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Chapter

Use of Common Buckwheat in the Production of Baked and Pasta Products

*Tatiana Bojňanská, Alena Vollmannová, Judita Lidiková
and Janette Musilová*

Abstract

This chapter introduces buckwheat as a possible raw material for the production of designed foods. It includes the description of common buckwheat as a source of basic nutrients for food production and gives specificities of buckwheat as a source of biologically active substances. Processed buckwheat seeds are important from the point of view of rational nutrition as a source of energy, carbohydrates, fibre, proteins, lipids, vitamins, and minerals. Buckwheat has also other nutritional advantages, especially the interesting content of polyphenolic compounds: phenolic acids, flavonoids, especially rutin, which are characterised by high antioxidant activity. This chapter describes how buckwheat can be processed into food products and discusses the results of the application of buckwheat to bread and pasta. Moreover, it includes the results of the clinical study. Based on the identified technological and sensory properties of bread products obtained during the baking experiment, the chapter summarises recommendations on the suitable added amount of buckwheat to get satisfactory results. Concerning pasta from buckwheat, it had very good technological, nutritional, and sensory qualities. The chapter concludes that, on the basis of findings, buckwheat is a raw material suitable for the production of designed foods.

Keywords: common buckwheat, polyphenolic compounds, technological properties, dough rheology, rheofermentometer, bread quality, pasta properties

1. Introduction

The sustainable development of agriculture is based, among other things, on the efficient use of gene funds. The use of species or varieties with high resistance, high yield stability, the ability to use nutrients efficiently and high nutritional quality is a guarantee of biodiversity conservation extending and intensifying the use of species and varietal diversity to less grown crops, whether traditional or forgotten, can bring new types of products with the higher nutritional quality or added value. This is also one of the ways how to innovate existing foods. Presently, there is a growing interest in such crops.

Without any doubt, buckwheat is one of these interesting raw materials. It is included among pseudocereals, which botanically do not belong to cereals, but their use is similar. It comes from Southeast Asia, the first written records of the plant are in Chinese documents of the fifth and sixth century AD. It came to Europe from Russia in the Middle Ages, and in the territory of today's Slovakia, it began to be grown in the thirteenth–fourteenth century [1]. For many centuries it was a vital food source for the inhabitants of mountainous regions where the climate is cold and the soil is poor [2]. It belongs to the family Polygonaceae, to the genus *Fagopyrum*. *Fagopyrum esculentum* (Moench) and *Fagopyrum tataricum* (L.) Gaertn can be grown for grain yield (*Fagopyri semen*), with the most important species being *Fagopyrum esculentum*. It is an annual plant 0.5–2 m high, branched at the top. The flowers are white, white-pink, and sometimes red, they bloom gradually from bottom to top and are foreign-pollinated, mainly by bees. The fruit of buckwheat is a triangular smooth achene (seeds of a curious shape, triangular in cross-section with pointed ends) with a brown to violet-red colour. The potential yield is 1.5–2.5 t/ha [3, 4]. It can also be used as fodder or honey plant. Buckwheat stems and leaves (*Fagopyri herba*), which were previously used only as animal feed, are currently also used for human consumption. Buckwheat was once a widely grown crop in Central Europe, but was gradually replaced by more intensive species. So it can be described as a “forgotten” crop. Buckwheat's renaissance is motivated mainly by health reasons.

In terms of nutrition, buckwheat seeds have a very favourable composition. Properly processed and modified buckwheat seeds are important from the point of view of rational nutrition as a source of energy, carbohydrates, fibre, vitamins, lipids, and minerals. Especially proteins of buckwheat seeds are valuable thanks to their composition which makes buckwheat suitable for food production for celiacs.

Buckwheat also has other nutritional advantages, especially the interesting content of polyphenolic compounds: phenolic acids, flavonoids, especially rutin, which are characterised by high antioxidant activity. Taking into consideration all characteristics, buckwheat is a raw material suitable for the production of designed foods [5, 6].

2. Common buckwheat as a source of basic nutrients for food production

This section gives an overview of buckwheat's seeds composition referring to the content of important nutrients, namely, proteins, fibre, amino acids, starch, fats as well as minerals. For food production, the dehulled seeds, called the groats, are the preferred used part of buckwheat. They are rich in proteins, their content in buckwheat groats is around 12% and more, and their biological value is relatively high [7]. Buckwheat protein contains a wide range of various amino acids, the most represented being glutamic acid, aspartic acid, and arginine. Of the essential amino acids, the content of lysine, leucine, valine, but also methionine and tryptophan is particularly important. Buckwheat can therefore serve as a natural plant source of these amino acids essential for the human body [8, 9]. Buckwheat proteins can be divided on the basis of their solubility into protein fractions, with the share of albumins and globulins as the most valuable fractions being up to 50–65%, and a low proportion of prolamin proteins (3–6%), which makes buckwheat a suitable raw material also for celiacs [9, 10]. In buckwheat, 13S globulin and 8S globulin have been identified, where 13S globulin contributes to 33% of total seeds proteins and is a major storage protein [11]. Most of the protein in buckwheat is localised in protein bodies.

The main proportion of carbohydrates found in buckwheat seeds consists mainly of starch, the content of which varies in a relatively wide range from 58 to 70%. This may be due to genetically fixed characteristics of the variety, agro-ecological cultivation conditions or climatic conditions. Buckwheat starch granule sizes are 2.9–9.3 μm with an average size of 5.8 μm and have a round or polygonal shape [9].

In addition to starch as an energy source, there is also the potential for resistant starch in buckwheat [12]. Resistant starch is a portion of starch and starch degraded products that escape enzymatic hydrolysis in the small intestine. There are indications that metabolites formed during the fermentation of resistant starch in the large intestine, contribute to the maintenance of colon health and have beneficial effects on glucose metabolism as well. For most healthy adults, consuming foods with a higher amount of resistant starch is, therefore, advantageous. Undigested starch may result in positive nutritional effects that are similar to effects observed with fibre [12]. Besides, foods with higher levels of resistant starch usually have a low GI (Glycaemic Index).

Moreover, buckwheat is rich in dietary fibre that has a positive physiological effect on the gastrointestinal tract and significantly influences the metabolism of other nutrients. Dietary fibre can be divided into insoluble fibre and soluble fibre. In buckwheat seeds, hemicellulose is the predominant fraction, while in buckwheat hulls lignin and cellulose are dominant [13]. In buckwheat seeds dietary fibre constitutes from 5 to 11%, the soluble fraction content is around 3–7%, while the amount of the insoluble fraction is approx. 2–4% [8]. The physiological effect of dietary fibre depends first of all on its origin, the proportions of individual fractions, the degree of comminution of raw materials and the applied thermal processes. The insoluble fraction of dietary fibre (generally includes lignin and cellulose) that activates the intestinal peristalsis is capable of binding bile acids and water. Soluble fibre (includes pectin and gums) reduces the blood cholesterol level, the risk of incidence of ischemic heart disease and postprandial glycaemia. The functional properties of dietary fibre, such as water holding capacity, cation binding, and sorption of bile acids, play a significant role in the prevention of diet-dependent diseases, e.g. obesity, atherosclerosis, and colon cancer [14]. However, dietary fibre can also have a negative role as it may bind proteins and minerals, inhibit digestive enzymes, and thereby lower digestibility or absorption.

With regards to the content of fats, achenes of buckwheat contain 2–3% of fats that are concentrated in the embryo. In buckwheat flour, the embryo is generally included (mostly in bran fraction), so the content of fats in groats and flour is 3–4% [15], and the risk of deterioration by lipids is therefore particularly important. Oleic acid is the dominant unsaturated fatty acid ($\approx 33\%$) in the seed oil, followed by linoleic acid ($\approx 32\%$), which belongs to the essential fatty acids and has many physiological functions. The main saturated fatty acid is palmitic acid ($\approx 13\%$). Stearic acid ($\approx 1.6\%$) and others are also present in smaller amounts [16].

As for the content of important minerals in buckwheat, it is also substantial, especially since the levels of Mg, Zn, K, P, Fe, Cu, and Mn are high when compared to cereals. For example, Mg, Zn, K, P, and Co are mainly stored as phytate in the protein bodies. Minerals such as Fe, Zn, Mn, Cu, Mo, Ni, and Al are primarily located in both the hull and seed coat [17]. The largest difference between the content of a particular mineral element in groats compared to seeds, is found with Ca (more than a fourfold decrease), Fe (more than a threefold decrease), and Mn (one and a half fold decrease) [18].

Buckwheat, therefore, provides all the important sources of basic nutrients for food production, and in addition, its great advantage is the presence of biologically

active substances, which generally affect the physiological processes in the body of consumers in the desired.

3. Common buckwheat as a source of biologically active substances

As illustrated above, buckwheat has a favourable composition of the protein complex, fibre content, and minerals. In addition, it contains also vitamins as well as phytochemicals with a prophylactic value and biological activity as presented in this section. Here, we also describe which compounds are found in different parts of a buckwheat plant.

Vitamins are a group of organic compounds that are essential in very small amounts for the normal functioning of the human body. Group B vitamins are very important components of the vitamin complex contained in buckwheat: B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine). Other vitamins present are vitamin C in buckwheat sprouts, and vitamin E (tocopherols). In buckwheat seeds, thiamine is strongly adhered to thiamine-binding proteins [6, 9]. An important component of the vitamin complex in buckwheat is choline, an essential nutrient, and choline esters that are potential functional food ingredients. Choline is used by the body for the biosynthesis of phospholipids and acetylcholine, which is used in the transmission of nerve impulses. It is also used therapeutically for liver damage. The daily requirement is about 600 mg. In 1 kg of common buckwheat seeds on a dry matter basis (dry weight/d.w.), the content is about 440 mg [19].

A larger proportion of phenolic compounds in buckwheat are flavonoids. Flavonoids are classified into numerous subgroups, namely, flavonols, flavones, flavanones, flavanols, anthocyanins, fagopyrins, proanthocyanidins, isoflavones, and flavonolignans. The major flavonoids in buckwheat are rutin, quercetin, orientin, homoorientin, vitexin, kaempferol, and isovitexin. Different types of flavonoids have been detected in the root, leaves, flower, seed, sprouted seed, seed coat, seed husk, and processed food of buckwheat [20]. Flavonoid compounds present in buckwheat are significantly important to improve human health and to prevent and heal different diseases [6].

Almost all parts of buckwheat are the source of many health beneficial components, however, the differences in the content of polyphenolic substances found in different anatomic parts (stems, leaves, flowers, and seeds) are significant. The concentration of flavonoids and main phenolic acids was monitored in the flowers, seeds, and leaves [21–24]. The highest concentration of chlorogenic acid and *trans*-sinapic acid was found in the flowers. For other studied phenolics, the highest concentration was established in the leaves, followed by the flowers and then the seeds [24].

The flavonoids content and composition in buckwheat seeds is affected by cultivar, location, growing phase, and growing conditions. When evaluating the dynamics of the total polyphenols formation, the maximum increase in the polyphenolic contents was observed during the full ripeness growing phase. The highest polyphenol content was found in the leaves, followed by the seeds and stems (there were no more flowers in this growing phase) [25]. Different polyphenol contents were also found in common buckwheat cultivars [26] and the determining role of the cultivar on the relative content of chlorogenic acid, *trans*-caffeic acid, *trans*-sinapic acid, vitexin, and kaempferol in buckwheat plants was confirmed. The content of the dominant flavonoid rutin in the seeds of buckwheat cultivars (8) varied in the range from 2.791 mg/g d.w. (cv. Pulawska, Poland) to 13.326 mg/g d.w. (cv. Ballada, Russia) [24].

The most important flavonoid in buckwheat is rutin, which has remarkable effects on the human organism. It reduces high blood pressure, the risk of arteriosclerosis, and has also antioxidant activity [5, 27]. Rutin is also used medicinally in many countries to reduce capillary fragility associated with some haemorrhagic diseases in humans. In 1 kg of buckwheat seed on a dry matter basis, there is approximately 60–80 g of rutin [24], which is an important amount, but this might decrease due to the culinary preparation (cooking). It is also necessary to take into account the distribution of rutin and possibly other flavonoids in buckwheat seeds according to the milling fractions during the milling process. In common buckwheat, rutin is mainly located in the hull, and its concentration is low in groats or flours (**Figures 1 and 2**) [21–26, 28].

All polyphenols are reducing agents, and as such, they may scavenge free radicals and protect cell constituents against oxidative damage. Especially flavonoids belong to the plant components with an antioxidant activity, which is a fundamental property important for life. The differences in the chemical structures of different flavonoids affect their antioxidant activities. Buckwheat appears to be a suitable component of food products with regard to its nutritional aspect and its antioxidant activity [29]. A significant relationship between the total phenolic as well as rutin content in common buckwheat and antioxidant activity was found [30]. The antioxidant activity differences were also found between buckwheat cultivars as well as among the different parts of the plant [31].

Figure 1.
Graphical overview of differences in flavonoids content in different parts of common buckwheat: L (leaves), F (flowers), S (seeds).

Figure 2.
Graphical overview of differences in phenolic acids content in different parts of common buckwheat: L (leaves), F (flowers), S (seeds).

The use of buckwheat in food production, and not just seeds but also other parts of the plant, can improve the nutritional value of foods thanks to adding an antioxidant activity from natural sources. However, the safety and toxicity profiles of the roots, leaves, and hulls of buckwheat have not been completely analysed until now. There may be some risks associated with eating buckwheat. Buckwheat parts, leaves, in particular, contain fagopyrins, phototoxic phenolic substances belonging to the group anthraquinones. When fagopyrins accumulate under the skin, it causes fagopyrism, which manifests itself when the skin is exposed to sunlight. Fagopyrism has been described in the past in livestock, which feeds on buckwheat leaves. The seeds contain very few fagopyrins but the whole plant, either dried or green, can cause serious problems potentially also for people, because of the consumption of buckwheat leaves, e.g. through the juice from the leaves [9, 32, 33].

The possibility of buckwheat allergy should be also mentioned. This is a clinical condition known for a long time and is frequent in Asia, where this crop is commonly eaten. An allergy to buckwheat is typically IgE mediated, several buckwheat proteins are described as being able to bind IgE in allergic patients. Proteins with a molecular weight of 9, 16, 19, and 24 kDa are considered major allergens [34]. In Europe, buckwheat allergy was not documented until a few years ago, when the consumption of buckwheat increased. Buckwheat allergy merits awareness in Europe since exposures are likely to increase via the use of buckwheat as it is becoming popular in the food sector. Failure to recognise buckwheat allergy could expose individuals to a considerable risk. A particular aspect of allergic reactions to buckwheat reported in Europe is that they are often severe and systemic, such as anaphylaxis, and often triggered by buckwheat not declared in dishes that are not supposed to contain it [35].

Despite these risks, and based on a comprehensive consideration of nutritional benefits, buckwheat appears to be an excellent raw material for food processing, which is described in the next section.

4. Food processing of buckwheat

For food production, the most usable part of buckwheat is achene, which is covered on the surface with a hard dark hull. Before processing the achenes, they must be separated without damaging the endosperm. Currently, two basic technological processes are used in the world for dehulling buckwheat, namely, mechanical dehulling and thermal dehulling. It must be taken into consideration that dehulling the seeds by using different temperature regimens results in drastic reductions of the total flavonoid concentration in the seeds (by 75% of the control) [36], thus, reducing considerably the amount of positive substances. Dehulled seeds are further processed into buckwheat groats or buckwheat flour.

Buckwheat dishes have a long tradition and certain specifics must be taken into account in their cooking. In dry state, buckwheat is relatively hard, but it loses this property after receiving a sufficient amount of water or other liquid. In the process of swelling, buckwheat groats absorb water and double their volume. From a practical point of view, this means that each kilogramme of buckwheat groats receives 2.0–2.5 l of water. When boiling water is poured over buckwheat groats, they can be even served without cooking after cooling slowly in a sealed container. It should be noted that sufficient time for swelling buckwheat groats cannot be replaced by intense cooking. There might be certain disadvantages of buckwheat products, mainly the typical buckwheat aroma, which must be accepted. Also the possible odour after becoming

musty, or acquired foreign odour could be perceptible as buckwheat is very prone to absorbing foreign odours [3]. A promising and unobtrusive way of how to apply buckwheat in food is its addition in the form of flour to other, often basic foods, for example, in bread, pastry, cakes, pancakes, biscuits, cookies, pasta, and noodles.

4.1 Application of common buckwheat to bread

As mentioned previously, the addition of buckwheat in basic food such as bread has proven to be a very convenient way of making bread more nutritionally attractive. This section describes the nutritional advantages of buckwheat additions in flours intended for the production of bread and pastries, but on the other hand, brings up the subject of the technological disadvantages.

Bread is food consumed on a daily basis and is generally very popular in the world. In Europe, bread is the main source of carbohydrates in the diet, but its consumption is on a declining trend. In Slovakia, for example, the consumption of bread and pastries (bread under 400 g) has fallen by almost 30 kg in the last 30 years, despite the nutritional recommendations, according to which the share of carbohydrates in the energy supply to the body should be 50–60%. In Slovakia, this recommended value according to age, gender, and work intensity ranges from $\approx 48\%$ for infants, through $\approx 60\%$ for adolescents (up to 18 years) and $\approx 58\%$ for working adults [37].

Bread is an integral part of the diet, it contains essential nutrients, antioxidants, as well as vitamins. Even after thousands of years of consumption, it remains the most commonly consumed food in the world, also thanks to its readiness, portability, nutritional value, and taste [38]. Currently, however, carbohydrate foods are considered by the public to be a group of foods with a lower nutritional value. There are several reasons for this lower bread consumption, one of them being the increasing number of consumers who reject foods containing gluten, even if they do not have any health reasons (celiac disease, non-celiac sensitivity). One way to increase the proportion of biologically valuable ingredients in bread, and thus make it a more attractive food, is to partially replace the typical bread and rye bread raw materials with non-bakery raw materials, which are expected to meet consumer requirements for bioavailable and nutritionally necessary ingredients [39–41]. Buckwheat is undoubtedly such raw material.

However, due to the properties of non-bakery raw materials that do not meet the technological requirements, it is often a problem to prepare a product with the required volume, porosity, or sensory properties [42, 43]. From the technological and sensory point of view, the volume of bread or pastry is very important. The volume is ensured by the processes taking place during fermentation and the ability of the dough to retain the fermentation gases in the required volume. However, the addition of non-gluten raw materials weakens the dough due to the fact that they do not form the gluten nets, which affects the viscoelasticity of the dough, incorporation of air during kneading, and gas retention during fermentation. This process is resulting in bread with a weak structure and crumb texture [44, 45]. It is important to recognise that although from a nutritional point of view, the enriching addition should be as high as possible, from a technological and sensory point of view, an acceptable compromise must be found.

The bakery and non-bakery buckwheat products are prepared in many countries according to various often traditional recipes. The following part focuses on the possibilities of preparing enriched breads as a source of biologically active ingredients in nutrition. Buckwheat flour was mixed with wheat flour in different proportions (10, 20, 30, 40 and 50%). We present below the results of the suitability of using

buckwheat flour in bakery products obtained by the available rheological instruments. We also carried out the baking test and gave possible suggestions on optimal amounts of buckwheat in bread. The raw materials used were not physically, chemically, or biologically treated to modify their technological properties, and were analysed for standard parameters of technological quality. The wheat flour used was good quality, strong flour with a high crude protein content (13% d.w.), with a good wet gluten content (25.6%), with an excellent swelling and adequate enzymatic activity (falling number 358 s). The buckwheat flour used had a slightly higher crude protein content (13.8%) and more than twice the ash content compared to wheat flour [46].

Measuring the rheological properties of dough intended for bread production is relatively complicated due to the exploitation of specific equipment. Rheology studies the relations between the tension a material is exposed to, the final dimension of material deformation and time. The rheological measurement is used to obtain a quantitative description of the material's mechanical properties and to get data with relation to its molecular structure and composition. It also enables to characterise and simulate the efficiency of the material during the production and the quality check [47, 48]. As part of rheological analyses (Farinograph-E, Extensograph-E, Brabender) the changes in the physical properties of wheat flour and composite flours with the addition of buckwheat were monitored. The influence of buckwheat added to composite flours on the properties evaluated by a farinograph was significant [49, 50]. With an increasing portion of buckwheat, the dough consistency (in comparison to wheat flour) decreased, the dough became weaker and the resistance against the farinograph blades was lower (**Figure 3**).

Rheological properties of wheat dough affect mainly the gluten content and its qualitative properties. The high gluten swelling in wheat flour was beneficial since buckwheat does not contain gluten-forming proteins and reduces the gluten content in buckwheat-containing composite flours. This reduction in bread making causes technological problems, as gluten proteins play a key role in ensuring the baking quality of wheat and affect water binding, cohesion, viscosity, ductility, flexibility, stretch resistance, kneading tolerance as well as the ability to retain fermentation gases [51–53].

The rheological properties of dough changed when increasing the amount of buckwheat in the composite flour. The water absorption of dough decreased slightly when increasing the addition of buckwheat in the mixture, which is less desirable from an economic point of view, as the amount of flour needed to produce the same weight of dough increases. The farinograph curve confirmed the prolongation of the dough development time and increased energy input demands for kneading the dough with an optimal consistency by increasing the buckwheat addition.

Figure 3.
Farinograph wheat flour and farinograph wheat flour with buckwheat 50%.

The development time of the dough with the addition of buckwheat 20% or more was considerably higher than in the control sample (9.0–9.5 min and 1.7 min, respectively) [43]. A longer dough development time is typical for bakery strong flours, but bakeries prefer flours with a shorter dough development because of the energy intensity of kneading. Subsequently, the behaviour of the dough with the addition of buckwheat was verified in different kneading modes. The Sigma blades of the farinograph worked with three different speeds (standard—63 revs./min, low—45 revs./min and high—120 revs./min). In composite flours with a higher proportion of buckwheat (20%<), the slow speed further prolonged the development time of the dough, but at high speed, the development time of the dough was already at the same level as in wheat flour. With the increasing addition of buckwheat, the extensographic energy (cm^2), extensographic resistance (BU Brabender unit), extensographic ductility (mm), as well as the ratio of resistance and ductility also decreased. With the increasing addition of buckwheat, the dough was less durable and unstable when kneading, which is a prerequisite for reducing the volume of bread [46, 54]. Therefore, when preparing dough with non-bakery raw materials, it is necessary to consider, verify and set the optimal kneading mode.

Determining the ability to form fermenting gases is crucial to produce bread with a good volume. To determine the rheofermentation properties a rheofermentometer Rheo F4 is used, by means of which the total volume of gas, the volume of gas lost, and the retention volume produced under the conditions of the method are determined. It is important to note that the produced CO_2 serves to expand the dough and achieve the final loaf volume. The unique properties of wheat flour to form a viscoelastic dough that can retain gas are due to the protein characteristics of wheat gluten when it is mixed with water [55]. Composite flours with buckwheat addition decrease the total amount of gluten, resulting in the formation of a weaker protein network. **Figure 4** clearly illustrates the CO_2 production during the fermentation of dough with an addition of buckwheat in a portion of 30%. In the dough with an addition of buckwheat, the gas production was more intensive. The total volume of gas in the composite flour dough was higher than in the wheat flour dough (1792 ml and 1408 ml, respectively), but the CO_2 losses in the composite flour dough were up to 2.6 times higher than in the wheat flour dough (580 ml and 219 ml, respectively), so finally the retention volume was at approximately the same level in both samples. This finding was positive and gave an assumption for an adequate volume of the final product—bread [47, 56, 57].

Figure 4.
Rheofermentometer curves of wheat flour and wheat + buckwheat composite flour.

Figure 5. *Experimental breads with the addition of buckwheat (wheat bread > with 10% of buckwheat > with 20% of buckwheat > with 30% of buckwheat > with 40% of buckwheat > with 50% of buckwheat). Photo: author.*

The baking test is the direct method for determining the quality of the applied raw materials and composite flours. During the baking process, the flour blends were subjected to mechanical work and heat treatment that promote changes in their physicochemical properties [58]. The final product has physical and sensory properties that make it a well-digestible and popular staple food. The experimental breads were prepared from composite flours with the addition of buckwheat in the amount of 10, 20, 30, 40 and 50%, water, salt, and yeast in the amount according to the recipe. They were baked according to the workplace methodologies in a steamed oven at a maximum temperature of 260°C [42, 46, 54]. Subsequently, they were subjected to evaluation by objective parameters and a sensory evaluation. Increasing the buckwheat amount in blends with wheat flour decreased the important parameters such as loaf volume, specific loaf volume, and volume efficiency (**Figure 5**). The same trend was observed for loaf arching, which is the ratio between height and width, and its higher value predicts a loaf with a more desirable, arched shape [59]. With the addition of buckwheat, the acidity of the crumb changed considerably. The acidity is an indicator of the content of acidic substances, or acids present in the starting material, but also formed during fermentation. Too low a value of titratable acids is not desirable, because such a pastry has a dull and unimpressive flavour. An increased crumb acidity can be considered desirable because of its distinctive flavour and taste during sensorial proofing.

The results of the sensory assessment of buckwheat-enriched breads show a gradual deterioration of most of the evaluated parameters depending on the amount of the addition. Although the addition of buckwheat did not have an important effect on the colour of the crust, it considerably intensified the colour of the crumb, the elasticity of which decreased when increasing the addition [50]. The colour of the bread crumb depends largely on the colour of the flour, the ash content, the presence of bran particles, the pore structure of the crumb and the way the dough is formed. The fineness of the crumb is directly related to the product volume, the pore structure, the additives used (emulsifiers, enzymes), the moisture content,

Figure 6.
Sensory profile of breads with the addition of buckwheat.

the baking conditions (time), and the storage conditions (temperature/time) [60, 61]. The appearance of the surface, the appearance of the crumb, the smell, the taste, and the overall acceptability expressed by the hedonic scale (0–9) are documented in **Figure 6**, from which the reduction in the point rating of these properties is evident [46]. Of all the loaves evaluated, the control loaf was the most acceptable (8.6) and the overall acceptability decreased with the amount of the addition: buckwheat addition of 10% (7.4) > buckwheat addition of 20% (5.8) > buckwheat addition of 30% (4.0) > buckwheat addition of 40% (2.6) > buckwheat addition of 50% (1.0).

W-common wheat flour, W + B10-common wheat flour + buckwheat wholegrain flour 10%, W + B20-common wheat flour + buckwheat wholegrain flour 20%, W + B30-common wheat flour + buckwheat wholegrain flour 30%, W + B40-common wheat flour + buckwheat wholegrain flour 40%, W + B50-common wheat flour + buckwheat wholegrain flour 50%.

From the consumer's point of view, the sensory acceptability of the product is especially important, so ultimately the organoleptic evaluation decides on its success on the market. Based on the results of measuring the physical properties of the dough and the baking experiment, the 10% buckwheat addition seems to be the most suitable. Such an addition did not significantly reduce the technological properties of the dough or pastry. Although higher buckwheat additions gave products with the expected higher nutritional value, they were technologically rated as worse, although still acceptable. We assume that technological shortcomings could be partially compensated by the use of suitable additives with improving properties. From the overall acceptability rating, it was concluded that bread with the addition of 10%, 20%, and 30% of buckwheat could be baked with satisfactory results. Such enriched bread is considered of a high nutritive value and acceptable from a sensory point of view, therefore, we can recommend these amounts of buckwheat additions as appropriate.

In general, the increasing addition of buckwheat worsens the technological and sensory parameters of bread compared to wheat bread, but on the other hand, there is an increase in nutritional value due to the content of valuable buckwheat components. The wheat bread contained 11.39% of protein, the acceptable addition of buckwheat at 30% increased the protein content to 13.63%, which is 17% more than in the control bread. The predominant protein fractions in buckwheat are albumin and globulin, rich in histidin, threonine, valine, phenylalanine, isoleucine and lysine [40, 62], which is undoubtedly a nutritional benefit. In such enriched bread the other important bioactive components (ash, fibre, vitamin B, rutin and antioxidant activity) increased as well [41, 63]. The rutin content in buckwheat wholegrain flour was 79.9 mg/kg (d.w.),

Figure 7. Rutin content in bread (d.w., consumption status, daily dose). W-common wheat flour, B-buckwheat wholegrain flour, WB-wheat bread, W + B10-bread with 10% of buckwheat, W + B20-bread with 20% of buckwheat, W + B30-bread with 30% of buckwheat, W + B40-bread with 40% of buckwheat, W + B50-bread with 50% of buckwheat.

in wheat flour it was 8.1 mg/kg (d.w.). With an increasing amount of buckwheat, the rutin content in bread increased as well (Figure 7).

To confirm the positive effects of daily consumption of bread enriched by buckwheat, the clinical study in a group of volunteers was realised. The bread enriched by 30% of buckwheat (from 34.7 mg/kg to 38.2 mg/kg rutin content [d.w.]) was prepared and consumed daily by a group of research volunteers during a period of 4 weeks. After this time period the selected parameters in blood, as well as anthropometric parameters, were evaluated. Three intravenous blood samples were taken: before the clinical study, immediately after it (after 4 weeks of consuming enriched bread) and after another 4 weeks. The consumption was accompanied by changes in blood biochemical parameters (cholesterol level, LDL, HDL, triglycerides), selected elements (Ca, Mg, Fe), creatinine, urea, chloride, glucose and total antioxidant status. The daily consumption of buckwheat enriched bread during the clinical study by volunteers led to a significant increase of the iron level in the blood and a significant decrease of calcium and magnesium. The significant decrease of the HDL cholesterol level was surprising as well as not desirable [64–66]. On the other hand, the expected and welcome decrease of the total cholesterol was statistically insignificant (Figure 8). Among the positive changes, there was a significant decrease in the triglyceride and creatinine level and an insignificant decrease in the chloride and urea level.

Figure 8. Total cholesterol, low-density lipoprotein (LDL), high-density lipoprotein (HLD) cholesterol and triglycerides levels (mmol/l) in the blood of volunteers.

Figure 9.
Total antioxidant status (mmol/l) in volunteers blood.

The powerful antioxidant activity of flavonoids in buckwheat suggests that these compounds could play a protective role in oxidative stress-mediated diseases [29, 67]. The results confirmed the increase of the total antioxidant status (TAS) in consumers eating buckwheat enriched bread (**Figure 9**). The most significant increase in comparison to the initial state was found with research volunteers with an initially low TAS, the increase reached nearly 40%. The highest TAS level (initially as well as finally) was found with younger research volunteers between 18 and 34 years old, the lowest with people between 35 and 54 years old. These data suggested that buckwheat was a significant antioxidant as TAS in human plasma and that the increased TAS level through doses of buckwheat bread could be useful as a free radical scavenger. It appeared that the TAS of the plasma of the volunteers who consumed buckwheat enriched bread daily during the period of 4 weeks was significantly higher than before its consumption. It was interesting to note that 4 weeks after the end of the consumption of buckwheat bread, a further increase in TAS was confirmed, and thus the body's ability to respond with a delay. Based on the findings, we assume that it is not possible to expect an immediate improvement in the required parameters characterising the body's health by changing the diet. It takes longer, and vice versa, after a certain diet, its positive effects persist for a long time.

In general, it can be concluded that the regular consumption of buckwheat enriched bread brings nutritional benefits to the consumers. Long-term consumption can have a protective effect, thanks to the numerous nutraceutical compounds of buckwheat. It is not realistic, though, to expect that the consumption of buckwheat bread would solve the health problems related to an unhealthy lifestyle and bad eating habits in general.

Based on the obtained results we can conclude that the buckwheat addition worsens the technological parameters of the blends used for the baking test. The rheological properties of the dough changed when the amount of buckwheat in the blend was increased. It means that the increased addition of buckwheat caused a lower dough resistance and instability during kneading. The baking test confirmed this, too. The loaves prepared with an addition of buckwheat were evaluated to be of lesser quality. The overall acceptability rating led to the conclusion that bread could be baked with satisfactory results after addition of buckwheat up to 30%.

In addition to the above described and recommended method of application of buckwheat to bread, in mixtures with wheat or rye flour, buckwheat is considered a very important ingredient for gluten-free formulations too [68]. Within the technologies of their production, when wheat flour does not form any portion in the composite flour, the preparation of the dough is more demanding, especially for the production of bread and pastries with the required volume and porosity [69]. The increase of

buckwheat flour in standard gluten-free flours results in an increased dough development time and a weakening of the protein network, and a decrease of the starch retrogradation degree. This indicates that the addition of buckwheat flour to gluten-free bread or other bakery products could lead to a product with improved anti-staling properties [70].

The diet based on gluten-free products is characterised by a low content of some nutritional components such as proteins and minerals, as well as non-nutritional components like dietary fibre. Especially for these reasons, buckwheat seeds are an excellent raw material. For example, the addition of 40% of buckwheat flour in standard gluten-free flour produced bread with high overall quality. Buckwheat flour as a natural source of minerals and antioxidant activity, and also as a structure-forming source and improving the sensory quality, can be used for the preparation of buckwheat enhanced gluten-free breads [71].

Buckwheat can therefore be considered, especially thanks to its nutritional benefits, as a raw material suitable as a supplement in a certain amount for the production of classic bread made from wheat flour, but also for the production of gluten-free bread.

4.2 Application of common buckwheat to pasta

Besides using the buckwheat in the production of bread and pastries, as described in the previous sub-section, buckwheat flour can be processed into various non-bakery products such as noodles or pasta. Noodles made from buckwheat flour-water dough are popular in some regions including Japan, where the traditional methods of preparing buckwheat noodles generally consist of six successive processes (*mizumawashi*, *kukuri*, *kiku-neri*, *nobashi*, *tatami*, *houchhou*). Apart from the type of flour used, the particle size of flour for noodles and pasta is also important since the data show that a positive correlation between the average diameter of buckwheat flour particles and the maximum water absorption capacity was found. It means that buckwheat flour with a larger particle size can exhibit a higher water absorption capacity than buckwheat flour with smaller particle size [72].

Pasta belongs to the most favourite dishes, especially for young people. The consumption of pasta has a long-term upward trend, so it is important to pay a lot of attention to its production and to improve its nutritional and sensory quality. In particular, pasta belongs to high-carbohydrate foods, which are an important source of energy. It is easily digestible and can be fortified with nutritionally interesting substances, as the easy preparation of pasta enables it. An important feature of pasta is its high degree of flexibility regarding its possible enrichment by different raw materials. If it is specifically designed from certain types of raw materials, it can be consumed as a safe food for certain types of diseases, such as celiac disease [73]. Given that pasta is not a porosity product with a need for gas retention (as with bread), but is a product prepared by cold extrusion, it is possible to use naturally gluten-free raw materials for their production.

Technologically, the most suitable raw material for the production of pasta is semolina, which is flour made from durum wheat (*Triticum durum* L.) and flour from common wheat (*Triticum aestivum* L.).

The experimental pasta was produced in a Fimar MPF 25 low-pressure extruder, in which 25–35% water, eggs, and salt were added to the flour. The formed dense dough was mixed for 15 min, then extruded through an extruder stamper and cut. In addition to the production of traditional pasta, the attention was focused on the preparation of products with a higher nutritional potential. Samples of semolina and

common wheat flour were prepared as controls, to be compared with the gluten-free pasta from buckwheat wholegrain flour and composite flour from buckwheat flour and rice flour in a ratio of 50:50. The pasta was dried to the required moisture (<13%), and the dried pasta was evaluated by the water activity (a_w , Novasina), which is an important indicator of the stability and durability of the products. The water activity values of pasta ranged from 0.538 to 0.552, and it can be stated that it achieved a satisfactory value for this characteristic which is below 0.6. This is a value of an activity corresponding to microbiological stability [19].

From a nutritional point of view, the application of buckwheat has brought into the system a high content of protein (in buckwheat flour 18% d.w., Kjeldahl) and minerals (in buckwheat flour 2.6% d.w., ash content), which was also transferred to pasta. Compared to the control products, the protein and minerals content was considerably higher, as documented in **Figure 10**.

The acidity of flours is indicated by the amount of acidic substances, which are represented by the presence of free fatty acids (products of hydrolytic fats breakdown), phosphates (formed by the breakdown of organic phosphorus compounds such as phytin, phospholipids), and protein hydrolysis products. A higher acidity was found in highly ground and wholemeal flours and groats, and the content of acidic substances also increased with the length of their storage [3]. The acid value of pasta from common wheat was very low (15 mmol/kg) and predicted less pronounced pasta. A high acidity was found in pasta from wholegrain buckwheat, and from a mixture of buckwheat and rice flour, since wholegrain buckwheat flour was used.

Based on the evaluation of the pasta experiment, a comparable level of the ability to be boiled was found. The cooking time of pasta, the binding of the water which is absorbed during cooking, the swelling, which expresses the increase in the volume of cooked pasta and sediment, or cooking losses, confirmed satisfactory values of these parameters in all samples of the experimental pasta. Compared to the control pasta, only the sediment values (cooking losses) of the whole grain buckwheat flour pasta were 100% higher. The sensory evaluation of raw pasta monitored its general appearance, surface properties, flexibility, and strength. After cooking, the sensory profile monitored colour, aroma, taste, stickiness, and general impression. After evaluating the pasta's sensory quality before and after cooking, it can be concluded that the pasta's sensory profile was at a comparable level with the control products. However, the raw and cooked pasta from semolina and common wheat flour had the highest score (**Figure 11**).

Pasta from composite flours was prepared as well. In these flours, whole grain buckwheat flour was added to common wheat flour in amounts of 10, 20, 30, 40, and 50%. All additions increased the content of minerals and proteins in proportion to the

Figure 10.
Graphic overview of protein content, minerals content, and titrable acidity in control pasta and in gluten-free pasta with buckwheat. S-semolina, W-common wheat flour, B-buckwheat wholegrain flour 100%, B + R-buckwheat whole flour + rice flour 50:50.

Figure 11. Sensory evaluation of pasta after cooking. S-semolina, W-common wheat flour, B-buckwheat wholegrain flour 100%, B + R-buckwheat whole flour + rice flour 50:50. 0-the worst evaluation, 5-the best evaluation.

Figure 12. Rutin content in pasta (dry, after cooking and in one consumable portion).

amount added. What was even more important, however, was the increasing content of rutin in buckwheat-enriched pasta (**Figure 12**), and its content in cooked pasta in the consumable state and per serving (80 g of cooked pasta) [72].

Based on our findings, we can conclude that pasta from buckwheat has excellent technological, nutritional, and sensory qualities.

5. Conclusions

This chapter describes the benefits and possible risks, of the inclusion of common buckwheat into the diet. Buckwheat seeds have a very attractive composition. In addition to essential nutrients, which are a source of energy and have other physiological functions, they also contain biologically active compounds that support the good health of consumers. For food production, the usable part of buckwheat is buckwheat achene, which is dehulled. The focus is on food products of daily consumption (bread and pasta) prepared with a portion of buckwheat flour of 10–50%.

The application of common buckwheat to bread as food consumed on a daily basis and generally very popular has proven to be a very convenient way of making bread more nutritionally attractive. Analyses using rheological and fermentographic methods revealed the following modes of behaviour of the dough with the addition of buckwheat flour:

- the influence of buckwheat added to composite flours on the properties evaluated by a farinograph was significant. While increasing the portion of buckwheat, the

dough consistency (in comparison to wheat flour) decreased, the dough became weaker and the resistance against the farinograph blades was lower,

- when preparing doughs with non-bakery raw materials, it is necessary to consider, verify, and set the optimal kneading mode,
- the gas volume and retention volume with an addition of 30% of buckwheat flour (an acceptable amount of the addition) were comparable to the control sample from wheat flour, which provided a precondition for a reasonable volume of the final product—bread,
- based on a baking experiment we can state that increasing the buckwheat amount in blends with wheat flour caused the decrease of important parameters such as loaf volume, specific loaf volume, and volume efficiency,
- the overall acceptability of the breads in a sensory evaluation decreased with the amount of buckwheat flour addition, but $\leq 30\%$ buckwheat flour gave acceptable results,
- from the overall acceptability rating, it was concluded that bread with additions of 10%, 20%, and 30% of buckwheat could be baked with satisfactory results,
- in general, it can be concluded that the regular consumption of buckwheat enriched bread brings nutritional benefits to the consumers.

The application of common buckwheat to pasta can play an important role given that the consumption of pasta has a long-term upward trend in the population. An important feature of pasta is its high degree of flexibility regarding its possible enrichment by different raw materials. Analyses and evaluations of pasta prepared with an addition of buckwheat flour to wheat flour confirmed that:

- from a nutritional point of view, the application of buckwheat brought into the system a high content of protein and minerals, which was also transferred to pasta,
- the cooking time of pasta, the binding of the water which is absorbed during cooking, the swelling, which expresses the increase in the volume of cooked pasta and sediment, or cooking losses, confirmed satisfactory values of these parameters in all samples of the experimental pasta,
- after evaluating the pasta's sensory quality before and after cooking, it can be concluded that the pasta's sensory profile was at a comparable level with the control products,
- all additions increased the content of rutin in buckwheat-enriched pasta proportionally to the amount of the addition.

Based on the findings and results of the analyses, common buckwheat can be recommended as an ingredient of basic carbohydrate foods such as bread or pasta.

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Author details

Tatiana Bojnanská*, Alena Vollmannová, Judita Lidiková and Janette Musilová
Slovak University of Agriculture in Nitra, Slovak Republic

*Address all correspondence to: tatiana.bojnanska@uniag.sk

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