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Nutritionally Important Components of Proso Millet (*Panicum miliaceum* L.)

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ABSTRACT

Proso millet (*Panicum miliaceum* L.) belongs to one of the first cultivated plants. Although the crop is traditionally grown, especially in Asia and from European countries through to Russia, nowadays it has become a new alternative crop and a new raw material for food production in many developed countries. Also changes of climatic conditions can support the growth of this drought-resistant plant. Millet products have found use in diets of patients with celiac diseases because the protein complex does not content gluten-forming proteins. While the protein is deficient in lysine like common cereals, proso millet has higher component of essential amino acids than barley, oat, rye and wheat. Therefore millet protein together with other proteins could be a basis for the development of new foods. Grains of proso millet are a rich source of starch, trace elements, dietary fibre and vitamins. Seeds also contain components with healing benefits, which decrease the level of low-density lipoprotein cholesterol in blood and injury to the liver. Phenolic compounds like antioxidants and beta-glucans are present, too. However compounds decreasing the nutritional value of the foodstuff like tannins, phytates or oxalates are included. The allergenic responses to proso millet are rare but have also been established. This review focusses on the knowledge of the chemical composition and some characteristics important for processing millet and its utilization for new products.

Keywords: antinutritive compounds, chemical composition, healthy effects, processing characteristics, products, quality

Abbreviations: BV, biological value; **BU**, Brabender units; **HDL**, high-density lipoprotein; **PER**, protein efficiency ratio; **TD**, true protein digestibility; **TIU**, trypsin inhibitory units per gram flour; **TGW**, thousand grain weight

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INTRODUCTION

Proso (common) millet (*Panicum miliaceum*) belongs to the one of the oldest cultivated crops. Vavilov assumed that proso millet originated in East Asia. The findings of seed pieces from Neolithic villages in China (4000 BC) supported this theory (Lu *et al*. 2005). However the earliest remains of proso millet come from the Neolithic sites of central Europe and therefore a new theory on the origin of proso millet was suggested. Proso millet was probably domesticated within the area ranging from Central Asia and Afghanistan to India and from there they were dispersed both to the west in Europe and to the east in Asia (Sakamoto 1987).

In Africa and India, it has been used as a staple food for thousands of years (Bough *et al*. 1986). In China, it was the prevalent grain before rice became the dominant staple (Bohle *et al*. 2003). In Mongolia, evidence about diet and land use from the 13th to the 15th century was revealed; then proso millet belonged to four the most frequent cereal species there (Rösch *et al*. 2005). In Europe, proso millet was one of the main cereals of Slavs. However during 18th cen-

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tury its importance gradually decreased with the development of potato growing, import of rice and increasing popularity of wheat bread. In the 17th century, proso millet was first introduced to Canada. Unfortunately, wild-proso millet has become one of the most aggressive grass weeds in North America since the early 1970s (Bough *et al*. 1986).

FAO data about production of all millets are given together under the general heading of millet. The minor millets include proso millet (*Panicum miliaceum*), foxtail millet (*Setaria italica*), kodo millet (*Paspalum scrobiculatum*), finger millet (*Eleusine coracana*), little millet (*Panicum miliare*, *Panicum sumatrense*) and barnyard millet (*Echinochloa colona*, *E. crusgali*, *E. frumentacea*). Total millet production reached 27.75 million tonnes in 2004 and about 22 million tonnes were consumed as food. Five countries - India, Nigeria, the Niger, China and Russia participated with about 75% in the total millet production. Millets play an important role especially in the nutrition of rural people of the semi-arid and arid tropics. About 86% of millet production was utilized in developing countries in 2004.

Exact statistical data about proso millet are unavailable. Proso millet is produced in China, Russia, India, and some countries of Eastern Europe and North America. Colorado is the largest producer of millet in the United States (Baltensperger 1996). In western nations proso millet is of minor economic importance because of the great abundance of wheat, maize and other cereal crops (Delost-Levis *et al*. 1992). Therefore the grain of proso millet is mainly used there as bird feed. However in recent years, it started to become a more popular crop due to its high-quality proteins. Grains are rich in minerals and vitamins and their nutritive parameters are minimally the same or better than common cereals (Seetharam 1999). Proso at 1427 kJ (341 kcal) per 100 g is comparable with wheat, maize or rice (348, 358 and 362 kcal) (Yanez *et al*. 1991; FAO 1995). The interest in millet utilization as a foodstuff is supported especially by health reasons, because a rational and varied diet could help to decrease the causes of many civilizational diseases. In Japan, consumption has recently increased due to health reasons, for instance as a replacement cereal for celiac disease or atopic dermatitis (Shimanuki *et al*. 2006).

In the Czech Republic, its popularity increased with a development of organic farming during the last 20 years. Its wide adaptability to soil and climatic conditions especially dry resistance and its very short growing season (80-90 days) connected with the ability to grow at a wide range of altitudes (0-2200 m with respect to the sum of effective temperatures 2300°C) help in the return of interest in millet growing. On the contrary, the main disadvantages are marginalization and low breeding of this crop yet, which is confirmed by the very close similarity of medieval proso millet to modern a millet variety (Lagler *et al*. 2005).

CHEMICAL COMPOSITION

Protein

The protein content in the millet caryopsis is comparable to maize and wheat. The content can range a lot dependending on the variety, environmental conditions and nutrients in the soil and weather conditions during grain formation. The most common protein level varies from 11.5 to 13.0% with a maximum of about 17% (Geervani and Eggum 1989a; Dendy 1995; Parameswaran and Thayumanavan 1995; Kalinová and Moudrý 2006). Varieties with a red seed coat (**Fig. 1**) have the lowest content and quality of protein (Essential Amino Acid Index, or EAAI) than light-coloured grains. Dry conditions cause an increase in protein but the quality of protein decreases (Kalinova and Moudrý 2006). Dehulled grains have a little bit higher protein content (12.3-16.3%) due to the removal of the seat coat that is poor in proteins (Jones *et al*. 1970; Ravindran 1991). The protein content of proso millet is higher than other millets (*S. italica*, *E. colona*, *Pasp. scrobiculatum*, *P. miliare*; 6.5-11.5%) (Geervani and Eggum 1989a).

Fig. 1 Different varieties of proso millet: Polyploid (white), Hanacka Mana (grey), Toldanskoe (red), Kharkovskoe (orange).

The protein quality (EAAI) of proso millet (51-67) is higher than in maize, wheat, rye, barley and oat (Velisek 1999; Kalinová and Moudrý 2006). The EAAI compares the amount of the essential amino acid to the amount present in a reference protein (egg or milk protein). The protein quality of proso millet is higher than in other minor millets (FAO 1995). Except for the EAAI, the nutritional quality of protein is possible to evaluate by biological methods like the biological value (BV), true protein digestibility (TD), proein efficiency ratio (PER) and others, which take into account the digestibility of protein and availability of amino acids. The BV of proso millet is similar to bean and wheat flours and varies between 42 and 56 (Geervani and Eggum 1989a; Becker 1994; Dendy 1995). Even though millet contains inhibitory tannins and protease, the digestibility of cooked millet is comparable to other cereals. The *in-vitro* true protein digestibility value of proso millet was 71.3% and in cooked samples 88.6% (Ravindran 1992). The calculated TD of protein ranged between 95.0 to 99.3 (Geervani and Eggum 1989b). A proso millet diet has a PER of about 1.2 (Badi *et al*. 1990).

The limiting amino acid of proso protein is lysine whose content ranges from 1.4 to 4.3% (Ravindran 1992; Dendy 1995; FAO 1995; Kalinová and Moudrý 2006). However the lysine level is still higher than e.g. in wheat (Kalinová and Moudrý 2006). According to Geervani and Eggum (1989a), the lysine content of proso millet is low compared to other millets (*S. italica*, *E. colona*, *Pasp. scrobiculatum* and *P. miliare*; 106-188 mg/g) although, according to FAO (1995), the lysine content in proso millet is the highest from minor millet (*S. italica*, *Pasp. scrobiculatum*, *Eleusine coracana*, *P. sumatrense*, *E. colona*). The protein of proso millet can be also marginal in threonine (Dendy 1995), while levels of the other essential amino acids in protein of proso millet is adequate (**Table 1**). The complex is rich, especially in leucine (Ravindran 1992; Kalinová and Moudrý 2006). Glutamic acid, alanine, proline and asparatic acid are the major non-essential constituents of proso millet protein (Ravindran 1992; Kalinová and Moudrý 2006).

The data on amino acid score relative to amino acid requirement for different age groups suggested that the protein of proso millet is not adequate to meet the growth requirements of young children. Lysine amino acid scores are only from 23 to 72% for infants, from 24 to 74% for pre-school children and from 32 to 98% for schoolchildren (10-12

Table 1 The content of essential amino acids in proso millet grain (g/16 g N).

Reference	Jones *et al.* 1970	Ravindran 1992	Dendy 1995	Velisek 1999	Kalinová and Moudrý 2006
Number of varieties	1	6	n[1]	n	8
Isoleucine	4.1	4.9	4.5	4.1	4.0
Leucine	12.2	14.0	12.9	9.6	9.9
Lysine	1.5	1.7	2.2	3.4	2.5
Methionine	2.2	4.1	2.0	2.5	1.7
Phenylalanine	5.5	6.3	5.2	4.8	4.5
Threonine	3.0	4.1	3.4	3.9	3.1
Tryptophan	0.8	-[2]	0.9	2.0	-
Valine	5.4	6.4	5.1	5.5	4.6
Arginine	3.2	4.1	4.4	5.3	3.3
Histidine	2.1	2.4	2.2	2.4	2.1
Alanine	3.2	-	9.3	7.9	7.8
Aspartic acid	6.2	6.7	5.5	8.0	8.6
Cysteine	1.0	1.0	1.7	2.4	-
Glutamic acid	21.3	25.2	20.5	18.6	19.00
Glycine	2.1	2.9	2.2	3.8	3.4
Proline	7.3	7.8	7.2	6.1	-
Serine	6.3	7.6	6.3	4.9	3.7
Tyrosine	4.0	4.5	3.9	3.2	3.3

[1] It was not stated
[2] It was not determined

years). However the protein is able to meet the maintenance requirements in adults (FAO 1995).

The proso millet protein consists mainly of globular bodies measuring up to 2.5 μm in diameter (Jones *et al.* 1970). Data about the content of individual protein fractions are very different due to diverse methods of determination. Prolamins are the major storage protein in most cereal seeds. Earlier studies recorded that prolamins constitute about 31-50% of the grain protein in proso millet (Jones *et al.* 1970; Dendy 1995). Other studies recorded glutelins as being dominant (13-42%) in the protein complex (Parameswaran and Thayumanavan 1995; Petr *et al.* 2003). Glutenous (waxy) millet (starch contains about 99% amylopectin) are characterised by a higher protein content of albumins and globulins (18-31%) than non-glutenous types (about 13-16%) (Jašovskij 1987; Parameswaran and Thayumanavan 1995).

The major storage protein in the other minor millets (*Pasp. scrobiculatum*, *P. miliare*, *E. frumentacea*) are glutelins, except for *S. italica* where prolamins constitute a major storage protein, from 40 to 60% of the total protein (Parameswaran and Thayumanavan 1995; Petr *et al.* 2003). A protein band at the molecular weight range of 20 kD is homologous in *Pasp. scrobiculatum*, *P. miliare*, *E. frumentacea* and *S. italica*, except for proso millet (Parameswaran and Thayumanavan 1995). The antibody of 20 kD prolamin from *Pasp. scrobiculatum* cross-reacted with the other minor millets and cereals (wheat, maize, rice) which shows the remarkable conservation of this polypeptide among minor millets and cereals, especially rice (Parameswaran and Thayumanavan 1997).

According to Godkin and Jewell (1998) maize, rice and millet have shown no evidence of toxicity for people with celiac sprue. By immunological tests with proso millet, the gliadin content was established below 10 mg per 100 g (Petr *et al.* 2003), thus under the permissible level for patients with gluten sensitive entheroterapy. Therefore proso millet is a suitable foodstuff for them. Gluten sensitive entherotherapy, also known as celiac sprue or celiac disease, is an autoimmune disease of the small intestinal mucosa in genetically susceptible persons. It is caused by an intolerance to grain prolamins and particularly gliadins, a protein component of cereal grains including wheat, oats, barley and rye (di Cagno *et al.* 2004).

The prolamines have less lysine (0.65%), arginine (11.64%) and glycine (2.56%) and more alanine (4.25%) methionine (1.30%) and leucine (13.55%) than the albumins or globulins (Jones *et al.* 1970; Parameswaran and Thayumanavan 1995). According to Kohama *et al.* (1999) the polypeptides of the prolamines in proso millet are represented by two groups and are very close to α-zein. The first group of 24 kD is rich in glutamin acid, leucine and alanine, whereas the second group of 17-14 kD is rich in methionine and cysteine. Glutelin-like proteins are high in proline content with major peptides 17 and 20 kD. Major polypeptides of glutelin-like protein contain a Pro-Pro-Pro-Leu-His sequence, like γ-zein. The globulins are rich in arginine and residue protein has less cysteine than soluble fractions (Jones *et al.* 1970).

Due to the relatively large non-protein N components (17.3-17.8%) the protein content of millet may be overestimated (Ravindran 1992; Parameswaran and Thayumanavan 1995). However the amount of the non-protein N components is lower than in *E. coronata* and *S. italica* (Ravindran 1992; Petr *et al.* 2003).

Protein and beneficial effects

The dietary protein of proso millet plays an important role in cholesterol metabolism because the protein increases high-density lipoprotein (HDL) cholesterol levels, especially the HDL_2 subfraction without an increase in low density lipoprotein cholesterol level (Nishizawa and Fudamo 1995; Shimanuki *et al.* 2006).

Experiments with rats confirmed that proso can be considered as a preventive food for liver injury like hepatic encephalopathy upon chronic liver failure. The suppressive effect of proso millet protein on liver injury consists in the ratio of branched-chain amino acids to aromatic amino acids in proso millet protein. The ratio of proso millet protein is 3:1 and it is in the ideal range for treatment of hepatitis (Nishizawa *et al.* 2002).

In India, three traditional food products (leavened steamed cake, kedgeree and sweet balls) prepared from millets, fenugreek seeds and legumes were well tolerated and acceptable to the subjects with diabetes (Pathak *et al.* 2000). In many parts of Asia millet, especially finger millet (*S. italica*) is considered to be an antidiabetic food. Lower carbohydrate content and more fibre than other cereal foods was considered to be the main reason (Ravindran 1991). According to late studies, foxtail millet protein may improve insulin sensitivity and cholesterol metabolism through an increase of adiponectin concentration. Adiponectin is a protein of human milk, which probably protects against obesity and diabetes (type II). Therefore foxtail millet protein would serve as a food component in obesity-related diseases (Choi *et al.* 2005). Similar studies in proso millet have not yet been conducted.

Allergy

Intolerance to food is one of the main causes of systemic anaphylaxis. The cases of anaphylaxis to millet (urticaria, dyspnoea, and unconsciousness) have been described after ingestion of food containing millet (Voit *et al.* 1996; Olivier and Hauser 1998; Stuck *et al.* 2001). Millet also plays an important role as an inhalant allergen. This case was observed by owners of birds during cleaning of cage, when the asthmatic reactions appeared due to hypersensitivity to millet containing birdseed (Bohle *et al.* 2003). A sensitisation to millet can subsequently also elicit food allergy. A skin scratch test of these patients was strongly positive to millet and other ingredients were negative. Intradermal testing was positive for rye, oats, maize, and barley (Stuck *et al.* 2001). The millet seed extract produced positive intradermal responses at a concentration of 100 pg/ml (Parker *et al.* 1981). In proso millet three major allergens were detected (36 kDa by 94% of patients, 70 and 90 kDa by 62 and 75% of patients) and IgE binding to millet was not based on cross reactivity with grass pollen (Bohle *et al.* 2003). Although anaphylaxis to millet is still rare, increased millet consumption could increase the incidence of millet-related allergic reactions.

Table 2 Mean content of some mineral elements in the proso millet grain.

	Ca	P	K	Na	Mg	Fe	Cu	Zn	Reference
			g/100 g				mg/kg		
Caryopsis	0.23	0.40	2.24	-	0.26	25.0	16.3	18.5	Demirbas 2005
Dehulled grain	0.03	0.26	0.37	0.06	0.12	20.0	4.0	11.0	Ravindran 1991
	0.02	0.23	0.32	0.01	0.14	52.0	8.3	17.2	Dendy 1995
	0.02	0.36	0.20	0.01	0.11	46.8	6.1	25.6	Kalinová 2002

Starch

Polysaccharides constitute the main part (97.1%) of the total saccharides (64.5 g/100 g) in proso millet (Becker 1994). Sucrose (0.66 g/100 g DM) and raffinose (0.08 g/100 g DM) are present from the soluble saccharides (FAO 1995).

Starch represents from half to three-fourths of caryopsis weight (Jašovskij 1987; Yanez *et al*. 1991). Starch granules of proso millet has a bimodal distribution with two basic shapes and sizes, small spherical and large polygonal. Dense packing of the endosperm with protein bodies causes indentations many large polygonal granules. The size of starch granules ranges from 1.3 to 13.5 µm (Kumari and Thayumanavan 1998; Yanez *et al*. 1991).

Starch consists of two main components; amylopectin and amylose. The amylose (straight-chain polymer of glucose) content in proso millet ranges from 17.21% to 32.6%, dry basis (Yanez *et al*. 1991; Kumari and Thayumanavan 1997). Proso millet starch has an amylose content slightly higher than maize (17-27%) (Yanez *et al*. 1991) and slightly lower than rice (28%) (Kumari and Thayumanavan 1997). Glutenous proso millet contains only traces of amylose (0.0-1.0%), therefore these types are perspective to utilization in food, chemical, textile and other industries (Jašovskij 1987).

Native starch of proso millet shows the maximum digestibility (50.0%) in comparison to other millet (*S. italica, Pasp. scrobiculatum* and *E. frumentacea*) (Kumari and Thayumanavan 1997) and the starch digestibility is similar to that of maize (43%) (Yanez *et al*. 1991).

Heat processing increases the digestibility of starch but a fraction of starch is resistant to digestive enzymes. Resistant starch plays an important role in decreasing blood glucose and influences the serum triglyceride level. The content of resistant starch in native starch of proso millet is markedly lower (0.39% dry basis) in comparison to *E. frumentacea* (Kumari and Thayumanavan 1997).

Grain starches in general show very little uptake of water. Solubility of proso starch is about 6.89% at 90°C (FAO 1995). Millet starch has a higher binding water capacity than wheat starch and also has a higher tendency to break down (about 50 Brabender units - BU). Proso and foxtail millets show lower set back values (about 330 BU) than other millet (Kumari and Thayumanavan 1998).

Heat treatment leads to swelling of the granules and partial gelatinization of the starch. Gelatinization temperature of proso millet is from 56-68°C (initial) to 61-76°C (final) (Dendy 1995; FAO 1995). Gelatinization temperatures and enthalpy values for proso starch are higher than those of maize (64°C initial and 75.5°C final) (Dendy 1995; Kumari and Thayumanavan 1998). Proso millet has a lower gelatinization temperature than barnyard millet (84.9°C) and peak viscosity of proso millet is higher (520 BU), then those of other millets (*S. italica*, *E. frumentacea*, *Pasp. scrobiculatum*, *P. miliare*; 375-485 BU). Varietal differences exist in pasting properties of millet starch (Yanez *et al*. 1991).

The freeze-thaw stability of proso millet starch gels is lower than that of maize starch, when 50% separated water was obtained in maize and from 60 to 68% in proso millet after 3 freeze-thaw cycles. However, the millet gels are unusually able to re-absorb water (Yanez *et al*. 1991).

Fibre

Cereal grains are the most important source of dietary fibre in the human diet. Fibre content in the human diet plays an important role in prevention and treatment of high blood pressure and high levels of cholesterol (He *et al*. 2001). Fibre content in dehulled grains of proso millet is at a similar level to oat (0.8-1.2%); in the caryopsis it constitutes about 9.6% (Jašovskij 1987; Geervani and Eggum 1989a; Kalinová 2002). The soluble fibre reaches about 36% of total fibre (Becker 1994).

Plant cell walls contain suberin or lignin, which probably protect against colon cancer in the human diet (Ferguson and Harris 1996). Lignin compositions vary among cereals; only the *threo*- and *erythro*-stereoisomers of 4-*O*-β-coupled ferulate-coniferyl alcohol cross products were identified in proso millet, rice and barley fibres (Bunzel *et al*. 2004). Oats, rye, spelt (*Triticum spelta*) and wheat contain more of these compounds (*cis* isomer of the threo-4-*O*-β-coupled ferulate-coniferyl alcohol cross product, β-8-ferulate cross products). The dehydrodisinapates presumably derived from radical coupling of sinapate-polymer esters was not established in the cell wall of proso millet unlike its presence in wheat (Bunzel *et al*. 2003).

Cell wall composition of proso millet is similar to that of tissues of other graminaceous species. The wall contains among others, xyloglucan, arabinoxylan, uronic acid, arabinosyl, galactosyl residues, arabinogalactan and β-D-glucans (Carpita *et al*. 1985). β-D-glucans (glucose units linked to a long polymer chain) play an important role in human nutrition because they decrease total blood cholesterol. In comparison to other crops, the content of β-glucans in proso millet (0.5-1.0%) is at the same level of lentils (0.4-1.1%), maize (0.5-1.3%), rice (0.4-0.9%), spelt (0.6-1.2%) or wheat (0.5-1.0%) (Demirbas 2005).

Mineral compounds

The main portion of mineral compounds is contained in the pericarp, aleurone layer and germ. The content of mineral compounds in proso millet grains ranges from 1.5 to 4.2% (Jašovskij 1987; Ravindran 1991; Kalinová 2002) and it is higher than in wheat caryopsis (1.5-2.0%). The mineral compounds content is decreased to about 27-53% during

Table 3 Content of mineral compounds (mg %) in dehulled grains of different millet species and cereals.

Crop	P	Mg	Ca	Fe	Zn	Reference
P. miliaceum	156-230	78-140	8-20	0.8-5.2	1.4-2.6	Dendy 1995; FAO 1995; Kalinová 2002
S. italica	310-360	68 -130	10-21	2.8-3.3	2.1-2.4	Dendy 1995; FAO 1995
P. miliare	220	139	13	9.3	3.7	FAO 1995
E. colona	267	39	28	5.0	3.0	FAO 1995
Pasp. scrobiculatum	161-320	82-130	10-20	0.5-0.7	0.7	Dendy 1995; FAO 1995
Wheat	387	126	38	4.1	2.5	Kalinová 2002
Rice	90	120	25	2.2	1.6	Becker 1994
Barley	400	110	40	2.8	3.0	Becker 1994
Oat	340	129	80	5.8	4.5	Becker 1994
Buckwheat	464	221	27	4.0	2.8	Kalinová 2002

common food processing, dehulling (Dendy 1995). The intensity of losses of mineral compounds content is depended on the economy of dehulling.

Proso millet is poor in calcium but the seeds contain a high amount of phosphorus (**Table 2**). However the bond of phosphorus with phytates decreases considerably phosphorus availability (Dendy 1995). Proso millet is rich in potassium but also in iron and manganese (19.5-20.6 mg/100 g) (Jašovskij 1987; Ravindran 1991). Other millets are comparable sources of calcium, phosphorus and iron to proso millet (**Table 3**). Proso millet caryopsis is almost free (0.01 g/100 g) from sodium (Dendy 1995). The contents for most minerals in proso millet are slight higher or similar to those of other cereal grains (**Table 3**).

Microelements have a replaceable physiological function in every living organism, because they are a component of enzymes. Proso millet is a good source of zinc, copper (**Table 2**) and boron (11.6 mg/kg) (Murzamadieva 1979; Demirbas 2005).

Lipids

Lipids are relatively minor constituents in cereal grains but lipid content in dehulled grains of proso millet ranges from 3.5 to 6.7% (Jones *et al*. 1970; Lorenz and Hwang 1986; Ravindran 1991; Kalinová 2002). From cereals, only oat has a higher content (7.14%) of lipids in the grain than proso millet (Becker 1994).

The germ contains about 25% of total lipids and the physico-chemical characteristics of proso millet lipids (consistence, setting point, acid number) are close to sunflower, maize and soya lipids (Jašovskij 1987).

The content of free, bound and structural lipids in the total lipids of proso millet is 62.2, 27.8 and 10.0% (Sridhar and Lakshminarayana 1994). In the free lipids, hydrocarbons, sterol esters, triglycerides, diglycerides, and fatty acids are present. In the bound lipids, monogalactosyl diglycerides, digalactosyl diglycerides, phosphatidyl ethanolamine, phosphatidyl serine, and phosphatidyl choline were described (Lorenz and Hwang 1986).

The lipids consist from 81 to 88% of non-polar lipids (their main constituents are triacylgylcerols, 81%; free fatty acids, 4%; free sterols, 7.8%), from 8 to 14% of glycolipids (their main constituents are monogalactosyldiglycerides: 40.4%) and from 2 to 5% of phospholipids (their main constituents are phosphatidylcholine: 36.8%) (Sridhar and Lakshminarayana 1994; Dendy 1995).

The proso millet lipids contain from 86 to 89% of unsaturated acids and polyunsaturated acids constitute about 42% of unsaturated acids (Becker 1994). Polyunsaturated lipids (especially linoleic acid) play an important role in cholesterol metabolism. The main fatty acids of proso millet are linolenic (38.4-66.68%) oleic (21.4-22.7%) and palmitic (6.61-11.3%) acids (Lorenz and Hwang 1986; Dendy 1995). These acids oxidise easily and give an unpleasant taste to dehulled grains when the storage time is too long. The storage period should not be longer than three months in common room conditions. Their amount is depended on the variety and growing conditions (Jašovskij 1987).

In the millet oil, one can find a crystalline sediment (about 0.2%), which is created by miliacin, a pentacyclic triterpenoid. Miliacin is exploitable in pharmacy to obtain steroid hormones (Jašovskij 1987).

Vitamins

The dehulled grains of proso millet are rich in vitamin B1 – thiamine (0.42-0.80 mg/100 g), B2 – riboflavin (0.22-0.40 mg/100 g), B3 – niacin (1.55-3.7 mg/100 g), B6 – pyridoxin (0.52-0.80 mg/100 g) and E – tocopherol (0.1-2.60 mg/100 g) (Gromova 1991; Becker 1994; Dendy 1995). The level of vitamins B1 and B2 is twice as high as rice, wheat or barley (Murzamadieva 1979). They are deposited above all in the germ and aleurone layer therefore decortication considerably decreases their content (Dendy 1995).

The colour of dehulled grains is connected with carotene content and xantophyll (Iljin *et al*. 1973). The carotene content is relatively stable in different growing conditions such as soil type, level of fertilization and interannual weather changes (Jašovskij 1987). The unrefined fat extracted from the grain of proso millet contains from 8.3 to 10.5 mg A vitamin and from 87 to 96 mg vitamin E per 100 g (FAO 1995).

Phenolic compounds

Polyphenols in cereals have an adverse influence on colour, flavour, and nutritional quality. These compounds are mostly located in the outer layers of the grain. Factors such as plant part, stage of development, and environment influence the polyphenol content in plants. The total content of phenolic compounds in proso millet is about 0.05-0.10 mg per 100 g of catechin equivalents, dry basis (Dendy 1995). Polyphenols interact with proteins and create tannin-protein complexes (Salunkhe *et al*. 1985).

Tannins decrease the nutritive value of a product by binding protein, thus they reduce protein digestibility, and also binding to amylase, thus they block starch degradation. In the case of high tannin content in grain, their chelating effect is higher than that of phytates (Lestienne *et al*. 2005). The tannin content in proso millet ranges from 0.055 to 0.178% catechin equivalents, when dark-coloured (black and brown) grains have a higher tannin content than light-coloured grains (Lorenz 1983; Odumodu 1992). Dehulling of grains reduces the level of tannin content to 65-80% because hulls contain 15-40 times more tannin as the dehulled grains (Lorenz 1983).

C-glycosylflavones (especially glycosylvitexin, glycolsylorientin, and vitexin) identified in pearl millet grains demonstrated antithyroid and goitrogenic effects (Salunkhe *et al*. 1985). No information exists about the presence of these compounds or such effects in proso millet.

However some phenolic compounds are potentially protective against cancer and heart diseases. Whole grain millet grits contains about 373 mg/kg fresh weight (89.4% dry basis) of total phenolic acids, mainly ferulic acid, *p*-coumaric acid, ferulic acid dehydrodimers and also soluble chlorogenic acid. Brans of wheat or rye have twelve times higher level of total phenolic acids than proso millet and alk(en)ylresorcinols, that are common in rye or wheat, but not found in proso millet (Mattila *et al*. 2005).

Phytates, oxalates, enzyme inhibitors

Knowledge about such antinutritional factors as tannins, phytates, oxalates and enzyme inhibitors is important to predict the nutrition value of products.

Phytates bind certain minerals, particularly multivalent cations including Ca, Mg Fe and Zn, thus made these biologically less available. Phytic acid P constitutes the major portion of total P in the millets (Ravindran 1991). Phytic acid content in proso millet ranges from 0.17 to 0.61 g/100 g and it is higher than in polished rice but lower than in wheat (Lorenz 1983). The percentage of total phosphorous present in the phytic acid form in proso millet is about 67.3% (Ravindran 1991). Dehulling reduces the phytate content by 17-24% (Lorenz 1983). Milling, soaking, cooking, fermentation and breadmaking (Ravindran 1991) can also reduce phytic acid content of foods. In pearl millet grains, malting with 72 hours of germination was most effective in reducing both levels (48% in polyphenols and 50% in phytic acid) and blanching for 30 seconds in boiling water at 98°C significantly reduced phytic acids (38%), too (Sehgal and Kawatra 1998). Data about the influence of proso millet germination on the decrease of phytate content are unavailable.

Oxalate content has nutritional importance for its interference with calcium availability. The consumption of foodstuffs rich in oxalate can induce hyperoxaluria (Ravindran 1991). Oxalic acid is primarily located in the outer layers of cereal grains (Siener *et al.* 2006). The content of oxalate (from 21 to 23 mg/100 g) in dehulled proso millet grain is low and about 60-91% of the oxalates are present in a soluble form (Ravindran 1991; Siener *et al.* 2006). Soluble oxalate can be leached out during normal cooking but in foods they have probably a major effect on oxalate absorption (Chai and Liebman 2004). The content of soluble oxalate in hulled grain of proso millet is close to the content in naked barley, and the amount is considerably lower than in wheat and rye (Siener *et al.* 2006). The dark-coloured varieties of millet have the highest oxalate content (Odumodu 1992).

Enzyme inhibitors are natural compounds present especially in legumes but also in cereals and they influence enzymatic activity. Protease inhibitors are the most important for human nutrition. According to Chandrasekher *et al.* (1982) proso millet has no protease-inhibitory properties. On the contrary, Ravindran (1992) established the protease inhibitor activity of proso millet with considerable varietal and generic differences. The anti-tryptic activity of proso millet was higher, 732 trypsin inhibitory units per gram flour (TIU), than finger and foxtail millet (589 and 511 TIU). The anti-chymotryptic activity of proso millet was lower (62 TIU) than finger millet. A trypsin/chymotrypsin inhibitor has been identified in the *E. frumentacea* of nearly 14 kD (Udupa and Pattabiraman 1985). Two trypsin inhibitors have been identified in pearl millet (Pattabiraman 1985).

Mycotoxins

High moisture of harvested grains or rainy harvest period, alternatively bad storage conditions can be a cause for moulding, thus grains have lower nutritive value and there is a possible danger of the presence of mycotoxins. The suitability of proso millet grains as a substrate for fungal cultivation confirms the possible danger (Mayer *et al.* 1985). In samples of proso millet from the Ivory Coast it was established that the content of ochratoxin A ranged from 0.017 to 0.204 mg/kg. So, most of the samples exceeded the EU regulatory limit (5 µg/kg) for this mycotoxin (Sangare-Tigori *et al.* 2006). Ochratoxin A is produced by storage fungi belonging to the genera *Aspergillus* and *Penicillium* (Kačergius *et al.* 2005). Kalinová (2002) reported that except for storage fungi such as *Aspergillus* and *Penicillium*, fungi from the genus *Fusarium* commonly occur on the surface of proso millet grains. She established that the millet grains were contaminated by *F. acuminatum* and *F. tricinctum*. *F. acuminatum* is, according Kačergius *et al.* (2005) a possible producer of T-2 toxin. The intensity of fungal occurrence is dependent on the variety and environmental conditions. During World War II intoxication of people was common due to consumption of proso millet grains infected with *Fusarium* spp. in Russia and the Ukraine (Jašovskij 1987).

PROCESSING

The main products of millet mill processing are dehulled grains, millet flour and flakes. Flour ground from proso millet has been used as a partial replacement for wheat flour in breads, cookies and pasta (Delost-Levis *et al.* 1992). A prehistoric sample of noodles was found in an earthenware bowl discovered in the Late Neolithic in northwestern China 4,000 years ago (Lu *et al.* 2005). In Eurasia, utilization of proso millet like boiled grains (like rice), gruel, mochi, porridge and dumplings (dango), flour porridge and bread, alcoholic or non-alcoholic drinks is common (Delost-Levis *et al.* 1992). In the USA, the dehulled grains has been used e.g. cooked cereal breakfast or small amounts of lightly pigmented millet are decorticated and processed into puffed or hot breakfast cereals (Baltensperger 1996).

Whilst a number of traditional dishes are made in the household, the lack of industrial processing and utilization of this crop still exists. The main difficulties for industrial processing are a small amount of this raw material and small grains with a hard pericarp, which is necessary to remove. However, the nutritive value makes proso millet suitable for large-scale utilization of both grain and flour form in various food products, e.g. baby foods, snack foods, dietary foods, etc. (Subramanian and Viswanathan 2003).

Table 4 TGW (g) of proso millet in different growing conditions (mean ± sd) (Kalinová 2002).

	1998	1999	2000
Place 1 (380 m a.s.l., sandy-loam soil)	5.63 ± 0.10	5.76 ± 0.10	5.86 ± 0.10
Place 1 + 50 kg N /ha before sowing	5.44 ± 0.19	5.76 ± 0.09	5.49 ± 0.17
Place 2 (420 m a.s.l, loamy-sand soil)	5.78 ± 0.12	6.32 ± 0.05	5.87 ± 0.11

Table 5 TGW (g) of different varieties of proso millet (Kalinová 2002).

Variety	Mean ± sd
Belgorodskoe	5.93 ± 0.16 d
Hanacka Mana	5.27 ± 0.20 a
Kharkovskoe	5.77 ± 0.17 cd
Lipetskoe	6.39 ± 0.15 e
Polyploid	5.98 ± 0.21 d
Toldanskoe	5.65 ± 0.16 bc
Veselopodolianskoe	5.51 ± 0.08 b
Uilskoe White	5.64 ± 0.10 bc

Different letters indicate differences among varieties after Tukey's HSD.

The millet processing as dehulling, milling is dependent on grain properties. Dehulling of grains is necessary because hulls contain a very high percentage of silica (Lorenz and Dilsaver 1980a). We can consider as the main technological properties of proso millet thousand grain weight (TGW), specific density, size balance of grains, the part of hulls, the yield of dehulled grains, possibly consistence of endosperm.

The TGW of proso millet ranges most often from 5.0 to 6.5 g; it is dependent on environmental conditions during plant development (**Table 4**), the position in the panicle (the better developed grains are on the top of the panicle) and on variety (**Table 5**) (Kalinová 2002). The specific density reaches from 600 to 780 g/l (Jelagin 1981). The grains with a higher TGW are the most valued because the yield of dehulled grains is higher and the part of hulls is relatively lower.

The part of purely dehulled hulls ranges from 11 to 20% of the grain and is dependent on the variety used – the light-coloured grains have a lower portion of hulls – and growing conditions; especially poor soil and dry weather during ripening (**Fig. 2**) increases the part of hulls (Lorenz and Dilsaver 1980a; Jelagin 1981). However the offal (hulls, a part of germs, fine particles) after mechanical dehulling reaches up to 30%. Therefore the most important information is the yield of dehulled grains, which represents from 45 to 68% of the grain. This characteristic is strongly influenced by environmental conditions. In a wet year the yield of dehulled grains was established as being lower than in a dry year due to the size imbalance and the high amount of small, unripe grains (Kalinová 2002). The size calibration is one of the possibilities for increasing the yield of dehulled grains. Then the part of dehulled grains reaches from 75 to 89% (Murzamadieva 1979).

The technology of millet dehulling (decortication) without subsequent milling includes the separation of impurities, eventually calibration of grains, the separation of hulls with abrasive decorticators, sorting of dehulled grains and polishing with cork or rubber discs. It is possible to successfully dehull millets with a barley pearler but the normal screen in the barley pearler has to be replace with a fine mesh screen (0.5 mm diameter openings) so that the hulls can be separate from the grains by winnowing (Lorenz and Dilsaver 1980a).

The dehulled grains are not suitable for long-time storage due to their high fat content. The dull dehulled grains are mostly rancid. The edible part can be use without next

Fig. 2 Stand of proso millet at the stage of ripening.

processing or is milled e.g. in the hammer mill (FAO 1995).

Roller mills, which are commonly used for wheat, are also possible to use for proso millet without being dehulled. The pericarp of millets has to be much moister than that of wheat; about 10% water must be equilibrated in the grain for four hours before it is ready for milling. The dry pericarp is broken into small pieces and it is not possible to separate the endosperm (FAO 1995). According to Lorenz and Dilsaver (1980a) comilling of wheat and nondehulled proso millets in a laboratory roller-mill (Quadrumat Jr. Mill) was feasible and tempering of millets to 12-15% moisture levels produced no advantage. The flours from the Quadrumat Jr. Mill were slightly lighter – L value = 86.9 – than from hammermill (L = 72.3-77.6).

FLOURS

Proso millet has a higher flour extraction (77.5-87.3%) than wheat (73.3%) (Jašovskij 1987). Milling yield of proso decreases with increasing levels of grain moisture (from 67-77 to 78-87%, depending on the variety). Flour extraction decreases as the grain is milled at moisture contents above 12%. As flour extraction decreases, the flour becomes lighter (Lorenz and Dilsaver 1980a).

According to Yanez and Walker (1986) the ash content increases with increasing moisture, especially at higher levels. The percent extraction and ash content decreases with increasing temper time, although flour extraction reductions are less evident (Yanez and Walker 1986). As flour yields are important, especially in developing countries, heating the grains before milling is not recommended (Lorenz and Dilsaver 1980a). Ash values of high-grade millet flours are considerably higher than of the wheat flour because the bran is very rich in ash (Lorenz and Dilsaver 1980a).

Millet flour can not be stored for long periods, as well as dehulled grains, because they have a tendency to turn rancid due to high fat content. Compared with wheat flour, except fat and ash, proso millet flour is higher or as high in nitrogen, depending on the flour extraction; graded flours milled without previous conditioning are higher in nitrogen than that of the wheat flour (Lorenz *et al*. 1980).

Nitrogen solubility values of proso millet flour are highest at pH 10. The solubility values might have been higher if the millet had been heat-treated before milling (Ravindran 1992). Nitrogen solubility is considerably lower in the proso millet flour than in wheat flour (Lorenz *et al*. 1980).

Heating the grain before milling increases the rate of proteolysis and makes the protein more susceptible to hydrolysis. The wheat flour is more easily hydrolysed than the proso millet flour (Lorenz and Dilsaver 1980b).

Digestibility of millet flour (86.1%) is lower in comparison to that of rice flour (94-95%) (Kasaoka *et al*. 1999). Autoclaving causes a reduction of 19-25 in TD and a 4-18 increase in BV (Geervani and Eggum 1989b).

Thermodynamic characteristics of millet are important for the design of machines, processes and controls. The specific heat and thermal conductivity of millet flour increases (from 1.33 to 2.40 kJ/kg/K and from 0.026 to 0.128 W/m/K) with an increase in moisture content (from 10 to 30%) while the thermal diffusivity decreases (from 0.820×10^{-3} to 0.592×10^{-3} m^2 /h) (Subramanian and Viswanathan 2003).

OTHER PRODUCTS

Leavened bread cannot be made from 100% millet flours because millets do not have gluten-forming proteins. Flours of 100% millet produce rather compact breads with a dense texture therefore they can be used only into flat breads (Schery 1972). Up to a replacement level of 15%, quite acceptable compared with a white bread and has typical nutty taste and pleasant aroma (Lorenz and Dilsaver 1980b). According to Jašovskij (1987) the bread, which is fully satisfactory in colour, taste, porosity and volume, is possible to bake from a mixture of wheat and millet flour (to 20-30% content of millet flour) or only from millet flour with 4% of rye pentosan. Increasing the amount of millet flour (from 0 to 20%) in the wheat-millet flour mixture reduces the farinograph absorption (from 67 to 61.5%), peak times (from 5.7 to 1.8 min) and specific volumes of breads (from 4.6 to 4.16 cc/g) and increases the mixing tolerance index (from 45 to 65 BU). Crumb colour became darker with higher amounts of millet flour (Lorenz and Dilsaver 1980b).

For decreasing the level of human gluten intolerance to a certain amount of wheat flour, new bread biotechnology that uses a mixture of non-toxic flours (oat, millet, and buckwheat) and wheat flour (30%), selected lactobacilli, which cause the hydrolysis of Pro-rich peptides (responsible for an inappropriate immune response), and a long fermentation time (24 h) was suggested (di Cagno *et al*. 2004).

Noodles of very acceptable taste and quality are prepared with 20% proso millet flour in the mixture. Levels of millet flour above 40% cause objectionable grittiness (Lorenz and Dilsaver 1980b).

Proso millet was found suitable for making cookies. Cookie spread factors increase and cookie top grain scores improve with increasing amounts of millet flour in the formulation (Lorenz and Dilsaver 1980b).

Except for good taste and nutrition, new possibilities of treatment are important, that would increase proso millet utilization as food. Roasting, microwave and heat-moisture treatments increase peak, trough, final viscosity, breakdown and a setback in rapid visco analyser viscograms; this increase results from inactivation of α-amylase in proso millet flour by the treatments (Shinoda *et al*. 2002).

Flaking is a process that is applicable also for making foods from millet. Decorticated grits are moistened with water and steamed or cooked to gelatinise some of the starch, dried to a moisture content of about 17% and rolled between flaking rolls (FAO 1995).

White proso (100%) is feasibly used in the formulation of flaked whole grain ready-to-eat breakfast cereals because they are moderately sweet (an acceptable degree) in combination with the nutty millet flavour but they are dark and with a strong aftertaste as "bitter" and "burnt". A used sweetener as dried honey or molasses positively affects not only sweetness but also the cereal colour, flavour and crispness in milk (Ferriola and Stone 1998).

Another possibility of processing is puffing. Proso millet is capable of explosive popping with a simultaneous increase in volume. The puffed products similar to popcorn demonstrate a greater rate of *in vitro* starch digestibility, they are higher in protein but lower in ash and fibre than unprocessed millet but nitrogen solubility of the puffed products is reduced. Puffing quality is significantly improved (more highly expanded, less dense and higher in protein content) by tempering to 15 or 18% moisture and gun-puffed at 140 or 160 psi and the puffing yield varies from 64 to 97% depending on the variety (Delost-Levis *et al.* 1992). Puffed millet is applicable for a whole-grain snack product.

Roller-drying millet or extrusion (grains cooked at high temperature for a short time) could probably be successfully applied to proso millet because they were described as suitable for the preparation of ready-to-eat, snack foods or other products from foxtail millet (Ushakumari *et al.* 2004).

According to Kasaoka *et al.* (1999) a method using a heat-stable α-amylase could be suitable for an industrial mass-production of a millet protein concentrate which would be useful to sustain protein nutrition in combination with other foods. The yield of millet protein concentrates is 10% or more, and the protein recovery of millet protein concentrates exceeds 85%, irrespective of the original millet flours. Protein composition of the concentrate is similar to that of flour (lysine was the limiting amino acid and protein digestibility = 80%). Protein concentration of proso millet in the concentrate is higher (777 g/kg) than concentrates of minor millets (*S. italica*, *E. crusgali*, *E. frumentacea* protein concentrates) but generally the foxtail millet concentrate is the best.

The proso millet grains and especially flours have a very low lysine content (0.79-1.14 g/100 g) (Lorenz and Dilsaver 1980a). Therefore the nutritive value of the final product is possible to influence by the addition of limiting essential amino acids or raw materials. Nishizawa *et al.* (2002) reported a positive effect of supplementation diet containing 73.3% proso millet flour by lysine and threonine on the growth of laboratory rats. The effect of fortification with lysine at 0.6 g/100 g dry matter on the increase of the BV and Net protein utilization is higher than by heating (Geervani and Eggum 1989b). The nutritive value of different millet-based baby foods supplemented with milk powder have about 20% higher protein level, and a slightly better amino acid composition in comparison to sorghum foods, thus they are adequate as the sole source of protein for children, according to the FAO (Badi *et al.* 1990). In some areas millets are the main source of energy. Therefore the addition of chickpea, which provides about 40% of total protein, is one of the possibilities to improve the nutritive value of a traditionally consumed fermented flat bread prepared from millet because the PER is increased by 0.7 (from 1.1 to 1.8) (Badi *et al.* 1990). PER is based on the weight gain of a test subject related to the intake of the given protein during the test period.

SPROUTED GRAINS

The practice of sprouting cereal grains has become popular in developed countries recently. They can be used in many different foods including breakfasts, salads, soups, casseroles, pasta, and baked products. Sprouted grains have an exceptional nutritive value (Lorenz 1980). Overnight soaking and germination up to 7 days significantly increases the free amino acids by 2.56% and total sugars by 11.14% while the content of dry matter and starch decreases by 18.5 and 42.5% (Parameswaran and Sadasivam 1994). The changes are caused by an increase in enzyme activity in the grain.

The degradation of starch during the germination is initiated by α-amylase, which produces soluble oligosaccharides from starch, and these are then hydrolysed by β-amylase to liberate maltose (Swain and Dekker 1966). Activity of α-amylase is very low at the initial stages of germination and increases steeply after a lag period. Maximal α-amylase activity is obtained on the fifth day of germination. The β-amylase activities increase gradually until the sixth day of germination, reaches a maximum level on the seventh day and thereafter shows a decreasing trend (Parameswaran and Sadasivam 1982). β-Amylase activity is an indicator of the germination ability and of seed vigour. The molecular weight of β-amylase is about 58 kD and the isoelectric point is 4.62. Amylose, amylopectin and soluble starch are the most suitable substrates for the enzyme (Yamasaki 2003). Finally, α-glucosidase breaks down maltose into glucose and plays a role for the respiration of seeds (Swain and Dekker 1966). The α-glucosidase (α-D-glucoside glucohydrolase) has a molecular weight of 85-86 kD and the isoelectric point is 8.3. Two forms of α-glucosidase (I and II) with identical MW have been isolated from proso millet grains (Yamasaki *et al.* 1996, 2005).

Germination also causes a change in amino acid composition and protein fractions. There is an increase in lysine by 2.76 g/16 g N, tryptophan by 1.5 g/16 g N, non-protein nitrogen contents by 0.99 mg/100 mg and albumin and globulin by 35.3%. A large decrease in prolamin (true prolamin by 7.3%, prolamin-like by 29%) accompanies germination (Parameswaran and Sadasivam 1994). A slight increase in crude fat and crude fibre, and slightly higher amounts of certain vitamins and minerals are evident, too. Most of the increases in nutrients are not true increases; the loss of dry matter, mainly in the form of carbohydrates, is caused by respiration during sprouting (Lorenz 1980).

Malting

Proso millet is a valuable malt material due to its high activity of amylase. This characteristic is dependent on the variety. Glutenous varieties are less suitable for malt production because they have lower amylase activity (Jašovskij 1987). The malt from proso millet was utilized as a substitute for barley malt in some European countries during World War II. Nowadays millet has been used in the malt industry in India, and in fermented beverages in Eastern Europe and Africa (Delost-Levis *et al.* 1992). Traditional beverages as *li* (low-alcoholic rice or millet beverage) and *jiu* (a fully fermented rice or millet beverage with an alcoholic content of about 10-15% by weight) are described in the earliest texts from China, *circa* 1200-1046 BC. Similar beverage samples were found in bronze vessels, dated to 1250-1000 BC (McGovern *et al.* 2004).

Germinated grains are suitable for the preparation of baby food in developing countries. Mixes consisting of 70% of either popped or malted proso millet flour, 15% roasted soy meal and 15% roasted peanut meal were successfully used to prepare 5 infant food products (sweet gruel, salty gruel, halwa, burfi and biscuits) in India (Srivastava *et al.* 2001).

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REFERENCES

Badi S, Pedersen B, Monowar L, Eggum L (1990) The nutritive value of new and traditional sorghum and millet foods from Sudan. *Plant Foods for Human Nutrition* **40**, 5-19

Baltensperger D (1996) Foxtail and proso millet. In: Janick J (Ed) *Progress in New Crops*, ASHS Press, Alexandria, VA, pp 182-190

Becker HG (1994) Buchweizen, Dinkel, Gerste, Hafer, Hirse und Reis- die Schäl- und Spelzgetreide und ihre Bedeutung für die Ernährung. *AID-Verbrauchrdienst* **39**, 123-130

Bohle B, Hirt W, Nachbergauer P, Ebner H, Ebner C (2003) Allergy to millet: another risk for atopic bird keepers. *Allergy* **58**, 325-328

Bough M, Colosi JC, Cavers PB (1986) The major weed biotypes of proso millet (*Panicum miliaceum*) in Canada. *Canadian Journal of Botany* **64**, 1188-1198

Bunzel M, Ralph J, Kim H, Lu F, Ralph SA, Marita JM, Ronald D, Hatfield RD, Hans Steinhart H (2003) Sinapate dehydrodimers and sinapate ferulate heterodimers in cereal dietary fibre. *Journal of Agricultural and Food Chemistry* **51**, 1427-1434

Bunzel M, Ralph J, LU F, Hatfield RD, Steinhart H (2004) Lignins and ferulate coniferyl alcohol cross-coupling products in cereal grains. *Journal of Agricultural and Food Chemistry* **52**, 6496-6502

Carpita NC, Jenny A. Mulligan JA, Heyser JW (1985) Hemicelluloses of cell walls of a proso millet cell suspension culture. *Plant Physiology* **79**, 480-484

Chai W, Liebman M (2004) Assessment of oxalate absorption from almonds and black beans with and without the use of an extrinsic label. *Journal of Urology* **172**, 953-957

Chandrasekher G, Raju DS, Pattabiraman TN (1982) Natural plant enzyme inhibitors Protease inhibitors in millets. *Journal of Science and Food Agriculture* **33**, 447-450

Choi YY, Osada K, Ito Y, Nagasawa T, Choi MR, Nishizawa N (2005) Effects of dietary protein of Korean foxtail millet on plasma adiponectin, HDL-cholesterol, and insulin levels in genetically type 2 diabetic mice. *Bioscience, Biotechnology and Biochemistry* **69**, 31-37

Delost-Levis K, Lorenz K, Tribelhorn R (1992) Puffing quality of experimental varieties of proso millets (*Panicum miliaceum*). *Cereal Chemistry* **69**, 359-365

Demirbas A (2005) β-Glucan and mineral nutrient contents of cereals grown in Turkey. *Food Chemistry* **90**, 773-777

Dendy DAV (1995) *Sorghum and Millets: Chemistry and Technology*, AACC, St.Paul, Minesota, 406 pp

di Cagno R, de Angelis M, Auricchio S, Greco L, Clarke C, de Vincenzi M, Giovannini C, d'Archivio M, Landolfo F, Parrilli G, Minervini F, Arendt E, Gobbetti M (2004) Sourdough bread made from wheat and non-toxic flours and started with selected *Lactobacilli* is tolerated in celiac sprue patients. *Applied and Environmental Microbiology* **70**, 1088-1096

FAO (1995) *Sorghum and Millets in Human Nutrition*, Food and Agriculture Organization of The United Nations, Rome, 184 pp

Ferguson LR, Harris PJ (1996) Studies on the role of specific dietary fibres in protection against colorectal cancer. *Mutation Research* **350**, 173-184

Ferriola D, Stone M (1998) Sweetener effects on flaked millet breakfast cereals. *Journal of Food Science* **63**, 726-729

Geervani P, Eggum BO (1989) Nutrient composition and protein quality of minor millets. *Plant Foods for Human Nutrition* **39**, 201-208

Geervani P, Eggum BO (1989b) Effect of heating and fortification with lysine on protein quality of minor millets. *Plant Foods for Human Nutrition* **39**, 349-357

Godkin A, Jewell D (1998) The pathogenesis of celiatic sprue. *Gastroenterology* **115**, 206-210

Gromova Z (1991) Buckwheat in human diet. In: Anonymous (Ed) *Common Buckwheat – the Important Source of Biofoodstuffs*, VULP, Nitra, pp 75-88 (in Slovak)

He P, Noda Y, Sugiyama K (2001) Suppression of lipopolysaccharide-induced liver injury by various types of tea and coffee in D-galactosamine-sensitized rats. *Bioscience, Biotechnology and Biochemistry* **65**, 670-673

Hinze G (1972) Millets in Colorado. *Colorado State University, Experiment Station, Bulletin* **553S**

Iljin VA, Michajlova JJ, Rasskazova OC (1973) The ways to obtaining highly prolific varieties of proso millet. In: *Selection and Seed Production of Proso Millet*, Kolos, Moscow, 61-74 pp (in Russian)

Jašovskij IV (1987) *Selection and seed production of proso millet*. Agropromizdat, Moskva, 255 pp (in Russian)

Jelagin IN (1981) *Agricultural Engineering of Proso Millet*. Rosselchozizdat, Moskva, 152 pp (in Russian)

Jones RW, Beckwith AC, Khoo U, Inglett GH (1970) Protein composition of proso millet. *Journal of Agricultural and Food Chemistry* **18**, 37-39

Kačergius A, Lugauskas A, Levinskaité L, Vrnaité R, Bakutis B. Baliukoniené V, Brukětiené D (2005) Screening of micromycetes producing toxic substances under various conditions. *Botanica Lithuanica* **7**, 65-75

Kalinová J (2002) *Comparison of productivity and quality in common buckwheat and proso millet* (in Czech). PhD Thesis, University of South Bohemia, Ceske Budejovice, 175 pp

Kalinová J, Moudrý J (2006) Content and quality of protein in proso millet (*Panicum miliaceum* L.) varieties. *Plant Foods for Human Nutrition* **61**, 45-49

Kasaoka S, Oh-hashi A, Morita T, Kiriyama S (1999) Nutritional characterization of millet protein concentrates produced by a heat-stable α-amylase digestion. *Nutrition Research* **18**, 899-910

Kohama K, Nagasawa T, Nishizawa N (1999) Polypeptide composition and NH_2-terminal amino acid sequences of proteins in foxtail and proso millets. *Bioscience, Biotechnology and Biochemistry* **63**, 1921-1926

Kumari SK, Thayumanavan B (1997) Comparative study of resistant starch from minor millets on intestinal responses, blood, glucose, serum cholesterol and triglycerides in rats. *Journal of the Science of Food and Agriculture* **75**, 296-302

Kumari SK, Thayumanavan B (1998) Characterization of starches of proso, foxtail, barnyard, kodo, and little millets. *Plant Foods for Human Nutrition* **53**, 47-56

Lagler R, Gyulai G, Humphreys M, Szabo Z, Horvath L, Bittsanszky A, Kiss J, Holly L, Heszky L (2005) Morphological and molecular analysis of common millet (*P. miliaceum*) cultivars compared to a DNA sample from the 15th century (Hungary). *Euphytica* **146**, 77-85

Lestienne I, Caporiccio B, Besancon P, Rochette I, Treche S (2005) Relative contribution of phytates, fibres, and tannins to low iron and zinc *in vitro* solubility in pearl millet (*Pennisetum glaucum*) flour and grain fractions. *Journal of Agricultural and Food Chemistry* **53**, 8342-8348

Lorenz K (1983) Tannins and phytate content in proso millets (*Panicum miliaceum*). *Cereal Chemistry* **60**, 424-426

Lorenz K (1980) Cereal sprouts: composition, nutritive value, food applications. *Critical Reviews in Food Science and Nutrition* **13**, 353-385

Lorenz K, Dilsaver W (1980a) Proso millets. Milling characteristics, proximate compositions, nutritive value of flours. *Cereal Chemisry* **57**, 16-20

Lorenz K, Dilsaver W (1980b) Rheological properties and food applications of proso millet flours. *Cereal Chemistry* **57**, 21-24

Lorenz K, Dilsaver W, Bates L (1980) Proso millets. Milling characteristics, proximate compositions. Nutritive value of flours. *Cereal Chemistry* **57**, 16-20

Lorenz K, Hwang YS (1986) Lipids in proso millet (*Panicum miliaceum*) flours and brans. *Cereal Chemistry* **63**, 387-390

Lu H, Yang X, Ye M, Liu K-B, Xia Z, Ren X, Cai L, Wu N, Liu T-S (2005) Culinary archaeology: Millet noodles in Late Neolithic China. *Nature* **437**, 967-968

Mattila P, Pihlava JM, Hellström J (2005) Contents of phenolic acids, alkyl- and alkenylresorcinols, and avenanthramides in commercial grain products. *Journal of Agricultural and Food Chemistry* **53**, 8290-8295

Mayer G, Quehl A, Leuchtenberger A, Ruttloff H (1985) Use of millet and millet agar as sporulation media. *Die Nahrung* **29**, 931-934

McGovern PE, Zhang J, Tang J, Zhang Z, Hall GR, Moreau RA, Nunez A, Butrym ED, Richards MP, Wang C, Cheng G, Zhao Z, Wang C (2004) Fermented beverages of pre- and proto-historic China. *Proceedings of the National Academy of Sciences USA* **101**, 17593-17598

Murzamadieva MA (1979) *Proso millet*. Kolos, Alma-ata, 80 pp (in Russian)

Nishizawa N, Fudamo Y (1995) The elevation of plasma concentration of high-density lipoprotein chloesterol in mice fed with protein from proso millet (*Panicum miliaceum*). *Bioscience, Biotechnology and Biochemistry* **59**, 333-335

Nishizawa N, Sato D, Ito Y, Nagasawa T, Hatakeyama Y, Choi MR, Choii YY, Wei YM (2002) Effects of dietary protein of proso millet on liver injury induced by D-galactosamine in rats. *Bioscience, Biotechnology and Biochemistry* **66**, 92-96

Odumodu CU (1992) Antinutrients content of some locally available legumes and cereals in Nigeria. *Tropical and Geographical Medicine* **44**, 260-263

Olivier J, Hauser C (1998) Anaphylaxis to millet. *Allergy* **53**, 109-110

Parameswaran KP, Sadasivam S (1982) Comparison of amylase activity and carbohydrate profile in germinating seeds of *Setaria italica*, *Echinochloa frumentacea*, and *Panicum miliaceum. Cereal Chemistry* **59**, 543-544

Parameswaran KP, Sadasivam S (1994) Changes in the carbohydrates and nitrogenous components during germination of proso millet, *Panicum miliaceum*. *Plant Foods for Human Nutrition* **45**, 97-102

Parameswaran KP, Thayumanavan B (1997) Isolation and characterization of a 20 kD prolamin from kodo millet (*Paspalum scrobiculatum* L.): Homology with other millets and cereals. *Plant Foods for Human Nutrition* **50**, 359-373

Parameswaran KP, Thayumanavan B (1995) Homologies between prolamins of different minor millets. *Plant Foods for Human Nutrition* **48**, 119-126

Parker JL, Yunginger JW, Swedlund HA (1981) Anaphylaxis after ingestion of millet seeds. *Journal of Allergy and Clinical Immunology* **67**, 78-80

Pathak P, Srivastava S, Grover S (2000) Development of food products based on millets, legumes and fenugreek seeds and their suitability in the diabetic diet. *International Journal of Food Science and Nutrition* **51**, 409-414

Pattabiraman TN (1986) Trypsin/chymotrypsin inhibitors from millets. *Advances in Experimental Medicine and Biology* **199**, 439-448

Petr J, Michalik I, Tlaskalova H, Capouchova I, Famera O (2003) Extention of the spectra of plant products for diet in coeliac disease. *Czech Journal of Food Sciences* **21**, 59-70

Ravindran G (1992) Seed protein of millets: amino acid composition, proteinase inhibitors and *in-vitro* protein digestibility. *Food Chemistry* **44**, 13-17

Ravindran G (1991) Studies on millets: proximate composition, mineral composition, and phytate and oxalate contents. *Food Chemistry* **39**, 99-107

Rösch M, Fischer E, Märkle T (2005) Human diet and land use in the time of the Khans-Archaeobotanical research in the capital of the Mongolian Empire, Qara Qorum, Mongolia. *Vegetation History and Archaeobotany* **14**, 485-492

Sakamoto S (1987) Origin and dispersal of common millet and foxtail millet. *Japan Agricultural Reserch Quarterly* **21**, 85-89

Salunkhe DK, Jadhav SJ, Kadam SS, Chavan JK (1985) Chemical, biochemical, and biological significance of polyphenols in cereals and legumes. *Plant Physiology* **79**, 480-484

Sangare-Tigori B, Dem AA, Kouadio HJ, Betbeder AM, Dano DS, Moukha S, Creppy EE (2006) Preliminary survey of ochratoxin A in millet, maize, rice and peanuts in Côte d'Ivoire from 1998 to 2002. *Human and Experimental Toxicology* **25**, 211-216

Schery RW (1972) *Plants for Man* (2nd Edn), Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 657 pp

Seetharam G (1999) Small millet research. *Indian Journal of Agricultural Sciences* **68**, 431-438

Sehgal AS, Kawatra A (1998) Reduction of polyphenol and phytic acid content of pearl millet grains by malting and blanching *Plant Foods for Human Nutrition* **53**, 93-98

Shimanuki S, Nagasawa T, Nishizawa N (2006) Plasma HDL subfraction levels increase in rats fed proso-millet protein concentrate. *Medical Science*

Monitor **12**, 221-226
Shinoda K, Takahashi T, Jin T (2002) Effect of roasting and heat-moisture treatments on physical properties of proso millet flour (Processing properties of modified proso millet flour). *Nippon Shokuhin Kagaku Kogaku Kaishi* **49**, 491-499
Siener R, Hönow R, Voss S, Seidler A, Hesse A (2006) Oxalate content of cereals and cereal products. *Journal of Agricultural and Food Chemistry* **54**, 3008 -3011
Sridhar R, Lakshminarayana G (1994) Contents of total and lipid classes and composition of fatty acids in small millets: foxtail (*Setaria italica*), proso (*Panicum miliaceum*), and finger (*Elelusine coracana*). *Cereal Chemistry* **71**, 355-359
Srivastava S, Thathola A, Batra A (2001) Development and nutritional evaluation of proso millet-based convenience mix for infants and children. *Journal of Food Science and Technology* **38**, 480-483
Stuck BA, Blum A, Klimek L, Hormann K (2001) Millet a potantially life-threatening allergen. *Allergy* **56**, 350
Subramanian S, Viswanathan R (2003) Thermal properties of minor millet grains and flours. *Biosystems Engineering* **84**, 289-296
Swain RR, Dekker EE (1966) Seed germination studies. II. Pathways for starch degradation in germinating pea seedlings. *Biochimica et Biophysica Acta* **122**, 87-100
Udupa SL, Pattabiraman TN (1985) Isolation and characterization of a trypsin/chymotrypsin inhibitor from the millet *Echinocloa fruneutacea*. *Journal of Agricultural and Food Chemistry* **33**, 642-646
Ushakumari SR, Latha S, Malleshi NG (2004) The functional properties of popped, flaked, extruded and roller-dried foxtail millet (*Setaria italica*). *International Journal of Food Science and Technology* **39**, 907-915
Velisek J (1999) *Food Chemistry*, OSSIS, Tabor, 328 pp (in Czech)
Voit C, Kalveram CM, Merkel M, Gall H (1996) Immediate type allergy to millet. *Allergologie* **19**, 379-381
Yamasaki Y (2003) β-Amylase in germinating millet seeds. *Phytochemistry* **64**, 935-939
Yamasaki Y, Fujimoto M, Kariya J, Konno H (2005) Purification and characterization of an α-glucosidase from germinating millet seeds. *Phytochemistry* **66**, 851-857
Yamasaki Y, Konnon H, Masima H (1996) Purification and properties of α-glucosidase from millet seeds. *Phytochemistry* **41**, 703-705
Yanez GA, Walker CE (1986) Effect of tempering parameters on extinction and ash of proso millet flours, and partial characterization of proso starch. *Cereal Chemistry* **63**, 164-167
Yanez GA, Walker, CE, Nelson LA (1991) Some chemical and physical properties of proso millet (*Panicum miliaceum*) starch. *Journal of Cereal Science* **13**, 299-305