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Nutrient Content of Puffed Proso Millet (*Panicum miliaceum* L.) and Amaranth (*Amaranthus cruentus* L.) Grains

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Abstract

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Puffed grains of the varieties of proso millet (*Penicum miliaceum* L.) and amaranth (*Amaranthus cruentus* L.) were evaluated as a source of nutritional compounds. The process of grain puffing was performed in prototype equipment of the "Szarłat" company. The analysed mean values for puffed grains were starch (proso millet 72.58%, amaranth 55.53%), fat (proso millet 8.43%, amaranth 8.99%), proteins (proso millet 13.89%, amaranth 14.04%), amino acids (proso millet 48.30 g/kg, amaranth 54.03 g/kg), crude fibre (proso millet 4.29%, amaranth 4.47%), and its fractions, as well as the total polyphenol content (proso millet 0.98%, amaranth 0.19%). Based on the results, puffed proso millet grains had the highest amounts of phenolic compounds and starch, and the lowest amount of crude dietary fibre and fat. Furthermore, both products were the sources of micro- and macrocomponents, primarily potassium, calcium, magnesium, and phosphorus.

Keywords: healthy food; nutritive value; puffed grains; composition

Millet and amaranth are among the oldest cereal plants. It was probably many thousands of years ago when millet was introduced into Central Europe from Central Asia. On the other hand, amaranth is a plant (pseudocereal) from South America which began to be cultivated in Europe, including Poland, as late as in the 20th century. Grains of both these plants are characterised by a high content of nutrients; however, it is due to the absence of gluten in the grains why nutritionists again became interested in the grains of both plants (Luis *et al.* 1982; Procyk 1995; Marciniak-Łukasiak & Skrzypacz 2008). In addition, it was found that fine particles of starch, which are easily expanded when heated, allow manufacturers to obtain a very attractive product, so-called "puffed" grain. Nowadays, puffed grains of proso millet and amaranth are products available in the market, which may be introduced into the diet of people suffering from food allergies associated with an intolerance to gluten. This is primarily due to the fact that grains of millet and amaranth contain no gluten, and thus may be used in the diet of coeliac disease sufferers. The health-promoting effects of products obtained from millet and amaranth were confirmed in medical prophylaxis. They are referred to in the context of suitability in treating constipation, and indirectly, of their antiatherogenic and antineoplastic action (intestine neoplasm); in addition, their contribution to the treatment of diet-related diseases was mentioned (Wierzewska & Taraszewska 2005; Wolska *et al.* 2010). Millet and amaranth grains, before consumption, are usually processed by commonly used processing techniques that include e.g. malting, roasting, and flaking, to improve their nutritional and sensory properties (Lara & Ruales 2002; Murakami *et al.* 2014). However, negative changes in these properties during processing are not avoidable because industrial methods for the processing of millet and amaranth grains are not as well developed as the methods used for wheat and rice processing. Therefore, the objective of the present study was to characterise nutrient contents of puffed grains. The puffing constitutes an interest for food industries and the results of this study will provide information in order to produce good-quality puffed grains.

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MATERIAL AND METHODS

The testing involved puffed grains of proso millet and amaranth. The process of grain puffing was performed in a prototype machine (Figure 1) at the PPHU "Szarłat" s.c. Company, Łomża, Poland. Grains with a moisture content of 9–12% were heated at a temperature of 260°C for 2–3 seconds. The experimental part of the study was performed in three independent replicates, and the obtained puffed grain samples were subjected to chemical analyses.

Scanning electron microscopy to investigate the microstructural properties of grains was performed using a Quanta 200 SEM (FEI Company, Hillsboro, USA). The samples were analysed using the SEM operating at accelerating voltage of 30 kV with 25× magnification.

In accordance with the objective of the study, the chemical part was primarily limited to the determination of the nutrients found in puffed grains.

Moisture content was determined by a method specified in the Polish Standard PN-ISO 712:2009 (Cereals and cereals products. Moisture measurement).

Protein content was determined by the Kjeldahl method in accordance with PN-75/A-04018/Az3:2002 (Determination of the nitrogen content and calculation of crude protein content–Kjeldahl method), using a Tecator Kjeltec System 1026 apparatus (FOSS, Hiller, Denmark). When converting the nitrogen content into proteins, the conversion factor N = 6.25 was applied.

Tryptophan content was determined in accordance with PN-77/R-64820:1997 (Tryptophan determination). The content of the other amino acids was determined using a Biochrom 20 Plus automatic amino acid analyser, with reagents produced by Biochrom Ltd. (Cambridge, UK). As a standard amino acid solution we used a mixture of amino acid standards (AASS-18), standard amino acid protein hydrolysates (A 2908) and L-methionine sulfone, L-cysteic acid, L-norleucine (Sigma, Sant Louis, USA). Sulphur amino acids (methionine and cystine) were determined as cysteic acid and methionine sulfone after performic acid oxidation testing (a mixture of formic acid HCOOH and hydrogen peroxide H_2O_2).

Figure 1. A prototype expander for the production of puffed grains (photo by B. Piłat)

Starch content was determined polarimetrically in a hydrochloric acid solution in accordance with PN-EN ISO 10520:2002 (Native starch. Determination of starch content – Ewers polarimetric method).

Lipid content was determined using two methods. Total lipid content was determined by the Folch method (Folch 1957), and the content of free (crude) fat by the Soxhlet method, described in the Polish Standard PN-ISO 6492:2005 (Determination of fat content).

Crude fibre in accordance with PN-EN ISO 5498:1996 (Asp *et al*. 1983) was determined using a Fibertec 2010 system.

Determination of the content of amylase-treated neutral detergent fibre (aNDF) was carried out in accordance with the method described in PN-EN 16472:2007 (Asp *et al*. 1983).

Determination of the content of acid detergent fibre (ADF) and acid detergent lignin (ADL) was carried out in accordance with the method described in EN ISO 13906:2008 (Asp *et al*. 1983).

The contents of Cu, Mn, Fe, Zn, Ca, and Mg in mineralisates were determined using flame (acetylene-air flame) atomic absorption spectrometry (AAS) in accordance with the method described by Whiteside and Miner (1984). The determination was performed using a Unicam 939 Solar atomic absorption spectrometer (Solar, Cambridge, UK), equipped with an Optimus data station, background correction (deuterium lamp) and proper cathode lamps. The contents of Na and K were determined using the emission technique (acetylene-air flame) in accordance with Whiteside and Miner (1984). The determination was performed using a Pye Unicam SP 2900 (Solar, UK) atomic absorption spectrometer operating in the emission system. Phosphorus in mineralisates was determined using a colorimetric method in accordance with PN-ISO 10540-1:2005 (Animal and vegetable fat and oils. Determination

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of phosphorus content. Part 1: Colorimetric method) with ammonium heptamolybdate, as well as with sodium(IV) sulphate and hydroquinone. The measurement of absorbance was performed using a VIS 6000 spectrophotometer by Krüss Optronic (A. Krüss Optronic GmbH, Hamburg, Germany) at a wavelength of λ = 610 nm.

The content of total phenolic compounds was determined colorimetrically by a method with the Folin-Ciocalteu reagent, using D-catechin for the preparation of a standardisation curve (AOAC 1974). The solution absorbance was measured at a wavelength of 720 nm using a SP6-500UV Pye Unicam spectrometer (Solar, UK).

RESULTS AND DISCUSSION

Puffed grains are products which are easy to use for the preparation of meals. After mixing with water or milk they can be used as a basic foodstuff, or added to other products, e.g. puddings, gelled desserts, dairy products, etc. Therefore, the present study made an attempt to determine the quantitative composition of essential nutrients in puffed grains of proso millet and amaranth.

SEM images (Figure 2) of the puffed grains showed their structure after puffing. Grains were fully puffed at 260°C for 2–3 s in hot air. Most of the grains had an irregular form and porous structure and in amaranth samples they exhibited a "butterfly" form.

A puffed grain is a product with a low content of water and a high concentration of chemical compounds forming dry matter (DM). Dry matter is understood as the part of the weight which remains following the removal of water as a result of the expansion process. As regards the expansion, only a slight concentration of dry matter components occurs. The content of dry matter in the puffed millet grains was at a level of 96.50 ± 3.04%, and in the puffed amaranth grains it was at a level of 97.38 ± 2.20%. The water content determines the elasticity of the

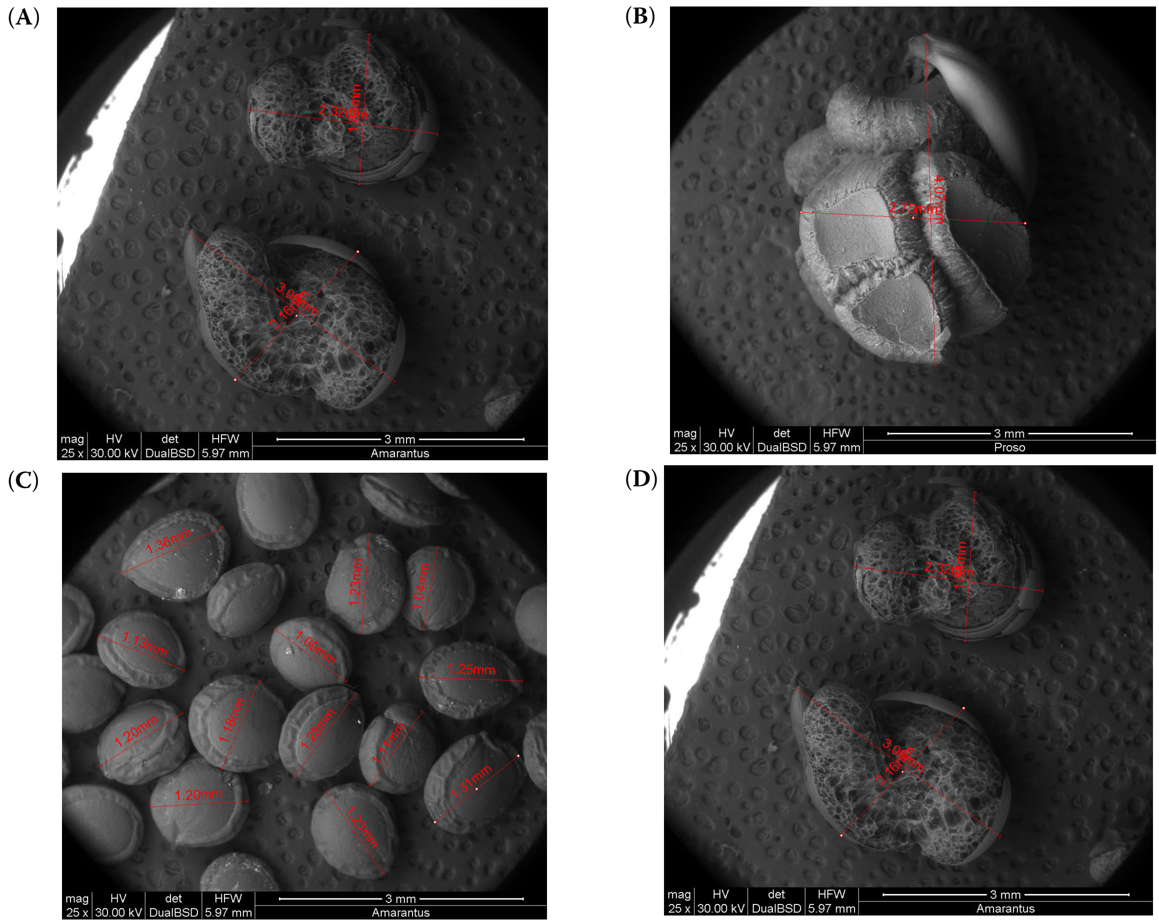

Figure 2. SEM images of unpuffed proso millet grains (**A**), puffed proso millet grains (**B**), unpuffed amaranth grains (**C**), puffed amaranth grains (**D**)

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Table 1. Selected chemical compounds of puffed grains expressed as % of dry matter

Puffed grains	Dry matter	Total fat	Free (crude) fat	Polyphenols	Protein
Proso millet	96.50 ± 3.04	8.43 ± 0.28	4.31 ± 0.20	0.98 ± 0.04	13.89 ± 1.58
Amaranth	97.38 ± 2.20	8.99 ± 1.00	6.03 ± 0.90	0.19 ± 0.00	14.04 ± 1.90

product, its hardness, and susceptibility to crushing. Moreover, it determines microbiological stability and shelf-life.

The second important component of puffed grains is the protein, the content of which determines the nutritional value of puffed products. It was found in the tested material that the protein content in the puffed proso millet grains was at a level of 13.89 ± 1.58%, while in the puffed amaranth grains it was at a level of approx. 14.04 ± 1.90% (Table 1). Protein content at a level of 10.50% in amaranth extrudates was found by Guerra-Matias and Arêas (2005). On the other hand, according to Chávez-Jáuregui *et al.* (2000), the protein content in extruded grains of *Amaranthus caudatus* was 14.04%. Gajewska *et al.* (2002) noted a similar content of proteins in puffed amaranth grains (14.4%), and Kalinova and Moudry (2006) reported that in millet grain flour the average content of proteins was at a level of 11.6% DM. Protein denaturation takes place during expansion. There occur changes in protein structure and also in protein digestibility but there are no changes in protein content. In the available literature there are conflicting opinions on the effect of the expansion process on protein content in popped grain products. Bavec and Bavec (2007) were of the opinion that during the production of puffed products a decrease in protein content to a level of 9% occurs in grains of *Amaranthus caudatus*, and to a level of 13% in grains of *Amaranthus cruentus*. On the other hand, Piecyk *et al.* (2009) reported that the protein content in puffed grain products (16.73%) does not differ significantly from the protein content in flour. The value of vegetable proteins is determined by the amino acid composition. Based on the amino acid composition it can be found that both types of puffed grain products are a good source of valuable proteins, which is indicated by their amino acid composition. Table 2 presents the contents of amino acids in puffed grains of proso millet and amaranth. The results show that the grains of proso millet and amaranth contain all the essential amino acids in their composition. However, the puffed product obtained from amaranth grains is superior in terms of the amino acid composition to the puffed product from proso millet grains. The essential amino acid pattern of puffed amaranth grains suggests a possible use as a supplementary protein source to most cereals because it is rich in lysine (9.48 g/kg). The requirement for lysine has received most attention given its nutritional importance as the likely limiting amino acid in cereals, especially wheat. A daily requirement for lysine in adults is 30 mg/kg (WHO 2002). As regards the essential amino acids, it is lysine, leucine, and valine that are found in the greatest quantities in puffed amaranth, while tryptophan and methionine are found in the smallest quantities (Table 2). The contents of other amino acids range from 4.56 g/kg to 6.23 g/kg of grains. As for endogenous amino acids, glutamic acid is predominant. These results are consistent with those reported by other researchers. While studying grains of *Amaranthus cruentus*, Bejosano and Corke (1998) also obtained the highest content of glutamic acid at a level of 1.63–1.91 g/100 g proteins, while in grains of *Amaranthus hybridus* it was at a level of 1.61–1.85 g/100 g proteins. Leucine content ranged from 5.6 g/100 g to 7.0 g/100 g of proteins in grains of *Amaranthus cruentus*, while in grains of *Amaranthus hybridus* it ranged from 1.61 g/100 g to 1.85 g/100 g proteins. For comparison, grains of *Amaranthus hypochondriacus* are also characterised by the highest content of glutamic acid (14.55 g/100 g proteins), while the content of methionine is the lowest (0.64 g/100 g proteins) (Dodak *et al.* 1997). Puffed proso millet grains, as compared with puffed amaranth grains, exhibited a lower content of certain amino acids. As regards the group of essential amino acids, in puffed proso millet grains a lower content of all amino acids was determined, except leucine and isoleucine. On the other hand, as for endogenous amino acids, the contents of all amino acids, except alanine, were lower (Table 2). No detailed information has been found in the available literature on the contents of particular amino acids in popped grain products. Bavec and Bavec (2007) reported that during the production of puffed products (at temperatures of 170–190°C, duration of 30 s), losses of valine and leucine occur. The content of total fat in popped proso millet grains, obtained through extraction using a mixture of chloroform

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Table 2. Amino acids of puffed grains (g/kg grains)

Amino acid	Proso millet	Amaranth	Amino acid	Proso millet	Amaranth
Endogenous amino acids			**Essential amino acids**		
Aspartic acid	11.65 ± 1.50	12.62 ± 0.98	Histidine	2.50 ± 0.25	4.56 ± 0.47
Serine	4.80 ± 0.21	9.27 ± 0.52	Threonine	4.20 ± 1.00	6.23 ± 0.54
Glutamic acid	24.85 ± 1.97	24.78 ± 1.87	Valine	6.86 ± 0.99	7.54 ± 0.45
Proline	5.72 ± 0.47	5.22 ± 0.77	Methionine	2.40 ± 0.34	3.17 ± 0.32
Cystine	4.65 ± 0.56	4.04 ± 0.21	Isoleucine	6.57 ± 1.90	5.68 ± 0.54
Glycine	4.50 ± 0.22	10.66 ± 1.00	Leucine	12.98 ± 1.22	8.90 ± 0.90
Alanine	10.25 ± 2.68	5.16 ± 0.68	Phenylalanine	6.79 ± 0.48	6.18 ± 0.32
Arginine	4.58 ± 0.39	13.90 ± 1.24	Lysine	3.50 ± 0.47	9.48 ± 0.89
Tyrosine	4.40 ± 0.47	6.19 ± 0.55	Tryptophan	2.50 ± 0.28	2.29 ± 0.32
Total	75.40	91.84	Total	48.30	54.03

and methanol (2 : 1 v/v), amounted to 8.43 ± 0.28%, while free fat amounted to 4.31 ± 0.20%. In turn, in puffed amaranth grains it amounted to 8.99 ± 1.00 and 6.03 ± 0.90%, respectively (Table 1). The presented data demonstrate that the fat contents in both puffed products under study were similar. There are differences in the form of fat, since in puffed proso millet grains the bound fat accounts for a significant percentage in the total fat content. Puffed amaranth grains are much richer in the lipids occurring in a free form than those in puffed proso millet grains; at the same time, this is a fat richer in bioactive substances, primarily squalene.

In the context of food analysis, the term "free fat" should be understood as an extract of all compounds capable of being extracted with an organic solvent (hexane, benzine, petroleum ether, or diethyl ether), being non-volatile after drying lasting for 1 h at a temperature of approx. 105°C. Its composition, in addition to triacylglycerols, includes: waxes, higher fatty acids, phospholipids, sterols, carotenoids, vitamins A, D, E, and K, as well as accompanying compounds, e.g. chlorophylls. Lipids may interact with other components of dry matter, e.g. sugars and proteins, to form glycolipids or lipoproteins. The total fat is the sum of free fat and fat bound with other components of dry matter. The fat content as determined in puffed proso millet and amaranth grains is higher than that in cereal plants. For example, wheat contains from 0.4% (wheat flour) to 2.1% (whole grains) of fat, and maize – 4.5% (Sindhuja *et al.* 2005). However, this fact, while advantageous from the nutritional point of view, contributes to more rapid rancidification (primarily due to oxidation and hydrolytic processes) of products obtained from millet and amaranth. Therefore, an important antioxidant function, in relation to fat, is performed by phenolic compounds.

Phenolic compounds are secondary plant metabolites with a very diverse structure, molecular weight, and chemical, physical, and biological properties, which are found in all parts of plants. They exhibit versatile functions in foodstuffs, impart colour, and taste, and stabilise fats, thus retarding oxidative rancidification. They represent the most important and the richest group of bioactive components (Barba de la Rosa *et al.* 2009). In the literature, phenolic compounds are divided, in terms of physicochemical properties, into methanol-soluble compounds which are in general low-molecular forms such as phenolic acids, anthocyanins, flavones, flavanes, chalcones, etc., and acetone-soluble compounds, which are primarily high-molecular forms which include e.g. tannins. Phenolic compounds separated from the plant raw material and determined using the Folin-Ciocalteu method are, in accordance with the AOAC Standards (1974), referred to as total polyphenols. The total content of methanol-soluble phenolic compounds (polyphenols) as determined in puffed proso millet grains amounted to 0.98 ± 0.04% DM, while in puffed amaranth grains it amounted to 0.19 ± 0.00% DM (Table 1). Polysaccharides are the essential, and at the same time dominant group of chemical components forming the dry matter of the products under study. The main nutritive polysaccharide is starch, and the main non-nutritive one is dietary fibre. Starch is the storage carbohydrate most commonly found in plants. In general, it is stated that starch content in hulled millet grains ranges from 70% to 83%, while in amaranth grains it ranges from 58%

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to 66%. The starch content in millet grains, which are the raw material for the production of puffed grains, amounted to 73.81 ± 4.29%, and in amaranth grains to 56.98 ± 2.99%. In the puffed product samples under study the percentage of starch was at a level of 72.58 ± 3.19%, and it was a value lower by 1.23 percentage units than that in the grains. For comparison, in puffed amaranth grains, the starch content was 55.53 ± 2.99%, and was also slightly lower than that in the grains. These slight differences may result from the mechanically disordered structure of starch polymers due to temperature and pressure. Partly damaged starch polymers slightly swell and slightly gelatinise, and after cooling the starch gel is formed. In an experiment by Gajewska *et al.* (2002) the starch content in puffed grain products was 56.6%. According to Piecyk *et al.* (2009), during the processing of amaranth grains, the content of starch does not change significantly. The above-mentioned authors reported that in flakes and in puffed grain products the starch content amounted to 65.64 and 61.73%, respectively.

From the nutritional point of view, as regards the group of polysaccharides, fibre is worthy of attention. Dietary fibre comprises a group of chemical compounds contained in the composition of plants, and being a structural part thereof. In plant products it is a mixture of polysaccharide substances (cellulose, hemicelluloses, pectins, and gums) and non-polysaccharides (lignins, cutins). Dietary fibre is an important component of food as it changes the nature of the chyme, and has an effect on the absorption of nutrients and chemical substances. It is not absorbed or digested in the gastrointestinal tract, and thus it is not a nutritive substance, yet due to its effects on numerous physiological functions it is an important component of the diet. An average daily nutritional ration for a European contains 15–20 g of fibre. The World Health Organisation (2003) recommended that the daily diet should contain at least 30 g of fibre. These compounds are not broken down by human digestive enzymes; however, they regulate the functioning of the gastrointestinal tract and the development of the intestinal microflora. The available literature distinguishes between insoluble fibre (cellulose and lignins), which is not degraded by the intestinal microflora, yet has an effect on both digestive tract motility and a reduction in the energy value of food, and soluble fibre, which mainly includes pectins, gums, part of hemicelluloses such as β-glucans, which may be degraded by the microorganisms of the gastrointestinal tract (e.g. to appropriate acids), and have a certain energy value (Gertig & Przysławski 2007). Grains of amaranth (*Amaranthus caudatus*) contain from 2.68% to 7.49% (Repo-Carrasco-Valencia *et al.* 2010) of crude fibre, and 20.6% of dietary fibre. It is composed of lignins, cellulose, and hemicelluloses (Grajeta 1997). According to Ratusz and Wirkowska (2006), the grains cultivated in Poland contain 4.5% of dietary fibre. During the performance of the study it was established that the content of crude dietary fibre in puffed proso millet grains amounted to 4.29 ± 0.79% and in amaranth to 4.47 ± 0.88%. Guerra-Matias and Arêas (2005) estimated the content of crude dietary fibre at a level of 8.20%, and its insoluble fraction (which includes lignins, cellulose, and certain hemicelluloses) at a level of 4.47%. In the studied samples, the content of neutral detergent fibre (NDF), consisting of cellulose, lignin, and hemicelluloses, amounted to 9.56 ± 0.15% for the puffed proso millet grains, and to 8.89 ± 0.59% for the puffed amaranth grains. The content of ADF fraction, i.e. acid detergent fibre consisting of cellulose, lignin, pectin, and tannin, was estimated at 7.57 ± 0.49% for the puffed proso millet grains, and 6.89 ± 0.20% for the puffed amaranth grains. The content of ADL fraction, only consisting of lignin, amounted to 1.79 ± 0.10% for the puffed proso millet grains, and 2.00 ± 0.19% for the puffed amaranth grains (Table 3).

As shown by data on the determination of mineral components (Table 4), puffed grains of proso millet and amaranth can be a good source of calcium and iron. Anyway, calcium and iron contents are higher in puffed amaranth grains (calcium 251.34 mg/100 g, iron 5.75 mg/100 g) compared to puffed proso millet grains (calcium 14.75 mg/100 g, iron 3.45 mg/100 g). Calcium and iron are of particular importance in the diet of pregnant women. A dietary intake of 1200 mg/day of calcium for pregnant women is recommended by

Table 3. Selected polysaccharides of puffed grains expressed as % of dry matter

Puffed grains	Starch	Crude fibre	NDF	ADF	ADL
Proso millet	72.58 ± 3.19	4.29 ± 0.79	9.56 ± 0.15	7.57 ± 0.49	1.79 ± 0.10
Amaranth	55.53 ± 2.99	4.47 ± 0.88	8.89 ± 0.59	6.89 ± 0.20	2.00 ± 0.19

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Table 4. Mineral components of puffed grains (mg/100 g)

Chemical element	Puffed grains	
	proso millet	amaranth
Pb	< 0.0050	< 0.0050
Cd	0.0041	0.0071
Cu	0.78	0.69
Fe	3.45	5.75
Mn	0.58	3.17
Zn	3.25	3.00
Ca	14.75	251.34
Mg	123.48	203.31
Na	0.92	0.55
K	235.11	413.28
P	377.50	523.90

WHO experts (WHO 2013). Daily oral iron supplementation in pregnant women is recommended as part of the antenatal care to reduce the risk of low birth weight, maternal anaemia and iron deficiency. A suggested daily iron supplementation in pregnant woman is 30–60 mg (WHO 2012). Also children are particularly vulnerable to iron deficiency anaemia because of their increased iron requirements in the periods of rapid growth, especially in the first five years of life (WHO 2008). The suggested weekly iron supplementation in preschool children is 25 mg and school-age children 45 mg (WHO 2011). In general, amaranth grains can be used to supplement daily requirements for different elements. Sanz-Penella *et al.* (2013) showed the contributions of mineral intake from bread with and without amaranth to the dietary reference intakes given by the Food and Nutrition Board of the Institute of Medicine, National Academy of Science. The authors reported that the bread without amaranth contributes 4.7% of Ca recommended for adults, whereas the breads incorporating amaranth contribute intakes of this mineral, ranging from 7.2% (amount of amaranth flour 10 g/100 g) to 14.7% (amount of amaranth flour 40 g/100 g). Additionally, "white" bread contributes 38.3% of Cu recommended for adults, whereas the breads with amaranth contribute 81.3% (amount of amaranth flour 40 g/100 g) intakes of this mineral.

The other elements found in large quantities are: phosphorus (puffed proso millet grains 377.50 mg per 100 g, puffed amaranth grains 523.90 g/100 g); potassium (puffed proso millet grains 235.1 mg/100 g, puffed amaranth grains 413.28 mg/100 g), and magnesium (puffed proso millet grains 123.48 mg/100 g, puffed amaranth grains 203.31 mg/100 g). Higher results for phosphorus in puffed amaranth grains (792 mg/100 g) were obtained by Gajewska *et al.* (2002). On the other hand, the cited authors noted a lower content of potassium for puffed grains (331 mg/kg). The elements found in smaller quantities include: zinc (puffed proso millet grains 3.25 mg/100 g, puffed amaranth grains 3.00 mg/100 g); copper (puffed proso millet grains 0.78 mg/100 g, puffed amaranth grains 0.69 mg/100 g), and sodium (puffed proso millet grains 0.91 mg/100 g, puffed amaranth grains 0.55 mg/100 g). Gajewska *et al.* (2002), while analysing the zinc content, obtained a similar result (31 mg/kg).

CONCLUSIONS

The puffed proso millet grains are richer in phenolic compounds and starch, while they contain less essential and endogenous amino acids when compared with puffed amaranth grains. In addition, puffed proso millet grains have a lower content of crude fibre and free fat. This study demonstrated that puffed proso millet and amaranth grains can be considered as nutritive products when compared with commonly used puffed products such as maize or rice. They have a relatively high content of amino acids and can be a good source of dietary fibre and other bioactive compounds such as phenolics. Future studies should be focused on the characterisation of chemical composition, especially bioactive compounds of proso millet and amaranth grains to determine the influence of process conditions on the nutritional value of products.

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