 0.08
Flavones		
Rutin	Buckwheat, onion, apple skin, berries, black grapes, tea and broccoli	2.4 ± 0.12

[a] Rice-Evans et al (1997).
[b] Antioxidant activity measured as the TEAC (Trolox equivalent antioxidant activity). Concentration of Trolox with the equivalent antioxidant activity of 1 m*M* concentration of the experimental substance.

antioxidants in buckwheat, and their effect on humans. Several glucuronides have been identified as quercetin metabolites in human blood. These potentially active glucuronides are identical, regardless of the type of quercetin glycosides administered. But the actual antioxidant in vivo is still disputable. In addition, quercetin and rutin have been mentioned for treatment of chronic venous insufficiency in humans, but scientific proof has not yet been offered.

Buckwheat is a major ingredient in a daily diet for coeliac sufferers. Starch is present in amounts similar to that in cereals. Shape and composition of buckwheat starch are similar to cereals, but other properties, such as high viscosity values, correspond more with tuber starches. Buckwheat groats (dehulled seeds) contain similar amounts of fiber as other cereals, while the hulls contain maximum amounts of fiber. Protein in buckwheat is of high nutritional quality because it contains a relatively higher amount of lysine than cereals. On the other hand, low digestibility has been reported, possibly due to tannins, phytic acid, and protease inhibitors. At least seven protease inhibitors have been isolated, all of proteinaceous origin. Malting may be one possibility for increasing protein digestibility through processing. In addition, germination increases levels of essential fatty acids, minerals, and vitamins. Malting can thus enhance the nutritional and functional quality of buckwheat even further.

More attention should be given to protease inhibitors because some have been found to be allergenic to humans. The main symptoms of buckwheat allergy are asthma and skin disorders. Precaution measures when handling buckwheat on a daily basis should be considered until more research has been conducted. This research should be focussed on the evaluation of allergenic compounds because both protease inhibitors and other proteins may cause allergic reactions. With regard to fatty acids, buckwheat contains a high level of polyunsaturated essential fatty acids because linoleic acid is the major fatty acid present in buckwheat. Several vitamins, such as B1, C, and E are present. Minerals are present in abundance. Buckwheat is a richer mineral source (except for Ca) than many cereals such as rice, sorghum, millet, and maize. The levels of Mg, Zn, K, P, Cu, and Mn are especially high when compared with cereals. In conclusion, buckwheat can be used as part of a daily diet, particularly by coeliac sufferers, and has great potential as a health and functional food.

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