

Amaranth as a bread enriching ingredient

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Abstract:

Amaranth is a promising raw material for enriching foods with protein, minerals, vitamins, dietary fibre, squalene, and other nutrients. However, its varieties differ significantly in composition and properties. The research included two stages. At first, we studied the composition of eight amaranth varieties grown in a collection nursery of Voronezh State Agrarian University. Their composition was a factor that determined their functional use as an enriching ingredient. We found that amaranth grain of the Universal variety could be best used to increase the biological value of foods, whereas the Universal and Valentina varieties could be recommended as multifunctional ingredients. The addition of enriching ingredients into foods, including breads, often leads to changes in their traditional consumer properties. Therefore, our next step was to study changes in the composition of Universal amaranth during extrusion using IR spectroscopy. Also, we assessed the effect of amaranth extrudate on the baking properties of model wheat flour and extrudate mixtures as the main factor of the product's consumer properties. The results showed a redistribution of moisture between flour gluten proteins and extrudate dietary fibre. We also established amounts of amaranth extrudate needed to ensure the preservation of crumb appearance and structure close to the traditional ones.

Keywords: Grain, foods, gluten, extrudate, flour, IR-spectra, leaves

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INTRODUCTION

Improving people's diet involves enriching foods with a variety of essential nutrients. First of all, these include vitamins, some macro- and microelements, dietary fibre, polyunsaturated fatty acids, and other substances [1–7]. Protein is another important component of a balanced diet [1, 4]. Amaranth is a promising raw material and a rich source of nutrients [8–10]. Numerous studies, both in Russia and abroad, have focused on enriching breads and bakery confectionery products with amaranth [11–24]. However, these developments have not yet been commercialized on a large scale. This confirms the need to continue the search for applications of amaranth and its products in the food industry, especially in the production of staple foods such as breads. Thus, we need to develop a technology based on amaranth – not only its composition

depending on variety, but also its functional and technological properties.

Our aim was to assess amaranth as a raw ingredient for breads, based on the study of its composition, as well as its functional and technological properties.

STUDY OBJECTS AND METHODS

Market research was conducted to identify people's attitudes to enriching ingredients, taking into account permissible changes in traditional consumer properties of a product determined by changes in its formulation. The sample of 405 respondents was representative of the general population in the region. The statistical error did not exceed 5% at a confidence level of 95%.

The object of study was amaranth grown in a collection nursery of Voronezh State Agrarian University. Geographically, the nursery is located in the

Table 1 Amaranth grain composition

Amaranth variety	Content, %					Ash on dry basis, %
	moisture	protein	fat	cellulose	mono- and disaccharides	
Voronezh-36	10.1	15.78	6.4	6.9	2.5	2.98
Voronezh	10.5	16.21	6.3	5.7	2.4	3.41
Imperator	10.2	19.57	11.7	7.5	2.4	3.99
Rubin	11.4	20.66	9.8	7.1	2.7	4.75
Universal	9.4	26.47	13.8	8.9	4.1	8.08
Gigant	10.1	19.29	10.3	7.1	2.9	3.03
Dobrynya	10.9	16.79	7.2	16.3	2.4	4.33
Valentina	11.6	16.10	6.9	19.4	2.6	6.04

forest-steppe zone of the Central Black Earth Region. The experiments were carried out on leached, medium loamy chernozem with medium and high availability of nitrogen, phosphorus, and potassium mobile forms. The humus content was 4.5%, pH 5.4–5.8. Precipitation during a period of temperatures above +10°C reached 250–260 mm. Total active temperatures amounted to 2581°C. The seeding took place in the second half of May.

The study covered the following amaranth varieties bred by Voronezh State Agrarian University and the Federal Research Centre of Vegeculture: Voronezh-36, Voronezh, Imperator, Rubin, Universal, Gigant, Dobrynya, and Valentina.

The composition of amaranth grain and leaf mass was determined at the All-Russian Research Veterinary Institute of Pathology, Pharmacology and Therapy according to the following state standards:

- moisture: State Standard 13586.5-2015^I;
- protein: State Standard 10846-91^{II};
- fat: State Standard 29033-91^{III};
- cellulose: State Standard 31675-2012^{IV};
- total sugar (mono- and disaccharides): State Standard 15113.6-77^V;
- ash: State Standard 27494-2016^{VI};
- phosphorus: State Standard 26657-97^{VII};
- calcium: State Standard 26570-95^{VIII};

^IState Standard 13586.5-2015. Grain. Method of moisture content determination. Moscow: Standartinform; 2019. 13 p.

^{II} State Standard 10846-91. Grain and products of its processing. Method for determination of protein. Moscow: Standards Publishing; 2001. 8 p.

^{III} State Standard 29033-91. Grain and derived products. Determination of fat content. Moscow: Standards Publishing; 1992. 5 p.

^{IV} State Standard 31675-2012. Feeds. Methods for determination of crude fibre content with intermediate filtration. Moscow: Standartinform; 2014. 10 p.

^V State Standard 15113.6-77. Food concentrates. Methods for determination of sucrose. Moscow: Standartinform; 2011. 11 p.

^{VI} State Standard 27494-2016. Flour and bran. Methods for determination of ash content. Moscow: Standartinform; 2019. 11 p.

^{VII} State Standard 26657-97. Fodders, mixed fodders, mixed fodder raw materials. Methods for determination of phosphorus content. Moscow: Standards Publishing; 2002. 10 p.

^{VIII} State Standard 26570-95. Fodder, mixed fodder and mixed fodder raw material. Methods for determination of calcium. Moscow: Standards Publishing; 2002. 14 p.

- carotene: State Standard 13496.17-95^{IX};
- copper and zinc: State Standard 30692-2000^X; and
- iron and manganese: State Standard 32343-2013^{XI}.

The content of digestible protein was determined by the PDCAAS method, with the degree of digestibility being 75% for amaranth grain protein and 65% for amaranth leaf protein [25, 26].

The quality of flour was determined according to State Standard 9404-88^{XII} (moisture) and State Standard 27839-2013^{XIII} (gluten quantity and quality).

We used top-grade baking wheat flour with a moisture content of 14.43%, a gluten content of 32%, and gluten quality rated as “satisfactory weak” (gluten deformation index, IDK).

Amaranth grain was subjected to extrusion. The extrudate was obtained from whole low-fat grains of Universal amaranth through an EUM-1 compact laboratory extruder at 110–120°C. Then it was ground to a particle size of max. 125 µm in a laboratory mill.

The infrared absorption spectra were determined in the range of 400–4000 cm⁻¹ on a Bruker VERTEX 70 FTIR spectrometer in the reflection mode.

Model mixtures were made of top-grade baking wheat flour and amaranth extrudate. The studies were performed at the Dokuchaev Scientific Research Institute of Agriculture of the Central Chernozem Zone. The data were processed in accordance with State Standard R 51414-99^{XIV}. The quantity and quality of gluten were determined according to State Standard 27839-2013¹³.

^{IX} State Standard 13496.17-95. Forage. Methods for determining carotin. Moscow: Standartinform; 2011. 5 p.

^X State Standard 30692-2000. Fodders, mixed fodders and animal raw foodstuff. Atomic absorption method for determination of copper, lead, zinc and cadmium. Moscow: Standards Publishing; 2002. 10 p.

^{XI} State Standard 32343-2013. Feeds, compound feeds. Determination of the contents of calcium, copper, iron, magnesium, manganese, potassium, sodium and zinc by atomic absorption spectrometry method. Moscow: Standartinform; 2014. 17 p.

^{XII} State Standard 9404-88. Flour and bran. Method of moisture content determination. Moscow: Standards Publishing; 2001. 4 p.

^{XIII} State Standard 27839-2013. Wheat flour. Methods for determination of gluten quantity and quality. Moscow: Standartinform; 2014. 19 p.

^{XIV} State Standard R 51414-99. Wheat flour. Physical characteristics of doughs. Determination of water absorption and rheological properties using a valorigraph. Moscow: Standartinform; 2007. 8 p.

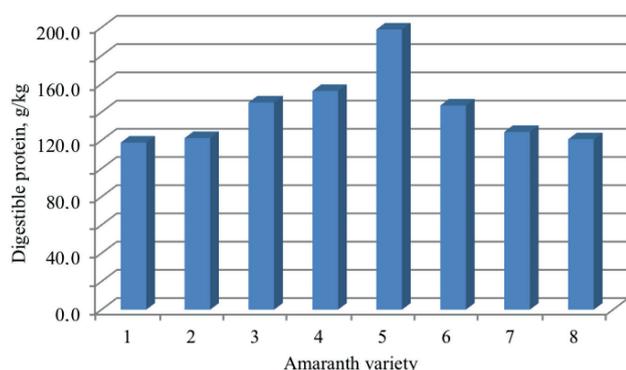


Figure 1 Digestible protein content in amaranth grain varieties: 1 – Voronezh-36, 2 – Voronezh, 3 – Imperator, 4 – Rubin, 5 – Universal, 6 – Gigant, 7 – Dobrynya, 8 – Valentina

RESULTS AND DISCUSSION

The comparative characteristics of the amaranth varieties studied are shown in Tables 1, 2.

We found that the composition of amaranth grain differed widely, depending on its variety. The highest content of protein was observed in Universal and Rubin, fat – in Universal and Imperator, mineral substances – in Universal and Valentina. Universal also contained the maximum amount of mono- and disaccharides and digestible protein (Fig. 1). Thus, this variety seemed to have the best composition for being used as an enriching ingredient to increase the biological value of foods, including breads. In addition, this grain is white with a slight yellowish tinge, which makes it suitable for any product, regardless of its intended color.

Another important aim of food fortification is an increase in dietary fibre and minerals.

We found that the varieties of Valentina and Dobrynya had the highest cellulose content. Universal and Valentina were also rich in minerals. The results of additional studies of amaranth mineral composition are presented in Table 2.

Calcium and iron are two key minerals that Russian diet has a deficiency of [12]. We found that the varieties of Valentina, Universal, and Dobrynya had the highest calcium content, whereas Voronezh-36 and Universal were rich in iron.

As for other minerals, we found a high content of phosphorus in Universal, copper in Gigant and Universal, zinc in Voronezh, and manganese in Valentina. The content of copper and manganese should be considered as a limiting factor when developing food formulations. It is also noteworthy that Valentina has a dark colour, which may affect the sensory perception of the finished product.

Another form of amaranth use is its leaf mass. After harvesting, amaranth leaves were dried by convection at 30–35°C. This method was used to preserve the maximum amount of biologically active substances.

The comparative characteristics of amaranth leaf mass by variety are given in Tables 3, 4.

Amaranth leaf mass showed significant differences in composition. The highest content of protein and digestible protein (Fig. 2) was found in Rubin and Dobrynya, cellulose – in Universal and Valentina, total sugar – in Universal and Gigant. All the varieties had a low fat content and a high ash content. On the whole, the

Table 2 Mineral substances in amaranth grain

Amaranth variety	Content					
	phosphorus, %	calcium, %	copper, mg/kg	iron, mg/kg	zinc, mg/kg	manganese, mg/kg
Voronezh-36	0.46	0.17	8.6	110	32.5	52
Voronezh	0.54	0.24	7.2	77	35.8	55
Imperator	0.45	0.25	7.2	82	31.0	51
Rubin	0.55	0.17	6.1	73	30.8	51
Universal	0.63	0.36	13.0	90	30.9	45
Gigant	0.54	0.20	14.9	77	32.7	29
Dobrynya	0.50	0.36	8.1	72	28.2	47
Valentina	0.46	0.48	5.4	76	31.3	82

Table 3 Amaranth leaf mass composition

Amaranth variety	Content, %					Ash on dry basis, %
	moisture	protein	fat	cellulose	mono- and disaccharides	
Voronezh-36	8.1	12.02	1.6	10.1	3.2	24.02
Imperator	8.7	10.48	2.0	10.3	3.9	18.46
Rubin	7.5	20.13	1.6	11.0	1.0	20.36
Universal	7.8	17.73	2.2	17.5	4.3	19.02
Gigant	8.1	11.77	2.1	9.9	4.4	20.55
Dobrynya	8.6	19.56	1.8	12.1	0.8	21.32
Valentina	8.3	14.08	1.5	14.3	3.7	17.55

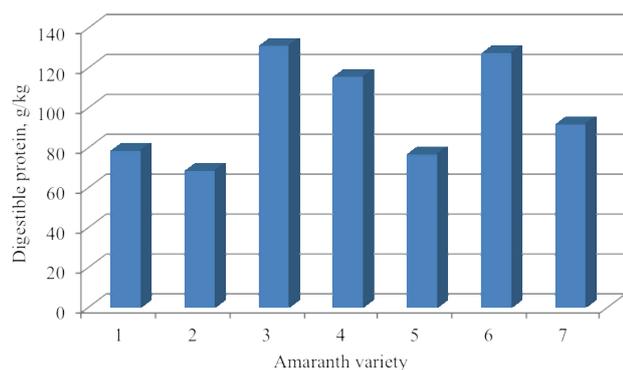


Figure 2 Digestible protein content in amaranth leaves by variety: 1 – Voronezh-36, 2 – Imperator, 3 – Rubin, 4 – Universal, 5 – Gigant, 6 – Dobrynya, 7 – Valentina

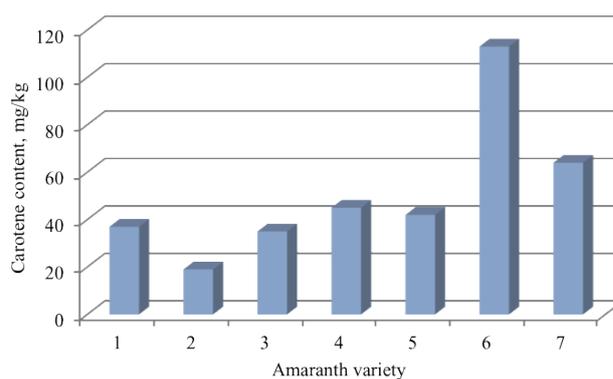


Figure 3 Carotene content in amaranth leaves by variety: 1 – Voronezh-36, 2 – Imperator, 3 – Rubin, 4 – Universal, 5 – Gigant, 6 – Dobrynya, 7 – Valentina

Table 4 Mineral substances in amaranth leaves

Amaranth variety	Content					
	phosphorus, %	calcium, %	copper, mg/kg	iron, mg/kg	zinc, mg/kg	manganese, mg/kg
Voronezh-36	0.42	6.00	1.4	0.2	0.4	1.5
Imperator	0.33	5.01	1.3	0.2	0.5	1.7
Rubin	0.35	4.32	1.8	0.7	0.4	1.4
Universal	0.31	4.80	1.6	0.4	0.4	1.2
Gigant	0.39	4.86	1.5	0.7	0.5	2.6
Dobrynya	0.42	4.60	1.6	3.0	1.1	1.9
Valentina	0.36	2.88	1.6	0.2	4.7	3.0

leaf mass of these varieties can be regarded as a protein ingredient. In addition, it can be used as a source of dietary fibre and mineral substances.

The data presented in Table 4 were used to find effective ways of correcting diets with macro- and microelements by introducing supplements from amaranth leaf mass.

We found that amaranth leaf mass was rich in calcium, especially Voronezh-36 and Imperator. Therefore, amaranth can be classified as a functional food ingredient. Compared to grain, amaranth leaves had a much lower content of iron, copper, zinc, and manganese. Of all the varieties, Valentina showed the highest content of zinc and manganese.

A high carotene content was found in the leaves of Dobrynya and Valentina (Fig. 3). Due to the antioxidant properties of carotenes, the leaves of these varieties can be recommended as enriching supplements.

Thus, the comparative analysis of amaranth composition showed the following results:

- amaranth grain and leaf composition differed significantly, depending on the variety; therefore, when developing formulations for functional or specialised foods, it is important to specify the recommended variety;
- Universal amaranth grain is best suited for improving the biological value of foods with a minimal effect on their color range;

- Valentina and Dobrynya grain, as well as Universal and Valentina leaf mass, can be recommended as a source of dietary fibre; however, the color of amaranth grain and its products should be taken into account;
- Valentina grain, as well as Voronezh-36 and Imperator leaf mass, can be used in foods to increase their calcium content, with an allowable level of manganese being max – 5 mg/day^{xv};
- Dobrynya amaranth leaves can be recommended for foods with antioxidant properties; and
- Universal and Valentina varieties can be used as polyfunctional ingredients.

Further studies were conducted with Universal amaranth variety, taking into account its color range and potential uses as an enriching ingredient in breads. To increase digestibility and adjust taste and smell, amaranth grain mass was subjected to extrusion. The extrudate was ground to a particle size of max. 125 µm.

The Universal extrudate is a loose powdery semi-finished product with a light cream color, a nutty aroma, and a faint bitterish taste, characteristic of amaranth. It contains 4.76% moisture, 27.51% protein, 4.53% fat, and 3.20% cellulose.

^{xv} MR 2.3.1.2432-08 Normy fiziologicheskikh potrebnostey v ehnergii i pishchevykh veshchestvakh dlya razlichnykh grupp naseleniya Rossiyskoy Federatsii [Methodological guidelines MG 2.3.1.2432-08 “The norms of physiological needs for energy and nutrients for various population groups in the Russian Federation”].

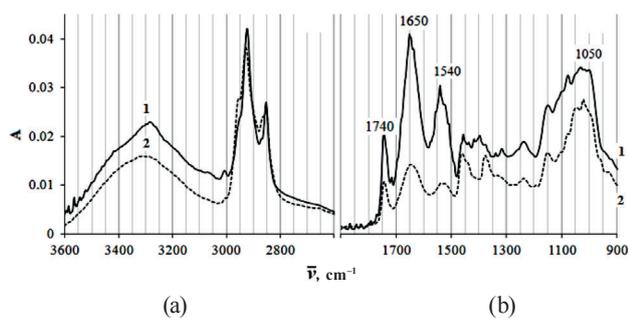


Figure 4 IR absorption spectra of Universal amaranth (1) and Universal amaranth extrudate (2)

Changes in the fractional composition of amaranth during extrusion were studied by IR spectroscopy (Fig. 4).

Absorption bands were identified in the short-wave (3600–2600 cm^{-1}) and long-wave (1800–900 cm^{-1}) spectral regions. The first band was characteristic of C–H stretching vibrations of methyl and methylene fragments at 2923–2933 cm^{-1} and 2855 cm^{-1} , as well as O–H and N–H stretching vibrations at 3280–3300 cm^{-1} [22]. In the long-wave region, intense absorption was observed at 1000–1050 cm^{-1} , with a well pronounced band at 1150 cm^{-1} , which corresponded to vibrations of the C–O–C ester group in the structure of cellulose [27]. The spectral behaviour of amaranth and amaranth extrudate samples was identical. Comparing the relative heights of the absorption bands for amaranth and amaranth extrudate, we found less intensive

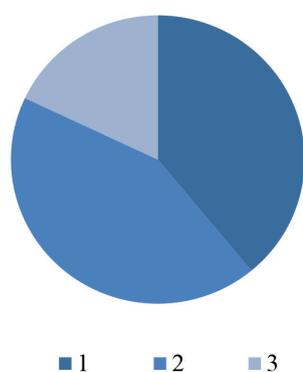


Figure 5 Attitudes to consumer properties of enriched breads: 1 – respondents preferring traditional characteristics, 2 – respondents accepting minor differences, 3 – respondents accepting significant differences

Table 5 Flour strength indicators

Indicator	Of model mixtures at different ratios of wheat flour and amaranth extrudate		Wheat flour : amaranth extrudate ratio	
	90:10	85:15	80:20	70:30
Water absorption capacity, %	57.76	58.42	62.14	62.82
Duration of dough development, min	4 min 30 s	6 min 10 s	5 min 30 s	5 min 30 s
Dough stability, min	4 min 05 s	3 min 55 s	3 min 30 s	2 min 50 s
Dilution, units	90	80	85	85
Valorimetric rating, units	70	72	72	71

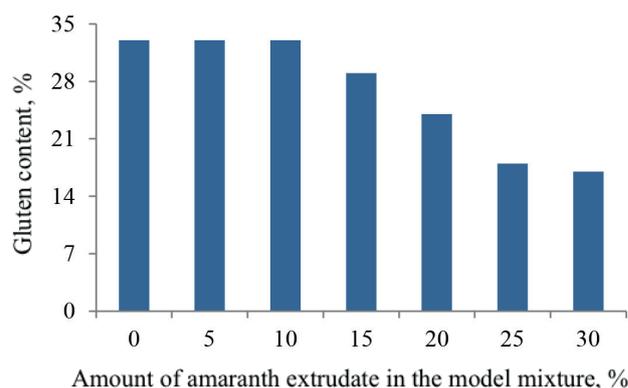


Figure 6 Gluten content in the model mixtures of wheat flour and amaranth extrudate

vibrations of the carboxyl group (1740 and 1650 cm^{-1}) and amide bonds (1650 and 1540 cm^{-1}), as well as a lower height of the “ester band” (1050 cm^{-1}). This was due to the fact that extrusion causes destructive changes mostly in protein components, rather than in cellulose substances. On the whole, the IR absorption spectra analysis confirmed a partial destruction of amaranth proteins and polysaccharides during extrusion. On the one hand, this suggested a better digestibility of the extrudate compared to grain. On the other hand, this indicated the extrudate’s sorption activity with respect to heavy metal cations due to the preserved native structure in some part of the carbohydrate-based biopolymers.

Thus, the study proved the efficacy of extrusion as a way of preparing amaranth for being used as a

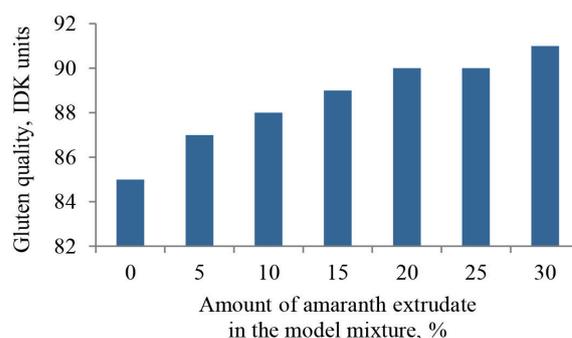
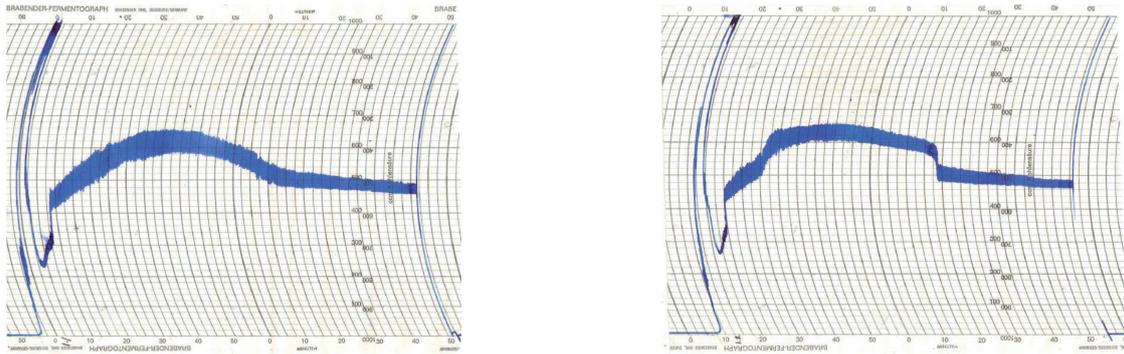
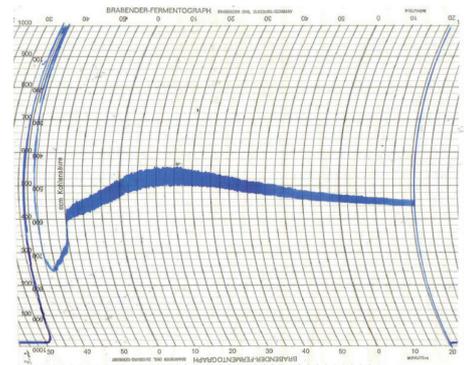
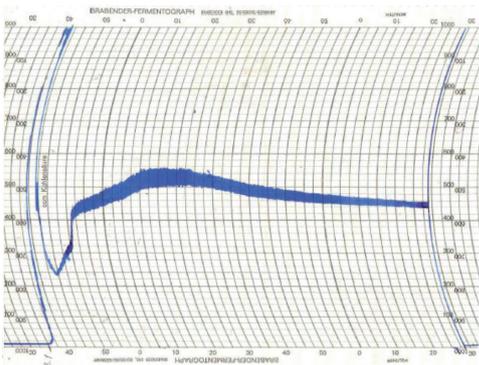


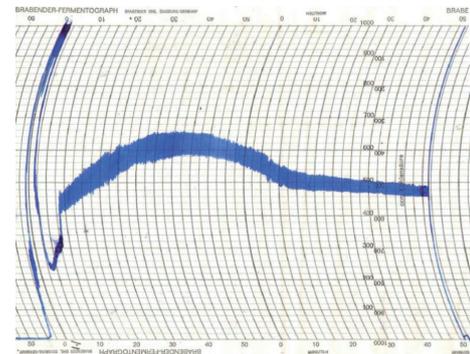
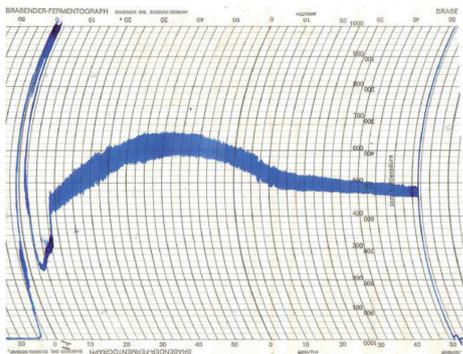
Figure 7 Gluten quality in the model mixtures of wheat flour and amaranth extrudate



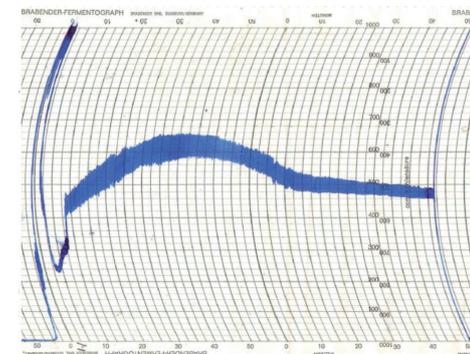
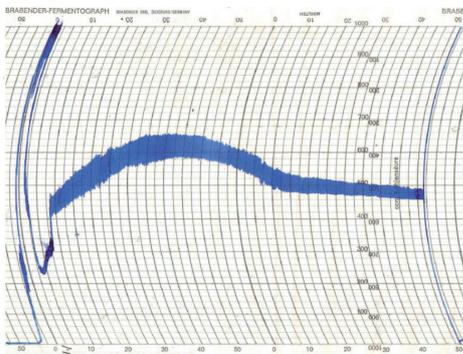
(a)



(b)



(c)



(d)

Figure 8 Valorigrams of flour mixtures with a ratio of wheat flour and amaranth extrudate of: a) 90:10; b) 85:15; c) 80:20; d) 70:30. Left – replication No. 1, right – replication No. 2

food ingredient. The extrudate of Universal amaranth variety was used in further research as a bread enriching ingredient.

One of the problematic issues in food fortification is changes in traditional sensory properties, primarily in product appearance, shape, condition, and texture (structure of porosity). Our market research showed that most consumers (80%) were not ready for drastic changes in these characteristics, even when the product had an increased nutritional value and an improved nutrient composition (Fig. 5).

Bread's shape, crumb, porosity, and other characteristics mainly depend on the baking properties of flour. New grain ingredients usually bring about quantitative and qualitative changes in the protein-proteinase and carbohydrate-amylase flour complex, altering the product's sensory properties. Therefore, the next stage of our research was to study the baking properties of model mixtures of top-grade wheat flour and amaranth extrudate. The choice of top-grade flour was motivated by a lower standardized amount of gluten and, therefore, a more pronounced effect of raw ingredients on the baking properties of the flour mix. The model mixtures were made of wheat flour and amaranth extrudate in the ratios of 95:5, 90:10, 85:15, 80:20, 75:25, and 70:30.

We studied the effect of amaranth extrudate on the content and elasticity of gluten proteins and, therefore, on their ability to form dough with certain rheological properties (Figs. 6, 7).

We found that an increased amount of amaranth extrudate lowered a gluten content in the model mixture. In addition, it raised the IDK index (gluten quality index). Gluten washed out from the model mixture was less elastic. However, it is noteworthy that the changes in gluten quality did not exceed 7% of the initial IDK value.

More detailed information on the effect of amaranth extrudate on the baking properties of the model mixture was obtained using a valorigraph (Fig. 8).

Table 5 presents flour strength indicators obtained from the analysis of the valorigrams.

We found that a higher content of amaranth extrudate in the model mixture raised its water absorption capacity. This can be explained by an increased water-binding ability of amaranth dietary fibre. Water absorption properties of amaranth extrudate were established in [28].

The increased duration of dough development might be due to the redistribution of water towards amaranth extrudate and the consequent slowing down of gluten swelling. This happened when the amount of amaranth extrudate was up to 15%. With a higher extrudate content, the duration of dough development decreased and almost stabilized. This was probably due to a lower content of gluten proteins in the model mixture (Fig. 6).

The decrease in dough stability appeared to be caused by a lower amount of gluten, since it is gluten

that gives dough a three-dimensional structure. Dilution is defined as a difference between the maximum dough consistency achieved during kneading and its consistency at the end of kneading. Excessive mechanical impact weakens dough consistency. A lesser dilution of the dough with a greater amount of wheat flour could probably be explained by the temperature parameters characteristic of water binding by protein substances. Another factor might be a better retention of the hydration shell on the protein globules.

All the model mixtures had similar calorimetric values (Table 5). Depending on the ratio of wheat flour and amaranth extrudate, the deterioration of some characteristics was compensated by the improvement of others. This confirmed a possibility of producing breads from a mix of wheat flour and up to 30% of amaranth extrudate with a crumb structure close to traditional. An extrudate content of up to 15% brought about smaller changes in the crumb shape, appearance, and structure, whereas an amount of up to 30% was more effective in increasing the product's nutritional value. To establish the optimal amount of amaranth extrudate, we need to study the changes in rheological properties during dough maturation and evaluate the product's taste, color, and nutritional value.

CONCLUSION

On the whole, the study confirmed the potential of extruded amaranth of the Universal variety as an ingredient that can enrich wheat flour breads with protein and dietary fibre and ensure consumer properties close to traditional.

CONTRIBUTION

Authors are equally related to the writing of the manuscript and are equally responsible for plagiarism.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

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