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Buckwheat, as a Food Component of a High Nutritional Value, Used in the Prophylaxis of Gastrointestinal Diseases

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ABSTRACT

An attempt was undertaken in this study to collect data from original works and reviews on two polymers in buckwheat grains: proteins and starch. Both polymers of buckwheat enter into interactions with other components naturally occurring in buckwheat grains, including tannins, phenolic compounds or flavonoids, as biologically-active substances with properties facilitating the health of humans and animals. Determinations were additionally conducted for the presence and interactions of buckwheat grains or components produced upon technological processing that exhibit physiological functions significant to the health of an organism, including dietary fibre and its fractions with different affinity to water as well as a fraction of starch resistant to enzymatic hydrolysis. The phenomenon of interactions proceeding between natural components is tangibly induced in the course of technological processes, hydrothermal ones in particular. Data was also collected on the subject of functional food products, the main constituents of which are buckwheat grains, as well as on green parts of plants discussed in the aspect of prophylactic functions and functions facilitating the health of humans and animals.

Keywords: coeliac disease, functional products, proteins, resistant starch, starch

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INTRODUCTION

Buckwheat (*Fagopyrum esculentum*, *Fagopyrum tataricum*) belongs to the family *Polygonaceae* and is referred to as a “pseudocereal” as it resembles cereals in terms of chemical composition and similar applications (Campbell 1997). Additionally, likewise cereals, buckwheat displays an A type crystalline structure according to the X-ray diffraction pattern (Christa *et al*. 2009). There are also a few botanical and physiological similarities between buckwheat and grasses. One of them is the capacity for the proper development without the use of herbicides, artificial fertilizers or pesticides (Kreft *et al.* 1996). Buckwheat absorbs substantially less water and nutrients from soil, as compared to cereals (Li and Zhang 2001). It has also been reported to display an allelopathic action that exerts an inhibiting effect on the growth of weeds (Mazurek and Wielgo 2001).

Buckwheat is one of the major honey-producing crops. Buckwheat honey is characterized by valuable therapeutic properties, dark tea-like colour and spicy flavour. Honey and pollen yield of buckwheat accounts for 400 and 56 kg ha^{-1}, respectively (Gheldof *et al.* 2003). The plant blooms only in the morning, and pollination by honeybees proceeds in the first half of the day. Flowers of buckwheat are rich in flavonoids, with the precedence of rutin. Due to a considerable content of antioxidant compounds, buckwheat honey is valued in phytotherapy, it may as well be applied for the production of meads and baking products (Krkošková and Mrázová 2005).

The major producers of buckwheat are: China, Russia, Ukraine and Kazakhstan (Li and Zhang 2001; Bonafaccia *et al.* 2003). Buckwheat is also cultivated in Slovenia, Brazil, Hungary, Austria, Nepal and Poland (Kreft *et al*. 1999). In Poland, the crop area of buckwheat reached ca. 73,000 ha in 2007 and was subject to an over 9% decrease as compared to the year 2006. The production of buckwheat is characterized by a high variability of crops. This lack of crop stability results from genetic properties of buckwheat and its high susceptibility to unfavourable climatic conditions in the vegetative season. Out of numerous species of buckwheat, only two are applied in the food industry, *i.e.*: common buckwheat (*Fagopyrum esculentum*) and tartary buckwheat (*Fagopyrum tataricum*).

Buckwheat occupies a special place amongst cultivable crops due to its nutritional, dietetic and therapeutic properties. Grains and other parts of that plant are applied in the food, pharmaceutical, cosmetic and feed industry. In addition, its valuable components are included into a group of nutraceuticals (Li and Zhang 2001). Buckwheat grains are rich in thiamine (vitamin B1), riboflavin (vitamin B2) and pyridoxine (vitamin B6) (Fabjan *et al.* 2003). Amino acid composition of buckwheat proteins is well balanced and displays a high biological value (Kato *et al.* 2001). Buckwheat grains are a significant source of microelements,

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including: Zn, Cu, Mn, Se (Stibilj *et al.* 2004), as well as of macroelements, including: K, Na, Ca, and Mg (Wei *et al.* 2003). With typically 80% unsaturated fatty acids and more than 40% polyunsaturated essential fatty acid–linoleic acid, buckwheat is nutritionally superior in fatty acid composition to cereal grains (Steadman *et al.* 2001). Buckwheat grains are additionally a rich source of dietary fibre (TDF), including its soluble fraction (SDF), being of significance in a diet of patients suffering from obesity or type II diabetes (Brennan 2005). Buckwheat grains have a significant content of rutin, catechins and polyphenols. Their potential antioxidant activity is also of significance to the dietary value (Oomah and Mazza 1996; Wanatabe 1998). The total content of the major compounds in buckwheat grains, including proteins, polysaccharides, dietary fibre, lipids, rutin, polyphenols, micro- and macroelements, depends on the variety or environmental factors (Kim *et al.* 2004).

NUTRIENT AND ANTI-NUTRIENT COMPONENTS

Buckwheat proteins and their relation with anti-nutrient components

Proteins are the main structural constituent of tissues in a human body and of biologically-active compounds, *i.e.* enzymes, hormones and antibodies. Nutritional surveys have demonstrated a high quality of buckwheat proteins, reaching 92.3% of the biological value of skimmed milk powder proteins and 81.4% of that of egg white protein (Pomeranz 1975).

Protein content of buckwheat grains has been reported to range from 12 to 18.9% (Christa and Soral-Śmietana 2008a). Soral-Śmietana (1984) demonstrated that protein content of commercial Polish and Brazilian buckwheat grains was almost the same. Likewise, in a recent study on buckwheat grains of three Polish cultivars (Luba, Kora, Panda), the protein content was found to be low and range from 11.9 to 12.6% d.m. (Stempińska and Soral-Śmietana 2006). It points to the high stability of buckwheat species in respect of their protein content. Some other data showed that protein content of buckwheat flour ranged from 8.5 to nearly 19%, as affected by variety, pesticides used or fertilization (Fornal 1999).

The major protein fractions of buckwheat grains are water-soluble and salt-soluble albumins and globulins. Globulins consist of 12-13 subunits with a molecular weight from 16 to 60 kDa (Krkošková and Mrázová 2005). The main storage protein of buckwheat grains is 13S globulin (Aubrecht and Biacs 1999; Li and Zhang 2001). A peculiar biochemical characteristics of buckwheat grain proteins is a negligible fraction of prolamines and the lack of α-gliadin (Guo and Yao 2006), which enables applying buckwheat grains or buckwheat products in foodstuffs for patients suffering from affections linked with gluten intolerance. Buckwheat grains are also a source of dietetic protein with a well-balanced amino acid composition as well as of lysine - the first limiting amino acid in cereals (Aubrecht and Biacs 2001; Krkošková and Mrázová 2005). In addition, a comparative analysis of buckwheat grain proteins with those of other cereals indicates that they are characterized by higher contents of arginine and tryptophan.

Buckwheat grains contain a specific group of thiamine-binding proteins (TBP). Mistunaga *et al.* (1986) were first to isolate those proteins from buckwheat grains. The TBPs are oligomers, and during SDS-PAGE electrophoresis they are migrating as single compounds with a molecular weight ranging from 42 to 45 kDa. A stechiometric ratio of TBP to thiamine accounts for 1:1, and in humans their complex with thiamine is digested by proteases releasing that vitamin (Li and Zhang 2001). In plants, the TBPs act as transporters of vitamin B1. They additionally stabilize that vitamin during technological processing. During storage, they are likely to improve thiamine stability and affect its biological availability. The TBPs may also be applied at deficiencies of that vitamin or at difficulties with its accumulation

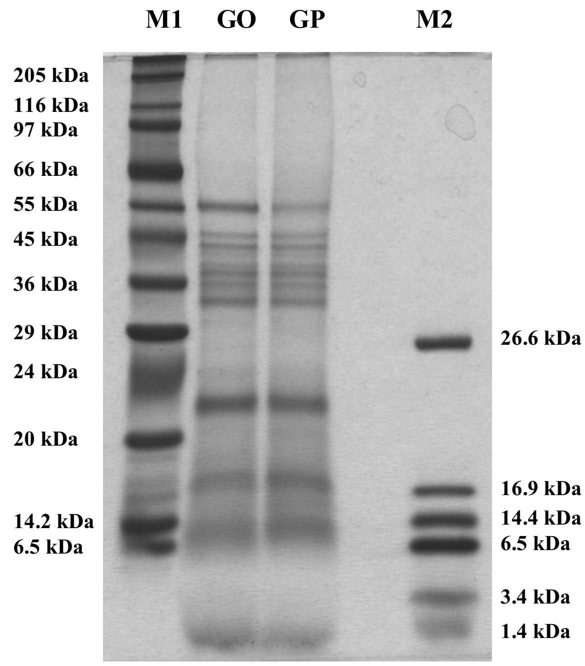

Fig. 1 SDS-PAGE electrophoresis of protein preparations isolated from buckwheat grains before and after roasting process (GO,GP), M1, M2-markers. Reprinted from **Christa K, Soral-Śmietana M** (2008b) Wpływ procesu prażenia na dostępność enzymatyczną białek ziarniaków gryki zwyczajnej (*Fagopyrum esculentum* Moench) (Effect of roasting process on the enzymatic digestibility of proteins in grains of buckwheat (*Fagopyrum esculentum* Moench). *Żywność. Nauka. Technologia. Jakość* **5 (60)**, 52-62, with kind permission of the Editorial Office of "Żywność. Nauka. Technologia. Jakość".

(Wanatabe *et al.* 1999).

In characterizing proteins of buckwheat flour and their changes upon extrusion at temperatures of 100, 120, 130°C, Fornal *et al.* (1985) demonstrated a considerable thermal stability of globulin proteins. Interesting results were obtained in that experiment when 25% of milk proteins were added to buckwheat flour. The addition yielded distinctly milder effects on that protein fraction, yet its thermal stability was still noticeable in the extrusion process. Determinations were also conducted in that study for hysteresis fields of a 0.5% suspension of buckwheat flour proteins as compared to a suspension of a mixture of buckwheat flour proteins with 25% of milk proteins before and after the extrusion process. In the case of buckwheat proteins, the hysteresis loops only confirmed a general decrease of hysteresis fields, but an opposite tendency was noted for milk proteins addition to buckwheat flour. The authors speculated that the addition of plant proteins containing polar and non-polar groups with varying contents of calcium ions would lead to the formation of polymers and protein aggregates upon extrusion process.

Buckwheat proteins are known to posses a high biological value and to be less susceptible to enzymatic hydrolysis. Heat treatment of buckwheat proteins in dehulled grains at a temperature of 160°C/30 min and at *ca.* 14% of free water, resulted in the degradation of a protein fraction with a molecular weight around 55 kDa (**Fig. 1**). Also in this study, the *in vitro* digestibility of buckwheat proteins, isolated from dehulled buckwheat grains before and after the roasting process was determined by means of multi-enzymatic hydrolysis with trypsin, chymotrypsin and peptidase. Results obtained demonstrated that buckwheat proteins might be digested in *ca.* 83%, and that the application of the roasting process slightly increased their availability to hydrolysing enzymes, to a level of 85.5% (Christa and Soral-Śmietana 2008b). In contrast, in feeding *in vivo* tests on albinotic rats, Pisulewska *et al.* (2001) obtained the biological value (BV) and true digestibility (TD) of buckwheat proteins at a level of BV = 81.5% and TD = 86.5%, respectively, which points to their better biological value and poorer true digestibility as compared to proteins of wheat (BV 75.2%; TD 91.5%) and triticale (BV 78.1%; TD 87.6%).

The relatively lower digestibility of buckwheat proteins is explained by the presence of trypsin inhibitors, fibre and tannins. Amarowicz *et al.* (2008) detected a dependency between sensory astringency of phenolic and tannins extracts obtained from selected tannin-rich foods and their total antioxidant activity (TAA). In this experiment, the authors indicated the following order of the TAA (µmol Trolox/mg) value: walnuts > buckwheat grits > buckwheat > vetch > hazelnuts > almonds. Furthermore, the extracts of walnut and buckwheat or buckwheat grits exhibited a strong antiradical activity against the 2,2-diphenyl-1-picryhydrazyl radical (DPPH) radical, IC_{50} was 0.020, 0.072, 0.120, respectively (Amarowicz *et al.* 2008). Based on UV spectra and HPLC analysis, they additionally confirmed the presence of condensed tannins in extracts of the investigated products. Thus, on the one hand a high concentration of tannins may increase the antioxidant activity of buckwheat grains and buckwheat grits, yet on the other hand – as it was mentioned above – it elicits a decrease in enzymatic availability and digestibility of buckwheat proteins. The digestibility of proteins of buckwheat grains is additionally not facilitated by a considerable content of total dietary fibre (TDF: 28-30%), in which the insoluble fraction (IDF) constitutes *ca*. 22%, and by a resistant starch fraction whose content in the whole buckwheat grains ranges from 16 to over 18% d.m. (Stempińska and Soral-Śmietana 2006).

In respect of most of plant proteins, a characteristic trait of buckwheat proteins is a low ratio between amino acid: lysine/arginine and methionine/glycine, which is implicated to have a positive effect on lowering the cholesterol level (Carroll and Kurowska 1995). Although the mechanism of that action has not been recognized yet, according to many researchers the ratio of these amino acids in plant proteins is a critical factor determining the cholesterol-lowering effects (Dewell *et al.* 2006).

In a nutritional study on hamsters, assays were conducted for the effect of a buckwheat proteins product (BWP) on plasma cholesterol, gallbladder bile composition and faecal steroid excretion as compared with other sources of proteins, as casein and soy proteins isolate (Tomotake *et al.* 2000). After 2 weeks, in the group of hamsters fed a buckwheat protein product the plasma and liver concentration of cholesterol were significantly lower than in the groups fed casein and soy proteins. Also, none of the hamsters in the group fed buckwheat had gallstones. The authors detected that BWP intake resulted in a significantly higher ratio of cholic acid to chenodeoxycholic acid and of cholic acid to lithocholic acid in gallbladder as compared with casein intake. They indicated also that bile acid synthesis and faecal excretion of both neutral and acidic steroids were enhanced by BWP more strongly than by soy proteins enhancing the suppression of gallstone and cholesterol level.

In a later research on rats and mice, Tomotake *et al.* (2006) applied casein, BWP or high protein buckwheat flour (PBF) as protein components of experimental diets. Based on result obtained from 3 different feeding experiments, they demonstrated that generally buckwheat protein products, high PBF in particular, suppressed hypercholesterolemia, obesity and gallstone formation because of their low protein digestibility.

Nevertheless, persons who consume buckwheat-containing foods frequently and in high quantities are reported to suffer from allergy or its symptoms. Park *et al.* (2000) studied the serologic findings of buckwheat food allergy and characterized its major allergenic components by means of IgE immunoblotting, periodate oxidation, two-dimensional PAGE, and sequencing of N-terminal amino-acids. These authors concluded that allergens of 24, 19, 16, 9 kDa were strong candidates for major allergens, and the 19 kDa allergen was relatively specific for buckwheat-allergic patients. However, other authors (Yoshioka *et al*. 2004; Handoyo *et al.* 2006; Morita *et al.* 2006) indicated low molecular weight proteins, particularly those with a molecular weight of 15, 22, or 26 kDa, to be the main causative agent of immunological disorders.

Buckwheat polysaccharides and their relation to/effects on other compounds

Buckwheat grains are classified as a high-starch material, in which starch content varies from 59 to 70% of dry matter (Qian and Kuhn 1999; Stempińska and Soral-Śmietana 2006). Buckwheat starch granules are spherical, oval and polygonal in shape, the granule size distribution ranges from 1 to 9 µm (Soral-Śmietana *et al.* 1984) or from 2 to 7 µm (Acquistucci and Fornal 1997). Soral-Śmietana *et al.* (1984) demonstrated that starch isolated from buckwheat grains after hydrothermal processing was characterized by higher contents of proteins, ash, and phosphorus. It indicated that technological conditions and processing might have affected the complexing of buckwheat starch with other native buckwheat biopolymer (proteins) and elements. In addition, a study on a mixture of maize grits/buckwheat flour (4: 1) demonstrated that upon the extrusion process the 20% share of buckwheat flour affected the content and changes of lipids, especially into polar fractions, glycolipids or phospholipids of free lipids and also of bound lipids (Soral-Śmietana 1992).

As reported by Campbell (1997), the content of amylose in buckwheat starch ranges from 15 to 52%, but usually it reaches around 20%. Acquistucci and Fornal (1997) analysed two varieties of buckwheat cultivated in different areas of North Italy around Bolzano or Sondrio and proved that these starch samples differed significantly in amylose content that accounted for: 2 or 28.5%, respectively. However in starch isolated under laboratory conditions from dehulled buckwheat grains of Polish variety Kora, the content of amylose was detected at a level of 17.1% d.m. (Christa *et al.* 2009). The authors reported on the diminishing of the amorphous fraction after the experimental roasting process (12.3% d.m.), as affected by technological conditions and mobility or leaching and degradation of the amorphous fraction of starch. According to X-ray diffraction patterns, the crystal structure of buckwheat starch is of the A type (Christa *et al* 2009), likewise in other cereal starches. However, the physicochemical properties of buckwheat starch are characterized by almost the same sorption ability to water or oil (Christa *et al.* 2009). It has a higher swelling power or lower solubility and higher viscosity than wheat starch (Acquistucci and Fornal 1997), and also than barley or corn starches (Fornal *et al*. 1987). *In vitro* investigations of the susceptibility of buckwheat starch to enzymatic hydrolysis confirmed that it was a good substrate for the action of pancreatic alpha-amylase with slow release of glucose ranging from 22 µg/ml after half an hour of this enzyme activity to 132 µg/ml after 6-hour hydrolysis (Christa *et al.* 2009). Scanning electron microscope pictures (**Fig. 2**) show buckwheat starch isolated from non-treated and thermally-roasted buckwheat grains at a low moisture content and also the same starches after 1-hour of pancreatic α-amylase activity in simulated duodenic hydrolysis *in vitro* from our previous experiment (unpublished data). The mode of action of pancreatic α-amylase was observed to be the same as in the cereal starch, *i.e.* wheat or corn (**Fig. 2C**) (Soral-Śmietana 2000). It was also detected that starch isolated from native buckwheat granules had a pin-like damage inside with a special action into the central part of granules. The same mode of action of the enzyme was demonstrated in non-damaged granules or in large agglomerates onto a long equatorial axis of the new structure for starch of roasted buckwheat (**Fig. 2D**).

In the last decade, food products have been expected to exert a beneficial effect on one or a number of functions of a human body. There is an increasing evidence that starch of different botanical origin, beside providing energetic components, may as well be a source of components being

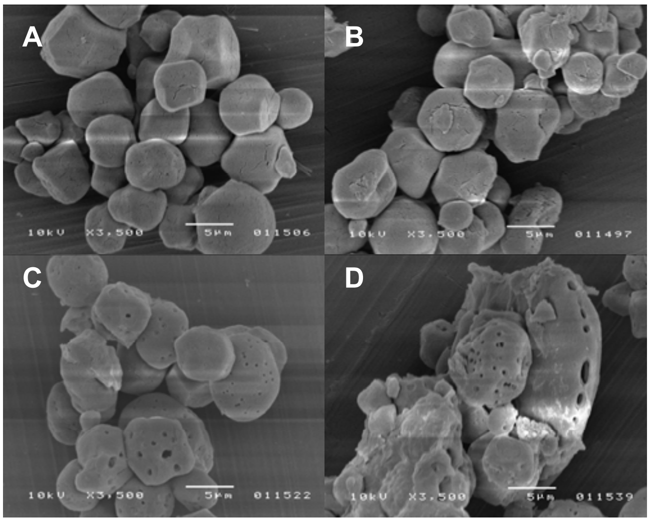

Fig. 2 SEM micrographs. Buckwheat starch isolated from non-treated grains (**A**) and roasted buckwheat grains at moisture of 14.5% (**B**) hydrolyzed for 1-hour by pancreatic α-amylase: (**C**) non-treated; (**D**) roasted.

of significance from the physiological perspective (Wronkowska *et al*. 2009). Starch is not only a source of energy to humans, but it is also reported to interact with the gut microflora, which is due to the presence of the resistant starch fraction (Bird *et al.* 2000; Wronkowska *et al.* 2006, 2008a). Stempińska and Soral-Śmietana (2006) demonstrated that resistant starch content of whole buckwheat grains of three Polish varieties constituted up to 28% of the total buckwheat starch. This fraction of starch resistant to pancreatic alpha-amylase activity occurred in the native form or was formed during technological processes. This component is highly significant for health and exhibits a biological activity in human or animal organism (Soral-Śmietana *et al*. 2001; Soral-Śmietana and Wronkowska 2004). However, the content of resistant starch determined in buckwheat starch isolated according to a laboratory scheme from dehulled native or roasted grains was at the same level, *i.e.* above 5% d.m. (Christa *et al.* 2009). In addition, analyses carried out on the same materials for the total dietary fibre showed a significant decrease in its content only under the roasting process applied at 14.5% moisture of buckwheat grains. Both these antinutrients may play a role of "colonic food" in the intestinal micro-ecosystem, as it was reported by Roberfroid (1995). In an experiment with rats, Préstamo *et al*. (2003) proved that a buckwheat diet diminished body weight of the rats but they did not find any significant differences in mass of organs, namely: liver, spleen, kidney and heart. In intestines of rats fed a buckwheat diet, an increase was shown in the counts of aerobic mesophilic and lactic acid bacteria with a simultaneous slight decrease in the count of *Enterobacteria* and pathogenic bacteria. *Lactobacillus plantarum*, *Bifidobacterium* spp. and *Bifidobacterium lactis* were found as a result of buckwheat addition to animal diet. Based on these results, the authors concluded that buckwheat could possibly be considered as a prebiotic product.

The beneficial effect of buckwheat grains on reducing cholesterol level is also ascribed to the soluble fraction of dietary fibre (SDF) and to fibre-like components of buckwheat starch, including resistant starch fraction not hydrolyzed by pancreatic α-amylase.

As a result of an experimental study on 12 human volunteers the effect of fibre on lipid profile and glucose tolerance was assumed by Bijlani *et al.* (1985). They demonstrated that the intake of 100 g of sieved buckwheat flour replacing other cereals at lunch for 4 weeks resulted in a significant rise in a high density fraction of cholesterol (HDL-C from 42.8 to 55.2 mg/100 ml) and the ratio of HDL-C/cholesterol (from 26.7 to 33.8%). The authors concluded that it was still not possible to say to what extent the effects on lipids may be attributed to its fibre content, but effects on glucose tolerance seemed to be more directly related to the content of fibre.

Buckwheat in food products, its nutritional and prophylactic value or functional properties

After a long period of restricted cultivation of buckwheat, its health-promoting properties have recently been re-appreciated. Products made from buckwheat are recommended at affections of liver, bile ducts, kidneys, colon polyps, and post-surgical convalescence (Christa and Soral-Śmietana 2007). Traditionally, buckwheat is a raw material of groats, it is consumed after the process of roasting or not-treated. The processing of buckwheat consists in dehulling grains, their breaking or roasting. Buckwheat flour is applied as a food additive or in the production of such foodstuffs as pancakes, pastas and noodles (Handoyo *et al.* 2006). Buckwheat grains and buckwheat flour may be applied for the preparation of multi-component mixtures and for the extension of the food-assortment with an assumed dietetic and nutritional value, *e.g.* ready-to-eat foods (Śmietana *et al.* 1985; Fornal *et al.* 1987; Śmietana *et al.* 1988). Lin *et al.* (2009) found that 15% of buckwheat flour incorporated into wheat bread could provide more functional components, such as rutin and quercetin, and more effective antioxidant properties to the bread. Buckwheat enhanced wheat bread was better in terms of flavour and mouthfeel sensory attributes as compared to wheat bread. Chillo *et al*. (2008) found that spaghetti of durum wheat semolina enriched with buckwheat flour and bran, in different percentages, had good performance both at dry state and in cooking. Also sensorial properties were fairly similar to the spaghetti made only of durum semolina. The addition of buckwheat flour (up to 40%) into tarhana formulation improved the nutritional contents of tarhana in terms of ash, protein, mineral and lysine content (Bilgiçli 2009). Kim *et al*. (2001, 2004) presented the nutritional evaluation of buckwheat sprouts, which not only have a soft and slightly crispy texture, and attractive fragrance, but are also rich in nutrients. Bejosano and Corke (1998) used the buckwheat protein concentrate in an emulsion-type meat product, and demonstrated that it could be suitable as a meat extender. Gawlik-Dziki *et al.* (2009) enriched wheat bread with a preparation obtained from the green parts of buckwheat plant and found an increase in contents of compounds characterized by well-documented antioxidant and health-promoting properties, such as rutin, 3-flavonols, phenolic acids, and their derivatives. They also studied the effect of simulated digestion *in vitro* on bioactivity of these type of breads. Despite the digestion stage, the highest antiradical activity, reducing power and ability to inhibit lipids peroxidation was observed in the sample with a 5% addition of the preparation. In a model study, examinations were conducted for the effect of thermal treatment of buckwheat grains on changes in the content of total polyphenols and on their antioxidative capacity (TEAC) (Stempińska *et al.* 2007). A high correlation was demonstrated between the total content of polyphenols and antioxidant activity of buckwheat grains (r=0.95). In addition, buckwheat grains were shown to be characterized by a high content of polyphenols, and by antioxidant activity being correlated with the content of phenolics. The thermal treatment was found to decrease contents of phenolic compounds and flavonoids only to a small extent. Thus, due to a high antioxidant capacity and a considerable content of flavonoids in the total pool of phenolic compounds, buckwheat products may constitute a valuable dietary supplement. Christa *et al*. (2009) demonstrated that thermal treatment evoked slight changes in the infrared spectra of buckwheat starch. In the spectrum of the thermally-treated starch, one new band was observed at 1530 cm^{-1}. This band corresponded to the unsaturated bonds C=C connected to the oxygen atoms O-C=C or the nitrogen atoms N-C=C. These changes could be elucidated by the destruction of an anhydroglucose ring or more likely by the Maillard reaction

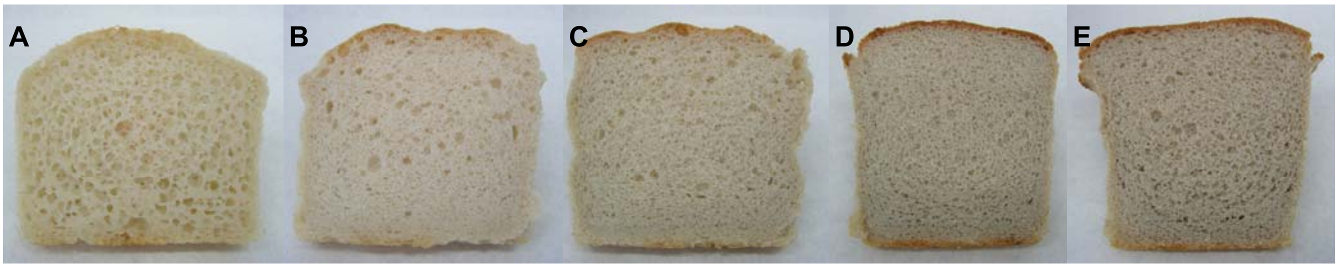

Fig. 3 Gluten-free breads supplemented with buckwheat flour. (**A**) Control, (**B**) 10% of buckwheat flour; (**C**) 20% of buckwheat flour; (**D**) 30% of buckwheat flour; (**E**) 40% of buckwheat flour (own study, unpublished data).

proceeding between proteins and carbohydrates during thermal treatment of buckwheat grain.

Tang (2007) presented the results of the functional and nutritional (*in vitro* digestibility) properties of buckwheat proteins obtained using various processing (mechanical or ultrasonic-assisted extraction; de-fatting treatment; spray or freeze drying). These results indicated that the functional properties of a preparation of buckwheat proteins, including protein solubility, emulsifying properties and *in vitro* digestibility, were associated with its lipid content, and/or ash content which could be affected by processing. The drying mode (spray-drying or freeze-drying) was also found to affect the functional properties of the buckwheat preparation examined.

Buckwheat has been used to reduce the serum glucose level in rats due to its high content of D-chiroinositol, a component of an insulin mediator (Kawa *et al.* 2003). Germinated buckwheat exhibits potential anti-liver activities caused partially by suppressing the gene expression of certain adipogenic transcription factors, like PPARγ and C/EBPα in hepatocytes (Choi *et al.* 2007). Compared to most fruits, vegetables and grain crops, buckwheat contains more rutin and its major health-promoting roles are anti-oxidative, anti-inflammatory and anti-hypertensive effects that originate mainly from the actions of flavonoids (Oomah and Mazza 1996; Velioglu *et al*. 1998).

Due to a very low content of α–gliadin in the grains, buckwheat flour can be a valuable ingredient in diets or food products for coeliac patients. Coeliac disease is an autoimmune gluten-sensitive entheropathy with a genetic, immunological and environmental background. Studies have shown that the prevalence of coeliac disease or non-typical coeliac disease, or allergic reaction/intolerances to gluten has been significantly underestimated (Gallagher *et al.* 2004). The clinical symptoms of coeliac disease changed from a full-blown symptomatic form to a major group with mild non-specific symptoms such as an iron and folate deficiency, anemia, vague abdominal discomfort and failure to thrive (Corazza *et al.* 1992). The reaction following the consumption of gluten-containing products leads to a small intestinal mucosal inflammation, which in turn leads to the malabsorption of several important nutrients, vitamins and minerals. The only effective treatment for coeliac disease is strict adherence to a gluten-free diet throughout the patient's life. Gluten is a protein complex occurring in cereals, hence it is generally believed that a gluten-free diet consists exclusively in the elimination of cereal-based products, including: bread, bread rolls, cakes, flours and pastas. Gluten occurs in commonly-available foodstuffs and – as a component of flour – is a frequently used food additive to cured meats, minced meat, spices, sweets, vegetable and fruit products, cottage cheese, yoghurts and cheeses. There is a number of natural products not containing gluten that may be consumed without any anxiety, *e.g*. rice, maize, potatoes, buckwheat, legumes, cassava, tapioca, milk, eggs, fish, vegetables and fruits. A diet based on gluten-free products is often characterized by a low content of some nutrients such as proteins and mineral components, as well as anti-nutritional but physiologically important components, like dietary fibre (Krupa *et al.* 2008; Wronkowska *et al.* 2008b). Wronkowska and Soral-Śmietana (2008) showed that the substitution of 30% of commercial gluten-free formulation basis with buckwheat flour increased the level of total proteins, macro- and microelements, and resistant starch. One of the most substantial reasons for the limited use of buckwheat arises from its specific flavour, volume and colour (**Fig. 3**). A significant improvement of the overall sensory quality was found for the commercial gluten-free bread partially supplemented with buckwheat flour. In the sensory profile of bread containing 30% of buckwheat flour the attributes (buckwheat odour and taste) were shown to predominate (Wronkowska *et al.* 2008c). The incorporation of buckwheat flour (10-40%) into a gluten-free experimental formulation caused the enrichment in protein and macroelements, moreover it affected an improvement of the technological quality of bread, like loaf volume and crust porosity (Wronkowska *et al.* 2010). Gambuś *et al*. (2009) demonstrated that buckwheat could be used as a supplement of gluten-free confectionery products.

A growing interest is being observed globally in buckwheat products as a healthy food and as a substitute for wheat flour in products for gluten-allergic person. Data on buckwheat allergy was presented in a review by Wieslander (1996). As indicated by available case reports, a large proportion of the allergic patients are children, and food allergy is a common type of allergy. Both children and adults show asthmatic response at respiratory tracts once exposed to low levels of buckwheat dust. Wieslander (1996) reported that the major allergen seemed to be 24 kDa protein, and the pathomechanism was type I, meaning an IgE-immediate-type reaction. Tanaka *et al*. (2002) found that a pepsin-sensitive 24 kDa protein unit has been identified as the most frequently recognized allergenic component in buckwheat, binding to IgE antibodies in the serum of almost all patients with proven buckwheat allergy. A 16 kDa buckwheat protein is also thought to be responsible for the immediate hypersensitivity reaction in patients with buckwheat allergy (Tanaka *et al*. 2002).

Several food-processing techniques have been applied to foods in order to increase the functional property and to reduce the levels of allergenic proteins. Handoyo *et al.* (2006) demonstrated the influence of *Rhizopus oligosporus* on the buckwheat grain during fermentation. They found that buckwheat fermented by *R. oligosporus* had a higher content of amino acids and minerals, but a lower content of allergic proteins than the non-fermented buckwheat samples.

CONCLUSION AND FUTURE ASPECTS

Due to the signalized allergenic properties of low-molecular proteins of buckwheat grains, a study is underway on a functional product obtained on the basis of dehulled natural grains of buckwheat or after their thermal treatment by oriented fermentation with a mould strain *Rhizopus oligosporus* (own study, unpublished data).

REFERENCES

Acquistucci R, Fornal J (1997) Italian buckwheat (*Fagopyrum esculentum*) starch: Physico-chemical and functional characterization and *in vitro* digestibility. *Die Nahrung* **41**, 281-284

Amarowicz R, Troszyńska A, Kosińska A, Lamparski G, Shahidi F (2008) Relation between sensory astringency of extracts from selected tannin-rich foods and their antioxidant activity. *Journal of Food Lipids* **15**, 28-41

Aubrecht E, Biacs PA (1999) Immunochemical analysis of buckwheat proteins, prolamins and their allergenic character. *Acta Alimentaria* **28**, 261-268

Aubrecht E, Biacs PA (2001) Characterization of buckwheat grain proteins and its products. *Acta Alimentaria* **30**, 71-80

Bejosano FP, Corke H (1998) Amaranthus and buckwheat protein concentrate effects on an emulsion-type meat product. *Meat Science* **50**, 343-353

Bijlani RL, Sud S, Sahi A, Gandhi BM, Tandon BN (1985) Effect of sieved buckwheat (*Fagopyrum esculentum*) flour supplementation on lipid profile and glucose tolerance. *Indian Journal of Physiology and Pharmacology* **29 (2)**, 69-74

Bilgiçli N (2009) Effect of buckwheat flour on chemical and functional properties of tarhana. *LWT - Food Science and Technology* **42**, 514-518

Bird AR, Brown IL, Topping DL (2000) Starches, resistant starches, the gut microflora and human health. *Current Issues in Intestinal Microbiology* **1**, 25-37

Bonafaccia G, Marocchini M, Kreft I (2003) Composition and technological properties of the flour and bran from common and tartary buckwheat. *Food Chemistry* **80**, 9-15

Brennan ChS (2005) Dietary fibre, glycaemic response and diabetes. *Molecular Nutrition and Food Research* **49**, 560-570

Campbell CG (1997) Buckwheat *Fagopyrum esculentum* Moench, Institute of Plant Genetics and crop Plant Research, Gatersleben / International Plant Genetic Resources Institute, Rome, Italy, 95 pp

Carroll KK, Kurowska EM (1995) Soy consumption and cholesterol reduction: review of animal and human studies. *Journal of Nutrition* **125**, 594-597

Chillo S, Laverse J, Falcone PM, Protopapa A, Del Nobile MA (2008) Influence of the addition of buckwheat flour and durum wheat bran on spaghetti quality. *Journal of Cereal Science* **47**, 144-152

Choi I, Seog H, Park Y, Kim Y, Choi H (2007) Suppressive effects of germinated buckwheat on development of fatty liver in mice fed with high-fat diet. *Phytomedicine* **14**, 563-567

Christa K, Soral-Śmietana M (2007) Gryka – cenny surowiec w produkcji żywności funkcjonalnej (Buckwheat – important raw material in functional food production). *Przemysł Spożywczy* **12**, 36-37 (abstract in English)

Christa K, Soral-Śmietana M (2008a) Buckwheat grains and buckwheat products – nutritional and prophylactic value of their components. Review. *Czech Journal of Food Sciences* **26**, 153-162

Christa K, Soral-Śmietana M (2008b) Wpływ procesu prażenia na dostępność enzymatyczną białek ziarniaków gryki zwyczajnej (*Fagopyrum esculentum* Moench) (Effect of roasting process on the enzymatic digestibility of proteins in grains of buckwheat (*Fagopyrum esculentum* Moench). *Żywność. Nauka. Technologia. Jakość* **5 (60)**, 52-62 (abstract in English)

Christa K, Soral-Śmietana M, Lewandowicz G (2009) Buckwheat starch: structure, functionality and enzyme *in vitro* susceptibility upon the roasting process. *International Journal of Food Sciences and Nutrition* **60 (S4)**, 140-154

Corazza G, Valentini RA, Frisoni M, Volta U, Corrao G, Bianchi FB, Gasbarrini G (1992) Gliadin immune reactivity is associated with overt and latent enteropathy in relatives of celiac patients. *Gastroenterology* **103**, 1517-1522

Dewell A, Hollenbeck PLW, Hollenbeck CB (2006) Clinical review: a critical evaluation of the role of soy protein and isoflavone supplementation in the control of plasma cholesterol concentrations. *The Journal of Clinical Endocrinology and Metabolism* **91**, 772-780

Fabjan N, Rode J, Košir IJ, Zhang Z, Kreft I (2003) Tatary buckwheat (*Fagopyrum tartaricum* Gaertn.) as a source of dietary rutin and quercitrin. *Journal of Agricultural and Food Chemistry* **51**, 6452-6455

Fornal Ł, Śmietana Z, Soral-Śmietana M, Fornal J, Szpendowski J (1985) Products extruded from buckwheat flour and its mixtures with milk proteins. II. Chemical characteristics and physico – chemical properties of proteins and starch of products extruded from buckwheat flour and its mixtures with milk proteins. *Acta Alimentaria Polonica* **11 (4)**, 397-411

Fornal Ł, Śmietana Z, Soral-Śmietana M, Szpendowski J (1987) Chemical characteristics and physico-chemical properties of the extruded mixtures of cereal starches. *Starch/Stärke*, **39 (3)**, 75-78

Fornal Ł (1999) Chemizm nasion gryki i kierunki spożywczego wykorzystania. (Buckwheat grain chemistry and directions of usage in food). *Biuletyn Naukowy* **4**, 7-17 (in Polish)

Gallagher E, Gormley TR, Arendt EK (2004) Recent advances in the formulation of gluten-free cereal-based products. *Trends in Food Science and Technology* **15**, 143-152

Gambuś H, Gambuś F, Pastuszka D, Wrona P, Ziobro R, Sabat R, Mickowska B, Nowotna A, Sikora M (2009) Quality of gluten-free supplemented cakes and biscuits. *International Journal of Food Sciences and Nutrition* **60 (S4)**, 31-50

Gawlik-Dziki U, Dziki D, Baraniak B, Lin R (2009) The effect of simulated digestion *in vitro* on bioactivity of wheat bread with tartary buckwheat flavones addition. *LWT – Food Science and Technology* **42**, 137-143

Gheldof N, Wang XH, Engeseth NJ (2003) Buckwheat honey increases serum antioxidant capacity in humans. *Journal of Agricultural and Food Chemistry* **51**, 1500-1505

Guo X, Yao H (2006) Fractionation and characterization of tartary buckwheat flour proteins. *Food Chemistry* **98**, 90-94

Handoyo T, Maeda T, Urisu A, Adachi T, Morita M (2006) Hypoallergenic buckwheat flour preparation by *Rhizopus oligosporus* and its application to soba noodle. *Food Research International* **39**, 598-605

Kato N, Kayashita J, Tomotake H (2001) Nutritional and physiological functions of buckwheat protein. *Recent Research Development Nutrition* **4**, 113-119

Kawa JM, Taylor CG, Przybylski R (2003) Buckwheat concentrate reduces serum glucose in streptozotocin-diabetic rats. *Journal of Agricultural and Food Chemistry* **51**, 7287-7291

Kim SL, Son YK, Hwang JJ, Kim SK, Hur HS, Park CH (2001) Development and utilization of buckwheat sprouts as functional vegetables. *Fagopyrum* **18**, 49-54

Kim SL, Kim SK, Park CH (2004) Introduction and nutritional evaluation of buckwheat sprouts as a new vegetable. *Food Research International* **37**, 319-327

Kreft I, Srabanja V, Ikeda S, Ikeda K, Bonafaccia G (1996) Dietary value of buckwheat. *Research Reports Biotechnical Faculty of the University of Lubljana* **67**, 73-78

Kreft I, Plestenjak A, Golob T, Skrabanja V, Rudolf M, Draslar K (1999) Functional value of buckwheat as affected by the content of inositol, phosphate, minerals, dietary fiber and protein. In: Sanberg AS, Andersson H, Amado R, Schlemmer H, Serra F (Eds) *Bioactive Inositol Phosphates and Phytosterols in Food*, COST 916. Office for Official Publications of the European Communities, Luxemburg, pp 69-72

Krkošková B, Mrázová Z (2005) Prophylactic components of buckwheat. *Food Research International* **38**, 561-568

Krupa U, Soral-Śmietana M, Wronkowska M (2008) Mieszanka bezglutenowa (gluten-free mixture), Polish patent specification No P 386253

Li S, Zhang QH (2001) Advances in the development of functional foods from buckwheat. *Critical Reviews in Food Science and Nutrition* **41**, 451-464

Lin L, Liu H-M, Yu Y-W, Lin S-D, Mau J-L (2009) Quality and antioxidant property of buckwheat enhanced wheat bread. *Food Chemistry* **112**, 987-991

Mazurek J, Wielgo B (2001) Allelopatyczne oddziaływanie gryki z wybranymi gatunkami chwastów. (Allelopathic interaction between buckwheat and some selected weeds species). *Zeszyty Naukowe Akademii Rolniczej im. H. Kołłątaja w Krakowie*, Sesja Naukowa **85**, 83-93 (in Polish)

Mistunaga T, Iwashima A, Matsuda M, Shimizu M (1986) Isolation and properties of thiamine-binding protein from buckwheat seed. *Cereal Chemistry* **63 (4)**, 332-335

Morita N, Maeda T, Sai R, Miyake K, Yoshioka H, Urisu A, Adachi T (2006) Studies on distribution of protein and allergen in graded flours prepared from whole buckwheat grains. *Food Research International* **39**, 782-790

Oomah BD, Mazza G (1996) Flavonoids and antioxidative activities in buckwheat. *Journal of Agricultural and Food Chemistry* **44**, 1746-1750

Park JW, Kang DB, Kim CW, Ko SH, Yum HY, Kim KE, Hong C-S, Lee KY (2000) Identification and characterization of the major allergens of buckwheat. *Allergy* **55**, 1035-1041

Pisulewska E, Szymczyk B, Zając T (2001) Ocena składu chemicznego i wartości odżywczej białka orzeszków gryki polskich odmian w świetle współczesnych kryteriów żywieniowych. (Chemical composition and nutritional value of Polish variety of buckwheat grains on the basis of contemporary nutritional requirement). *Zeszyty Naukowe Akademii Rolniczej im. H. Kołłątaja w Krakowie* **392**, 95-101 (in Polish)

Pomeranz Y (1975) Proteins and amino acids of barley, oats and buckwheat. In: Friedman M (Ed) *Protein Nutritional Quality of Foods and Feeds*, Marcel Dekker Inc., New York, pp 13-78

Préstamo G, Pedrazuela A, Peñas E, Lasunción MA, Arroyo G (2003) Role of buckwheat diet on rats as prebiotic and health food. *Nutrition Research* **23**, 803-814

Qian J, Kuhn M (1999) Physical properties of buckwheat starches from various origins. *Starch/Stärke* **51 (2-3)**, 81-85

Roberfroid MB (1995) A functional food-chicory fructo-oligosaccharide: a colonic food with prebiotic activity. *The World of Ingredients* **2**, 42-44

Śmietana Z, Fornal Ł, Szpendowski J, Soral-Śmietana M, Fornal J (1985) Products extruded from buckwheat flour and its mixtures with milk proteins. I. Technological aspects of extrusions and their relationship with the expansion and porosity of structure. *Acta Alimentaria Polonica* **3**, 275-284

Śmietana Z, Fornal Ł, Szpendowski J, Soral-Śmietana M, Fornal J (1988) Utilization of milk proteins and cereal starches to obtain co-extrudates. *Die Nahrung* **32**, 545-551

Soral-Śmietana M (1984) Białka ziarna gryki. (Buckwheat grain proteins). *Postępy Nauk Rolniczych* **3**, 35-46 (in Polish)

Soral-Śmietana M, Fornal Ł, Fornal J (1984) Characteristics of buckwheat grain starch and the effect of hydrothermal processing upon its chemical composition, properties and structure. *Starch/Stärke* **36**, 153-158

Soral-Śmietana M (1992) Badania interakcji skrobi zbożowych z tłuszczowcami, indukowanych cieplnie w procesach technologicznych. (Studies on thermally induced interactions between cereal starch and lipids in the technological processes). *Acta Academiae Agriculturae ac Technicae Olstenensis, Technologia Alimentorum* **429 (24)**, 3-57 (abstract in English)

Soral-Śmietana M (2000) Resistant-starch – nutritional or non-nutritional component of food. *Polish Journal of Food and Nutrition Sciences* **9/50 (3S)**, 15-21

Soral-Śmietana M, Wronkowska M, Amarowicz R (2001) Health-promoting function of wheat or potato resistant starch preparations obtained by physico-biochemical process. In: Barsby TL, Donald AM, Frazier PJ (Eds) *Starch, Advances in Structure and Function*, The Royal Society of Chemistry, Cambridge, UK, pp 116-128

Soral-Śmietana M, Wronkowska M (2004) Resistant starch – nutritional and biological activity. *Polish Journal of Food and Nutrition Sciences* **13/54 (SI 1)**, 51-64

Steadman KJ, Burgoon MS, Lewis BA, Edwardson SE, Obendorf RL (2001) Buckwheat seed milling fractions: description, macronutrient composition and dietary fibre. *Journal of Cereal Science* **33**, 271-278

Stempińska K, Soral-Śmietana M (2006) Składniki chemiczne i ocena fizykochemiczna ziarniaków gryki – porównanie trzech polskich odmian. (Chemical compounds and physicochemical estimation of buckwheat grains – comparison of three polish varieties). *Żywność. Nauka. Technologia. Jakość* **2 (47) (Suppl.)**, 348-357 (abstract in English)

Stempińska K, Soral-Śmietana M, Zieliński H, Michalska A (2007) Wpływ obróbki termicznej na skład chemiczny i właściwości przeciwutleniające ziarniaków gryki. (Effect of thermal treatment on chemical and antioxidant properties of buckwheat grains). *Żywność. Nauka. Technologia. Jakość* **5 (54)**, 64-74 (abstract in English)

Stibilj V, Kreft I, Smrkolj P, Osvald J (2004) Enhanced selenium content in buckwheat (*Fagopyrum esculentum* Moench) and pumpkin (*Cucurbita pepo* L.) seeds by foliar fertilisation. *European Food Research and Technology* **219**, 142-144

Tanaka K, Matsumoto K, Akasawa A, Nakajima T, Nagasu T, Iikura Y, Saito H (2002) Pepsin-resistant 16-kDa buckwheat protein is associated with immediate hypersensitivity reaction in patients with buckwheat allergy. *International Archives of Allergy and Immunology* **129**, 49-56

Tang C-H (2007) Functional properties and *in vitro* digestibility of buckwheat protein products: influence of processing. *Journal of Food Engineering* **82**, 568-576

Tomotake H, Shimaoka I, Kayashita J, Yokoyama F, Nakajoh M, Kato N (2000) A buckwheat protein product suppresses gallstone formation and plasma cholesterol more strongly than soy protein isolate in hamsters. *Journal of Nutrition* **130**, 1670-1674

Tomotake H, Yamamoto N, Yanaka N, Ohinata H, Yamazaki R, Kayashita J, Kato N (2006) High protein buckwheat flour suppresses hypercholesterolemia in rats and gallstone formation in mice by hypercholesterolemic diet and body fat in rats because of its low protein digestibility. *Nutrition* **22**, 166-173

Velioglu YS, Mazza G, Gao L, Oomah BD (1998) Antioxidant activity and total phenolics in selected fruits, vegetables, and grain products. *Journal of Agricultural and Food Chemistry* **46 (10)**, 4113-4117

Wanatabe M (1998) Catechins as antioxidant from buckwheat (*Fagopyrum esculentum* Moench) groats. *Journal of Agricultural and Food Chemistry* **46**, 839-845

Wanatabe K, Shimizu M, Adachi T, Mitsunaga T (1999) Characterization of thiamin-binding protein in buckwheat seeds. *Journal of Nutritional Science and Vitaminology* **78 (2)**, 323-328

Wei Y, Hu X, Zhang G, Ouyang S (2003) Studies on the amino acid and mineral content of buckwheat protein fractions. *Nahrung/Food* **47**, 114-116

Wieslander G (1996) Review on buckwheat allergy. *Allergy* **51**, 661-665

Wronkowska M, Soral-Śmietana M, Krupa U, Biedrzycka E (2006) *In vitro* fermentation of new modified starch preparations – changes of microstructure and bacterial end-products. *Enzyme and Microbial Technology* **40**, 93-99

Wronkowska M, Soral-Śmietana M (2008) Buckwheat flour – a valuable component of gluten-free formulations. *Polish Journal of Food and Nutrition Sciences* **58/1**, 59-63

Wronkowska M, Soral-Śmietana M, Biedrzycka E (2008a) Utilization of resistant starch of native tapioca, corn and waxy corn starches and their retrograded preparations by *Bifidobacterium*. *International Journal of Food Sciences and Nutrition* **59/1**, 80-87

Wronkowska M, Soral-Śmietana M, Krupa U (2008b) Mieszanka wypiekowa bezglutenowa. (Gluten-free banking mixture). *Polish patent specification* No P 386254

Wronkowska M, Troszyńska A, Soral-Śmietana M, Wołejszo A (2008c) Effects of buckwheat flour (*Fagopyrum esculentum* Moench) on the quality of gluten-free bread. *Polish Journal of Food and Nutrition Sciences* **58/2**, 213-216

Wronkowska M, Soral-Śmietana M, Krupa-Kozak U (2009) Native wheat, potato and pea starches and their physically modified preparations tested *in vitro* as the substrates for selected *Bifidobacterium* strains. *International Journal of Food Sciences and Nutrition* **60 (S4)**, 191-204

Wronkowska M, Zielińska D, Szawara-Nowak D, Troszyńska A, Soral-Śmietana M (2010) Antioxidative and reducing capacity, macroelements content and sensorial properties of buckwheat enhanced gluten-free bread. *International Journal of Food Science and Technology* in press

Yoshioka H, Ohmoto T, Urisu A, Mine Y, Adachi T (2004) Expression and epitope analysis of the major allergenic protein Fag e 1 from buckwheat. *Journal of Plant Physiology* **161**, 761-767