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PSEUDOCEREALS AND THE POSSIBILITIES OF THEIR APPLICATION IN FOOD TECHNOLOGY

AMARANTH AND QUINOA APPLICATION IN FOOD PROCESSING

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Abstract: Amaranth (Amaranthus) and quinoa are the two basic pseudocereals, which have already found application not only in food production, but also in other industrial sectors. In food processing, the seeds of both plants can be used in various ways – from milling into flour or turning into porridge, through roasted, expanded or extracted seeds production and further usage or processing of the obtained products. The seeds and products are e.g. transformed into various food concentrates. They can undergo pressing or fat extraction, which is rich in squalene. A relatively highest and widest application of both plants' seeds can be found in bread, pastry and even confectionery production.

Key words: pseudocereals, amaranth, quinoa, application in bakery, bread

Introduction

The group of pseudocereals [1] includes:

- amaranth (kiwicha, amarantus, amarant) and
- quinoa [2] 'Inca wheat', 'Peruvian rice' and even 'the mother of crops' [2],
- and also (although there is no unanimity in this case),
- buckwheat,
- tartary buckwheat,
- millet,
- triticale.

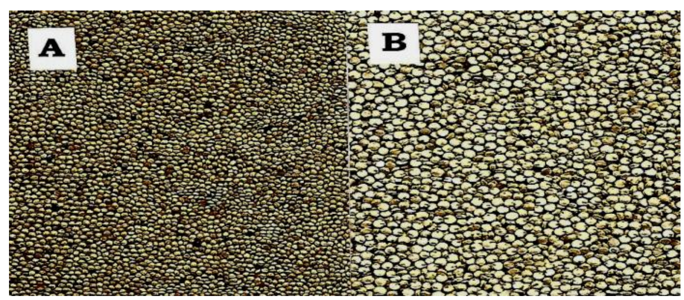

Fig. 1: The appearance of amaranth (A) and quinoa (B) seeds [photo taken by the authors].

Either amaranth as well as quinoa are plants with great potential of application possibilities not only in food production but also feed for livestock. Their general appearance was presented in Figure 1 and their potential application options were gathered and revealed in Table 1.

Among the numerous research that have already been conducted on amaranth and quinoa application [2, 3, 8–17], a relatively little attention was paid to the issues concerning their milling, flaking or porridge production.

One of the first works on the subject was the joint research [18] conducted in the former Central Laboratory of Crops Technology, Processing and Storage and in Warsaw University of Life Sciences (SGGW). They related to the selection of the most appropriate ways of amaranth seeds milling. It was concluded [18] that they can be milled with the use of cylindrical millstones, typical for milling. Milling can be conducted in two variants: as a one- or two-fold milling, with each time chop sieving. The selection of the milling manner should be dictated by the type of final products one wants to obtain and their further application.

With one-fold milling, higher efficiency can be obtained of the thinner fractions (porridge) with lower percentage share of flour (smaller fraction). By implementing two-fold milling, the obtained porridge was additionally ground, which automatically caused the increase in the amount of the obtained flour and the reduction of porridge quantity [18].

Table 1: Practical possibilities of amaranth and quinoa application as well as products obtained from them in food technology and human nutrition [3–7].

Parts of amaranth/quinoa plants or products obtained from them	Direction/directions of practical application
Seeds:	Milling and related industries (porridge and flakes production)
	Bakery and related industries (pastry, cakes)
	Brewing
	Confectionery
	Food concentrates
	Gastronomy (ingredients in dishes: boiled, stewed and baked)
	Feed industry
Seeds: roasted, soaked, extruded and expanded.	Bakery. Pastry. Confectionery: including cakes. Popcorn type products. Snacks. Milk drinks.
Flour: (of various extraction rate)	Bakery. Pastry. Cakes. Pasta production.
Instantized flour:	Food concentrates (breakfast concentrates). Nutrients. Cured meat.
Flakes and porridge:	Muesli ingredients and other food concentrates.
Brans:	Dietary nutrition products. Animal feed.
Amaranth seed oil:	Food industry (concentrates). Medicine. Pharmacy. Cosmetics industry. Computer industry.
Starch:	Food concentrates. Other branches of food industry (used as the so-called carriers). Pharmaceutical industry. Cosmetics industry.
Amaranth leaves:	Gastronomy (as a vegetable: to raw salads, salads, creams etc). Feed industry (green forage, ensilage, hay, dried fodder, briquettes).
Stems, young shoots:	Feed industry (dried fodder, briquettes)

The technical conditions for milling amaranth seeds were set. It was stated [18] that the most favourable conditions are obtained by engaging rollers with the diameter of 250 mm and with grooving density of 9 – 10 grooves/ 1 cm of the roller's perimeter with a mutual positioning of rollers: edge on edge and their overtaking of 1:2.5.

From amaranth as well as quinoa seeds, the so-called instantized flour can be obtained [5]. The flour is heat-treated and as a result there occurs the denaturation of proteins contained in it, partial gelatinization of starch as well as reduction of its enzyme activity. This kind of flour can be applied to e.g. the production of food concentrates and especially nutrients for children, athletes and convalescents [5].

No publications have been found on quinoa seeds milling and/or porridge production, although either flour as well as porridge from quinoa are available on the market. However, taking into account the chemical composition of quinoa seeds (and especially protein content) and the related seeds toughness, it can be assumed that they constitute a better resource than amaranth seeds for milling or porridge production. Quinoa seeds features allow to obtain thicker porridge with the simultaneously greater efficiency of its production process. It is fostered by greater sizes of quinoa seeds, which diameter reaches from 1.1 to 2.5 mm [19].

Porridge production, either from amaranth as well as quinoa seeds, should not be troublesome especially as the manner of their dehusking and the removal of their fruit and seed covering has already been elaborated [20]. Porridge from amaranth and quinoa constitutes an excellent additive to all kinds of soups and also it is a fantastic substitute for traditional porridge.

Other manner of amaranth or quinoa seeds application is their flaking. The process can be conducted with the use of traditional millstones [7, 18], however, with smooth rollers (i.e. grinders) with the diameter of 300 – 350 mm and their overtaking should amount to 1:1.25. It is advisable to moisten the seeds to about 16% about 24 hours before flaking. The flakes either from amaranth as well as quinoa are soft, well blanching and also very tasty and with very high nutritional value [36]. Both quinoa and amaranth-based flakes are available on the market.

The product that is very popular and applied widely and in various ways is the so-called 'popping', i.e. expanded amaranth seeds. The 'popping' is presented in Fig. 2.

Expansion, also called puffing, is a process applied in relation to a grain or sometimes the seeds of other plants. The process consists of exposing the grain/seeds to high temperatures (hot steam) and simultaneously high pressure [21]. No chemicals are used. No anatomical parts are erased and the whole grains/ seeds are used in the expansion process and due to this they preserve their full natural nutrients [21].

The process of expansion is applied mainly to grains. The expanded rice grains, popularly called 'puffed rice', were one of the first on the market. Currently, the grains that are used for this purpose are: wheat, oat, buckwheat, corn, barley or millet as well as seeds of amaranth, quinoa, soya and pea [21].

Expanded grains/seeds are an excellent additive to the so-called fast breakfasts, milk drinks (yoghurt, kephirs, buttermilk) with which the nutrients perfectly supplement and match [21].

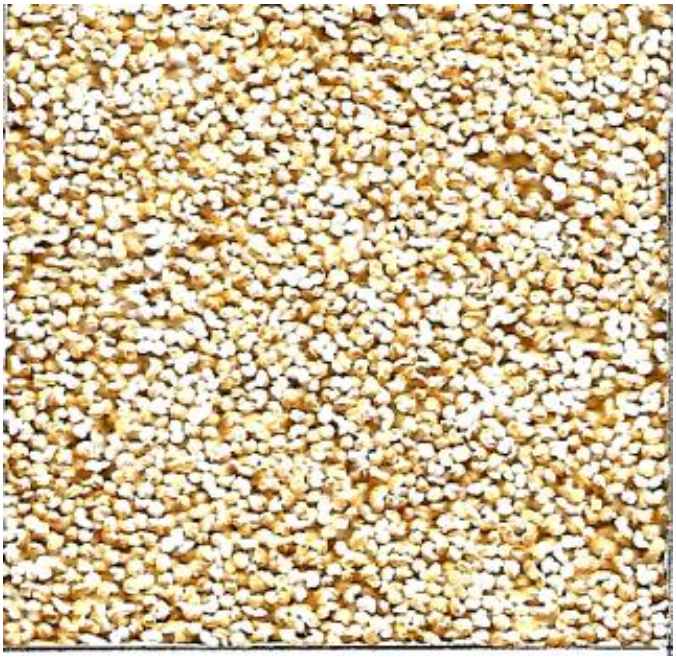

Fig. 2: The so-called 'popping', i.e. expanded amaranth seeds [photo taken by the authors].

Amaranth and quinoa seeds application in bakery

It seems that the best way of applying both of the discussed plants, or products obtained from them, is by adding them to bread [5, 6, 10, 12–14, 22–24]. It results from the nutritional significance of bread, as it is:

- one of the most important food products,
- consumed every day in considerable amounts (about 220 – 250g/day/person),
- food for all social groups (adults and children, healthy and ill, women and men, white and blue collar workers), it is thus:
  - a perfect carrier for many substantial but deficit nutrients.

The purpose of amaranth and quinoa seeds application as the additive to various kinds of bakery products is indicated in many works [3, 9, 12, 23, 25, 26], conducted either in the country and abroad.

In the cited articles, it was stated that it is deliberate to enrich bakery with the flour from amaranth or quinoa seeds and the recommended amount was even 30% in relation to the wheat or rye flour.

It seems, however, that the optimal amount is not greater than 15 – 20% as with higher share of these additives, there is a considerable deterioration in numerous features of bread and especially its volume and porosity of the pith. It is caused by lack of gluten proteins in amaranth and quinoa seeds and thus the higher their share in the dough, the greater the unfavourable changes in the obtained bakery products. Gluten plays a dominant role in creating dough structure and is responsible for many of its features. It should also be remembered that gluten has a direct impact on such characteristics of flour, dough and bread as:

- the ability to bind water by the flour (i.e. it influences flour's water absorption)
- dough efficiency (and indirectly also bread's efficiency)
- the time of doug's formation (i.e. its growth),
- the ability to retain gases in the dough, and by this on:
- the obtained bread's volume as well as
- the porosity and structure of bread crumb.

Extensive studies on amaranth and quinoa seeds application as additives to bread dough were conducted in SGGW [14, 18, 23, 27]. In the research, it was stated that adding 10% of the flour from both of the plants' seeds caused changes in the speed of dough fermentation, which was linked with larger volume of released CO_2 in much shorter time. The obtained results indicated that the acceleration of dough fermentation process was linked with a positive impact of amaranth and quinoa on baker's yeast. It was proved by the conducted trials on the fermentation of pure glucose, maltose and sucrose solutions by baker's yeast. Adding 10% of amaranth flour to aqueous solutions of sugar significantly stimulated fermentation (see Fig. 3).

The observed changes in fermentation speed were very beneficial from technological point of view. They could also indicate that amaranth flour acted as a natural bakery improver.

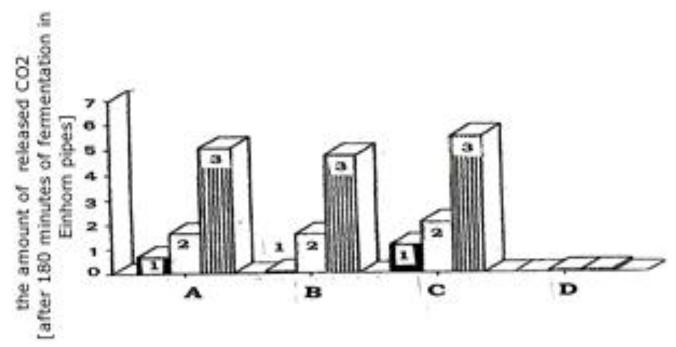

Fig. 3: Influence of adding amaranth flour on sugar fermentation speed by baker's yeast. A – glucose, B – maltose, C – sucrose, D – amaranth flour without sugar, 1 – control trial, 2 – trial after adding 5% of amaranth flour, 3 – trial after adding10% of amaranth flour [7].

The above observations are convergent with the stimulating activity of amaranth amino-acids. It was determined when examining biological value of proteins in amaranth blends with other traditional crops, e.g. corn [12, 28]. When examining the influence of 5 or 10% addition of wholegrain flour from amaranth on the dough and wheat bread features, it was stated [12, 14, 27, 29, 30] that:

- there was no deterioration of dough or bread features to the extend disqualifying it,
- the ability to bind water by wheat flour combined with amaranth flour did not significantly change, although amaranth starch with relatively high water absorption was added to the blend,
- the rheological features of the dough (its softening and flexibility) did not undergo significant changes (although there were changes!),
- there was an improvement in the general volume of wheat bread of about 20% in relation to the control trial,
- crumb porosity significantly improved (Picture 4B) and thus its plumpness,
- organoleptic features of bread did not deteriorate and the appearance of nutty taste and smell was positive, however, among the people assessing, there were those who did not accept amaranth addition,
- the bread freshness was extended, i.e. its consumption usability.

The addition of amaranth flour had a positive impact on dough features and the quality of the obtained bread [12, 14, 27]. However, it should be remembered that end quality depends on many factors, e.g. such as:

- the type of bread baked (wheat or rye),
- quality (baking value) of the flour used for baking,
- quantity and quality of additives used,
- adopted production technology.

In the research cited above [14], the increase in the volume of wheat bread after adding 5% of amaranth and quinoa seed flour was respectively: 19.0 and 16.5% in relation to the control trial. The cross-sections of the obtained breads, together with their crumbs' structure, were presented in Fig. 4.

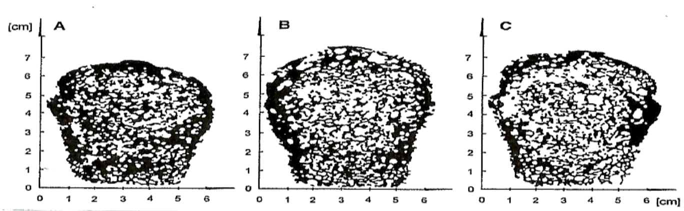

Fig. 4: The influence of adding 5% of amaranth and quinoa flour on the volume of wheat bakery products and the structure of their crumbs. A – control trial, B – trial after adding amaranth flour, C – trial after adding quinoa flour [7].

The influence of adding amaranth and quinoa flour on the features of wheat dough was not significant. In the studies carried out in SGGW [7, 14, 23], the assessment of the influence of amaranth and quinoa flour on basic features of wheat dough was conducted on the basis of the farinograph research. Adding 5 or 10% of amaranth and quinoa flour was not much and it did not cause great changes either positive or negative. The most significant of the observed changes were presented in Fig. 5.

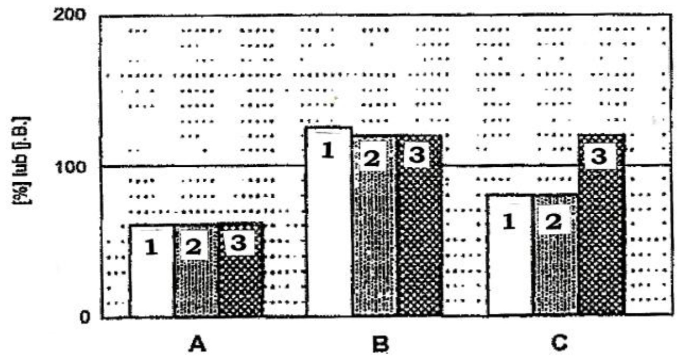

Fig. 5: The influence of adding 10% of amaranth or quinoa flour on wheat flour's water absorption (A), flexibility of the obtained dough (B) and its softening (C). 1 – control trial, 2 – trial after adding amaranth flour, 3 – trial after adding quinoa flour [7].

Adding 10% of amaranth or quinoa flour did not cause almost any changes in flour water absorption as it reached the level of the control trial. Both of the applied additives had a slight or unfavourable impact on the dough flexibility, which underwent reduction of about 5% in relation to the control trial. Due to adding quinoa flour, the dough's softening negatively increased and during blending it became less consistent and more ductile and sticky. Those changes were the greatest and reached about 40% (See Fig. 5C).

There was no negative impact of amaranth and quinoa flour on amylographic characteristics of wheat flour, i.e. its amylolytic activity and/or susceptibility to amylase. These changes were presented in Fig. 6. Adding 5% of amaranth or quinoa flour caused the increase in the maximum viscosity of starch gruels of respectively 45 and 40 BU. (conventional Brabender Units). In case of the applied wheat flour, these changes should be considered positive.

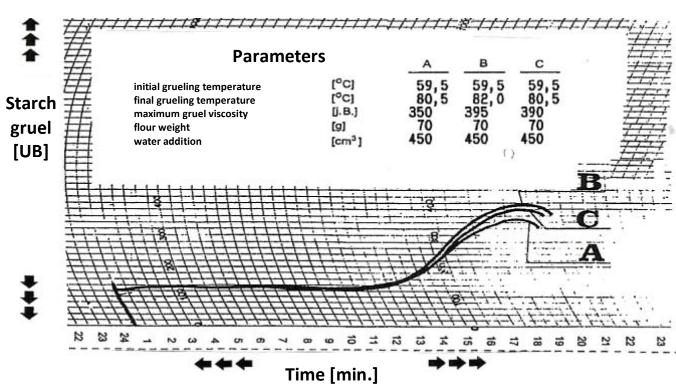

Fig. 6: The influence of adding amaranth and quinoa flour on amylographic characteristics of wheat flour type 550. A – control trial, B – trial after adding amaranth flour, C – trial after adding quinoa flour [7].

On the basis of the research carried out so far, it can be assumed that amaranth and quinoa seeds can be applied to enrich all types (what, rye and mixed) and species of bakery products. Either the flours obtained from them (refined or wholegrain) and the so-called dusts, but also whole seeds previously soaked, scalded or roasted. Adding any form of seeds gave satisfying results and contributed not only to the increase in bread's nutritional value, but also provided it with specific organoleptic features. When using whole grains, it is advisory [7,18] to firstly soak them with water for about 2-3 hours, i.e. until the moment of proper expansion and softening of seeds [18].

The research conducted by the Institute of Food Technology and Gastronomy at Lomza State University of Applied Sciences confirmed the positive influence of adding amaranth and quinoa seeds, or products obtained from them (flour, flakes), on dough characteristics and the quality of the obtained wheat bread [20, 31]. It is proved by, among others, the cross-sections photos of bread taken during the research and presented in Fig. 7 and 8.

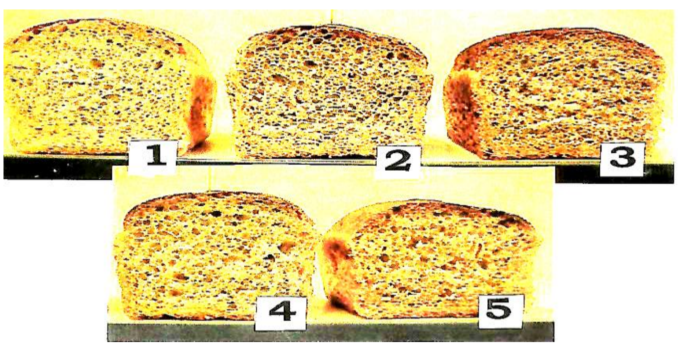

Fig. 7: Cross-sections of wheat breads with the addition of popping and flour from amaranth seeds. 1 – control trial (without additives), 2 – trial after adding 10% of popping, 3 – trial after adding 20% of popping, 4 – trial after adding 10% of flour from amaranth seeds, 5 – trial after adding 20% of flour from amaranth seeds (all the additives in relation to flour) [20].

Amaranth and quinoa seeds application in pastry and confectionery production

Amaranth and quinoa seeds can be an attractive and widely utilized raw material in the production of pastry and confectionary. The potential possibilities were revealed in numerous research conducted not only at laboratory scale, but also half-technical one [5, 13]. However, it should also be stated that amaranth is much more frequently used than quinoa.

Great interest of consumers in amaranth seeds can be confirmed by numerous recipes for using them in home-made cookies available on various webpages.

The research on amaranth application in pastry products related mostly to shortcrust pastry (for biscuits) and sponge dough (for sponge cookies) as well as, but to a much lesser extent, to confectionery products [4, 7, 25, 32].

In biscuits formula, the traditional biscuit wheat flour type 650 was replaced by amaranth seeds in the amount of 15% [4]. The seeds were either ground (wholegrain flour) or the whole or ground roasted ones were added. Wholegrain amaranth flour was characterized by 4% higher protein content than traditionally applied biscuit flour type 650. In the blend of those flours (in the proportion of 15:85), the increase in protein content of up to 11% was noted with the simultaneous decrease in gluten content to about 18% (in relation to biscuit wheat flour type 650).

Smaller amount of gluten in the blend did not deteriorate the dough consistency which is confirmed by the parameters of the farinograph curve (it is proved by the research results cited above). The dough constancy time was much extended and its relaxation decreased in relation to the control trial. Adding wholegrain amaranth flour vividly affected dough features by acting as a typical 'improver'. This kind of amaranth seeds activity was also indicated by other authors [33].

Replacing a part of biscuit wheat flour type 650 with wholegrain amaranth flour or roasted seeds, whole or ground, did not cause significant differences in the quality of the obtained biscuits. However, their sizes changed and it is a significant feature for their automatic packaging. The obtained biscuits were smaller and therefore less attractive to consumers.

A very valued feature of biscuits is their crunchiness. Those obtained after adding wholegrain amaranth flour were characterized by a greater content of water in relation to the traditional ones and those with roasted seeds (whole or ground) demanded the use of greater force in order to deform them, which vividly indicated their lesser brittleness and thus there was deterioration in crunchiness and as a result in their quality.

In pastry production, an attractive additive may be products obtained from amaranth seeds, e.g. popping. Its application, in the amount of 5, 10, 15 and 20% caused the proportional decrease in individual biscuits mass and their surface revealed the seeds of the applied additive, not always and not accepted by all the observers. Also the biscuits color changed. Using popping as an additive to sponge cookies gave better results [32], what was expressed by lighter color of the final product, more homogeneous fracture, or generally more favourable appearance.

A considerably fewer studies were carried out on the application of amaranth seeds and products obtained from them in confectionery production. Only a small number of research [4, 7] included trials e.g. on full substitution of sesame seeds with amaranth seeds when producing the so-called eastern products (sesame snaps). Formerly soaked

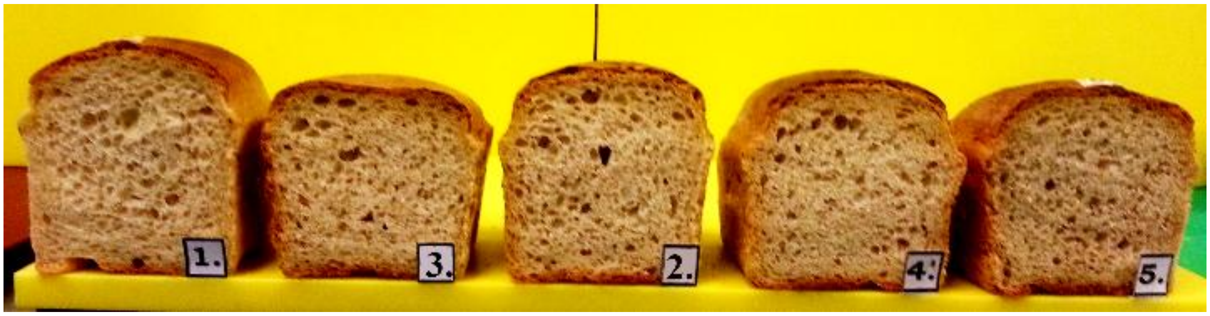

Fig. 8: Cross-sections of wheat breads with the addition of flakes and flour from quinoa seeds. 1 – control trial (without additives), 2 – trial after adding 5% of flour from quinoa seeds, 3 – trial after adding 10% of flour from quinoa seeds, 4 – trial after adding 5% of flakes from quinoa seeds, 5 – trial after adding 10% of flakes from quinoa seeds [31].

and roasted non-hulled amaranth seeds were used for it. As a result, the product with smooth and dry surface and with intensive dark honey color as well as with sweet nut-coffee taste was produced. It seems, however, that it would be possible to obtain a better and more acceptable product if amaranth seeds were previously hulled.

A very popular confectionery product in Poland is a non-cristalline fudge, so-called 'krówka'. People tried to modify these products by adding 10% of amaranth seeds, previously soaked and roasted, whole or ground. However, it was difficult to precisely define the influence of the applied products on the characteristics of the obtained 'krówka'. Its appearance was different than that of the traditional one, which was perceived as an unfavourable and undesired change, especially as at the same time no significant improvement in other features was detected, such as e.g. taste or smell. There is no doubt that these were different products than the traditional ones.

Amaranth and quinoa seeds application in pasta production

These kinds of efforts were taken by Czerwińska [34], who tried to substitute 100% of traditionally used wheat flour with quinoa seeds flour. As a result, she obtained a new product and additionally gluten-free. From quinoa flour, the cited author [34] received either long (spaghetti) as well as short (tubes) forms of pasta.

In comparison with traditional pasta, quinoa pasta revealed greater losses while boiling. Larger number of ingredients was washed out and left in water, in which pasta was boiled. It was definitely a negative feature of the obtained pasta. However, it seems that this drawback can easily be removed by a proper selection of pasta crust components, e.g. by an adequate choice of raw materials. Moreover, Czerwińska herself achieved this goal [34] by mixing quinoa flour (20%), amaranth flour (20%) and buckwheat flour (60%). As a result, also a gluten-free product was obtained with good technological and organoleptic features.

The additional and unintentional achievement of these trials was a statement that amaranth flour can also be applied in pasta production.

The improvement in nutritional value of pasta can be achieved by mixing traditional pasta flour or semolina with quinoa flour. What is left is the issue of selecting adequate proportions of those two components.

Other possibilities of amaranth and quinoa seeds application in food technology

In some works [7, 27] there were pieces of information that components included in amaranth seeds have positive and stimulating activity on the biological application of other crops' proteins (e.g. corn), or at least they can influence fermentation processes occurring due to baker's yeast. This information inspired to conduct trials on amaranth seeds application in brewing [11].

In one of the works [11], amaranth seeds in the amount of 10% were added to rye or triticale brewing mashes. It was stated [11] that the applied additive did not have practically any influence on the amount of fermented ethyl alcohol, however, it considerably stimulated the process of fermentation itself (acceleration of about 20%).

When conducting research, it was determined also [11] that adding amaranth seeds to mashes resulted in increasing the contents of aldehydes in the obtained alcohol. It is an unfavourable phenomenon from the alcohol cleanness and quality point of view and in order to improve it additional destillation is necessary. A positive side of the increased aldehydes content can be, however, that these compounds boost fermentation they result from [11].

The results of the conducted research were an encouraging signal indicating that amaranth seeds can be successfully applied in this branch of food industry. Additionally, it seems that nothing prevents against conducting trials on their application in beer production [9, 17, 35].

The attempts to use quinoa seeds have already been taken. Bogdan and Kordialik-Bogacka [35] added to the wort either seeds as well as flakes in the amount of 10 or 30%. When selecting quinoa seeds to the research, the feature that was taken into account was their content and especially the saccharides (foremostly starch), protein and fats as well as beta-glucans, as these components have a direct influence on the characteristics of the obtained wort and the quality and durability of beer produced from it [35].

The cited authors [35] claim that from the brewing point of view, high content of saccharides (starch) is especially favourable, which translates into the amount of ethyl alcohol and CO_2 produced. On the other hand, a less positive thing is too excessive quantity of total protein and fats and their content was higher either in quinoa seeds as well as in flakes obtained from it as compared to the barley malt applied in the research [35].

High content of total protein can have a twofold meaning, negative by causing turbidity of the obtained beer or positive by the increased share of amino-acids, which in turn influences fermentation ability of brewer's yeast. It should be reminded that quinoa seeds have more beneficial amino-acid content as compared to the traditional crops, including barley. It is an additional factor in favour of applying quinoa seeds for brewing purposes.

Fats entered into a wort together with raw materials can lead to the acceleration of beer ageing processes. The research conducted by Bogdan and Kordialik-Bogucka [35] disclosed that either quinoa seeds as well as flakes obtained from them can be utilized for beer production and have higher applicability than amaranth seeds and products.

Either amaranth as well as quinoa seeds and also other parts of these plants (leaves, stems and even roots) can be applied in the production of protein preparations (isolates, concentrates) [26,30]. This is supported either by high protein participation, its amino-acid content and also the prolificacy of both plants.

The research on amaranth and quinoa application – and not only their seeds – are being conducted constantly more often and on a larger scale. It can even be assumed that they are becoming popular and many scientific centers undertake new or repeat formerly conducted ones. As a result of it, many new formulas for new and attractive food products were invented. The vast majority are culinary recipes e.g. for soups, sauces, creams, gratins, wafers (especially interesting) as well as supplemented milk drinks [5,36].

Summary

1. Amaranth and quinoa seeds can be applied:
   - in milling (in flour and flakes production and potentially even porridge),
   - in bakery (as an additive to various types and species of bread) and also in related industries (pastry and confectionery).
2. Food concentrates production and widely understood gastronomy provide very high possibilities of application.
3. Amaranth seeds are used in the so-called 'popping' production (process of expansion). In this form, they can be used as additives to milk drinks and also applied in bakery, pastry and confectionery and provide the products with very favourable and characteristic nutty taste.
4. Relatively high amount of protein in quinoa seeds, its beneficial amino-acid content as well as a fairly good prolificacy, easiness to adopt to difficult soil and climate conditions cause that this plant already is, and can be to a greater extent, a valuable raw material of widely understood food processing industry.
5. Starch from the seeds of both plants possesses many advantages, from technological perspective: small sizes of granules and thus easier and faster digestion as well as high nutritional and energetic value. Due to small sizes of granules they are and can be utilized as the so-called carriers in such branches of industry as: food concentrates, medicine, pharmacy as well as cosmetology (powders, backfills).
6. Amaranth seeds contain much more fat than traditional bread crops and its specific feature is high content of squalene. In this respect, amaranth is one of the richest natural sources of this component. Squalene finds its application in medicine, pharmacy, cosmetology and even computer industry.
7. Amaranth and quinoa (their seeds, leaves as well as other parts) constitute also a valuable feed for livestock and their value comprises not only of the quantity and quality of protein, but also mineral compounds, vitamins and fibre.

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