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BAKING PROPERTIES OF DIFFERENT AMARANTH FLOURS AS WHEAT BREAD INGREDIENTS

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Abstract. The technological properties of full-fat amaranth flour depend on the varietal characteristics of the Ukrainian amaranth grain and differ significantly from amaranth flour from flakes and amaranth flour from groats. In comparison with patent wheat flour, amaranth flour has a lower moisture content, higher water absorption capacity and autolytic activity. The variety of *Amaranthus hypochondriacus* significantly effects on the whiteness of full-fat flours, the lightest of which is obtained from the grain cultivar Kharkivsky-1. A higher fat, protein, and fibre content makes amaranth flours more acidic. The water absorption capacity of the flours shows positive correlation with their autolytic activity (+0.885). The acidity negatively correlates with the moisture (-0.939) and whiteness (-0.814) of the flours. Using amaranth flour of the different types to replace 5, 15, and 25% of patent wheat flour when making bread increases its specific volume and crumb porosity and decreases its shape stability. The positive correlation of the overall quality of the bread samples under study with their specific volume (+0.540) and the negative correlation with the acidity (-0.685) are statistically significant. The shape stability negatively correlates with the porosity (-0.598), and the latter positively correlates with the specific volume (+0.533). The use of full-fat amaranth flour increases the specific volume and porosity of bread by 1.1–1.3 and 1.1 times respectively. The use of defatted flour from flakes leads to a 1.3–1.9 -fold increase in the specific volume and to a 1.1–1.2 -old increase in the porosity. Incorporation of amaranth flour from groats allows increasing the specific volume and porosity of bread by 1.3–1.5 and 1.1–1.2 times respectively. The bread samples with 25% of all amaranth flours considered and with 15% of full-fat flour of the Liera variety have the lowest consumer characteristics. It has been proved that using 5–15% of full-fat flour from the amaranth grain of variety Kharkivsky-1 and defatted flour from flakes and groats (by-products of processing amaranth grain into oil) improves the quality and nutritional value of bread.

Keywords: *Amaranthus hypochondriacus*, full-fat amaranth flour, defatted amaranth flour from flakes, defatted amaranth flour from groats, wheat bread, baking properties.

Introduction. Formulation of the problem

Amaranth, as well as quinoa, belongs to gluten-free pseudocereals. *Amaranthus* L. includes more than 60 species [1]. Amaranth originated from South and Central America, where suitable climatic conditions allow growing a wide range of its species [2]. In Ukraine, amaranth is one of the most profitable agricultural crops grown mostly in the Southern and the Eastern regions. In comparison with other crops, amaranth is drought-tolerant, undemanding of soil fertility, and highly adaptive to climatic changes. Amaranth leaves and grain have significant potential to be processed into not only animal feed, but into food products, too [3]. Amaranth is an excellent source of protein, starch, lipids, fibre, and minerals.

Grain of *Amaranthus caudatus*, *Amaranthus cruentus*, and *Amaranthus hypochondriacus* has the highest nutritive value. The protein content in grain of these species is close to the level WHO/FAO recommends for people's diet [4]. Desides, amaranth grain is rich in lysine and has high biological value.

Carbohydrate-containing components of amaranth are, first of all, fine-grained starch, inositol, glucose, fructose, raffinose, sucrose, maltose, and stachyose [5]. The composition of amaranth fibre is similar to that of fruit and vegetables, and legumes, and the amount of it is close to that in wheat. The physicochemical properties and content of soluble and insoluble fibre make amaranth grain biologically valuable, too [6].

Amaranth grain contains more lipids (up to 10%) than most cereals do. Amaranth lipids consist of triacylglycerols (80%) and other minor components: squalene, sterols, tocopherols, carotenoids, phospholipids. Amaranth fats are mostly represented by unsaturated fatty acids (around 76%). Phospholipids take 9% of all lipids, with phosphatidylcholine prevailing [7]. Squalene is an important nutrient of amaranth. This organic compound carries oxygen directly to cell membranes throughout the human body. Amaranth oil contains 6–8% of squalene. Squalene is found to reduce damage to the skin caused by UV radiation, normalise the cholesterol level in the blood, prevent cardiovascular diseases, and have antitumor effects against ovarian, breast, lung, and colon cancer [8].

Amaranth grain is a rich source of minerals, such as calcium, magnesium, potassium, manganese, copper, iron, selenium, and molybdenum. Besides, amaranth grain contains vitamin E and B-group vitamins, bioactive phenolic acids and flavonoids with high antioxidant and anticancer activity. The main phenolic compounds in amaranth grain are caffeine acid, p-hydroxybenzoic acid, and ferulic acid [9].

Despite the growing interest in amaranth cultivation worldwide, amaranth oil producers face a problem of using partially defatted amaranth by-products such as solvent-extracted cake and press cake [10]. These by-products contain carbohydrates, proteins, dietary fibre, polyphenols, flavonoids, water-soluble vitamins, and minerals. Depending on the processing technology, the by-products can contain some lipid residue. Amaranth by-products can significantly increase the nutritional value of bread, which is a staple food all around the world. However, these amaranth by-products are scarcely used in the bakery industry: people are often unaware of the nutritive benefits of amaranth grain, and besides, there is lack of theoretical and practical basis for how to use amaranth by-products as bread ingredients.

Analysis of recent research and publications

Varietal characteristics of *Amaranthus* L. and grain processing technologies have a strong impact on the amaranth flour properties. M. M. L. Grundy et al. [11] established the physicochemical properties and nutritive value of different amaranth processing products: full-fat amaranth flour of *A. cruentus* and *A. hypochondriacus* grown in Kenya and Tanzania; raw flour, roasted grain, roasted flour, and puffed amaranth (all produced in Kenya). Most of the flours had similar particle size distributions, ranging from 245 and 430μm. Both the amaranth genotype and the processing methods were proved to have an influence on lipid and protein digestion of the products. The highest digestion was shown by the raw amaranth flour.

The water absorption capacity of amaranth flour is 431%, and after roasting it tends to decrease up to 395%, which is still higher than the water absorption capacity of wheat flour (387%) [12]. The autolytic activity of heat-treated amaranth grain and amaranth flour is 36–54%, which is much higher than autolytic activity of wheat flour [13]. Whole-grain amaranth flour and amaranth flour produced from amaranth perisperm flakes have the water retention capacity which is higher, respectively, by 1.56 and 5.3 times than that of wheat flour. This is due to the higher water absorption capacity of amaranth starch granules, especially in the flour from flakes [14].

The effect of amaranth bran on the gluten GDI was studied by N. Shmalko et al [15]. Replacing 10% of wheat flour with amaranth bran strengthens wet wheat gluten from 79 to 68 units. Moreover, the dough adhesion decreases by 20.4% [16]. Besides, incorporation of 5-20% of amaranth bran reduces wet wheat gluten extensibility by 1.5 times due to the dehydrating effect of the fibre on wheat gluten proteins, which compete for water binding in the dough [17].

Despite the health benefits of amaranth flour, total replacement of wheat flour with amaranth flour is hardly possible. The high content of water-soluble proteins in amaranth dough does not allow obtaining a semi-finished product of the required consistency, which prevents baking it properly [18]. When using yeast or sourdough in breadmaking, it is not recommended to take amaranth flour alone: it has low gas retention due to lack of gluten, so it should be mixed with wheat flour [19]. However, using the amaranth spontaneous fermentation starter to make gluten-free bread from a maize and rice flour mixture is quite promising and results in increasing the volume yield of the loaves [20].

A. M. C. De la Barca et al [21] studied baking properties of composite flour including full-fat flour and that from puffed amaranth (grown in Mexico). The best formulation for bread included 60–70% of puffed amaranth flour and 30–40% of full-fat amaranth flour. This ratio allows obtaining loaves with uniform crumb and a higher specific volume (3.5 ml/g) than with other gluten-free breads. Incorporation of 6% of amaranth flour in wheat sprouted bread leads to improving the bread quality [22] too.

To improve the nutritional value of bread [23], full-fat amaranth flour was used to replace 2, 4, 6, 8% of patent wheat flour. Increasing the percentage of amaranth full-fat flour resulted in a slightly sweet taste of the loaves. The crumb porosity increased by 0.7–3.8% and was the highest with incorporation of 4% of full-fat amaranth flour. The increased level of full-fat amaranth flour in the formulations led to the titratable acidity of the loaves higher by 21%.

It was established that by-products obtained after vacuum extraction of amaranth grain grown in Ukraine changed wheat bread quality too. These by-products included amaranth flour (as the undersize fraction passing through a 0.45mm woven-wire-cloth sieve and residue on a 0.45mm woven-wire-cloth sieve) and amaranth bran (as coarse residue on a 0.45mm woven-wire-cloth sieve). Incorporation of 5-15% of amaranth by-products led to deterioration of the specific volume and sensory characteristicsof wheat bread [10].

M. Bodroža-Solarov et al. [24] suggested using 10, 15, and 20% of flour from puffed grain of *Amaranthus cruentus* in a wheat and amaranth flour mixture. The loaves from the composite flours proved to be higher in squalene, zinc, manganese, and calcium, but the shape stability and specific volume of the bread decreased by 1.3–1.5 times. The sensory characteristics of the bread deteriorated, too, except for the aroma.

Partial replacement of wheat flour with full-fat amaranth flour obtained from grain of *Amaranthus caudatus* grown in Peru was studied by C. M. Rosell et al [25]. Bread from the wheat and amaranth composite flour including 12.5-25% of the full-fat amaranth flour differed but insignificantly in the specific volume from the control sample. Only the minimal replacement of wheat flour in the mixtures can improve the sensory acceptability of the loaves.

Karla Carmen Miranda-Ramos et al. [26] determined the technological and nutritional qualities of bread enriched with 25 and 50% of full-fat amaranth flour, obtained from *Amaranthus spinosus* and *Amaranthus hypochondriacus* grain, grown in India and Mexico respectively. The biological value of bread from the wheat-amaranth composite flour significantly improved, but the bread quality did not: the specific volume of the loaves decreased by 1.1-1.7 times as well as the shape retention. The bread showed the deterioration of its sensory quality by 1.1-1.3 times, especially when using the *Amaranthus spinosus* flour. Increasing the amaranth flour in the formulations resulted in a higher moisture, ash, and protein content of the bread. Despite the significant bread quality deterioration, it is recommended to include up to 25% of full-fat amaranth flour of *Amaranthus hypochondriacus* in the formulation to improve nutritional value of the bread. The authors [27] noted that the use of wheat-amaranth composite flours in bread making prolonged the freshness of the bread, improved its taste and appearance, and allowed providing people with a wholesome product.

In Ukraine, 20 varieties of *Amaranthus* L. are registered for dissemination. More than 90% of amaranth cultivated are the varieties Kharkivsky-1, Liera, Sem, and Ultra. In 2020, the area under *Amaranthus* L. was about 2,000 hectares. Ukraine is characterised by the following proportions of amaranth processed products: about 70% of amaranth grain is used to manufacture amaranth oil, 10% of the grain is processed into amaranth groats, and the rest is flakes and popped amaranth grain. So far, there are almost no studies aimed at determining comprehensively how processed amaranth grain of Ukrainian varieties can be used in bread making. Different researchers paid considerable attention to using full-fat flour, rather than defatted by-products of amaranth oil production, such as flakes or groats.

So, the **purpose** of this work is studying the characteristics of amaranth flour obtained from different Ukrainian amaranth varieties and by different technologies in order to obtain wheat-amaranth bread of improved quality. The **research objectives** of this work include the following:

– to study quality characteristics of different amaranth flour such as particle size distribution, moisture, water absorption capacity, whiteness index, autolytic activity, acidity;

– to study the baking properties of wheat-amaranth composite flour made with different types of amaranth flour and with different ratios of wheat and amaranth flours, and to determine the changes in the gluten resilience during the dough fermentation and in the bread's physicochemical and sensory characteristics.

Research materials and methods

Amaranth flours (Fig. 1) were provided by the Association of Producers of Amaranth Grain and Amaranth Products (Dnipro): full-fat amaranth flour was obtained from different Ukrainian varieties of *Amaranthus hypochondriacus* such as Kharkivsky-1 (FFK), Liera (FFL), Sem (FFS); defatted amaranth flour from flakes (DAF) and defatted and debranned amaranth flour from groats (DAG) as by-products of amaranth oil production. Defatted amaranth flour is a milled product obtained from amaranth flakes as a by-product in cold-pressed amaranth germ oil production. Defatted and debranned amaranth flour is a product of milling polished amaranth grain with the germ and pericarp removed (groats). All types of the flour were obtained under production conditions of the Agrosnab LLC. The basis of the composite flours was the patent wheat flour Dnipromlyn with the following characteristics: moisture content 14%, wet gluten 26%, gluten deformation index (GDI) 62 units. The compressed fresh yeast Lvivski and salt were also used for trial laboratory baking.

The particle size of flour was determined by sieving through a set of polyamide sieves with the mesh sizes 240, 160, 150, and 130μm according to AOAC 965.22. The moisture content was analysed by the thermogravimetric method according to ISO 712. The water absorption capacity of flour was determined as the ability of 100g of flour to absorb moisture during dough kneading (ISO 17718). The whiteness of flour was analysed as the ability of flour to reflect light on the device RZ-BPL-CM according to GOST 26361. The autolytic activity of flour was determined as the ability of flour to form water-soluble compounds during heating of water-flour suspension in accordance with the standard method (GOST 27495). The total titratable acidity was analysed titrimetrically by AOAC 939.05. The influence of different amaranth flours on wet wheat gluten resilience was determined for composite flours with wheat and amaranth flours mixed at the ratio 90:10.

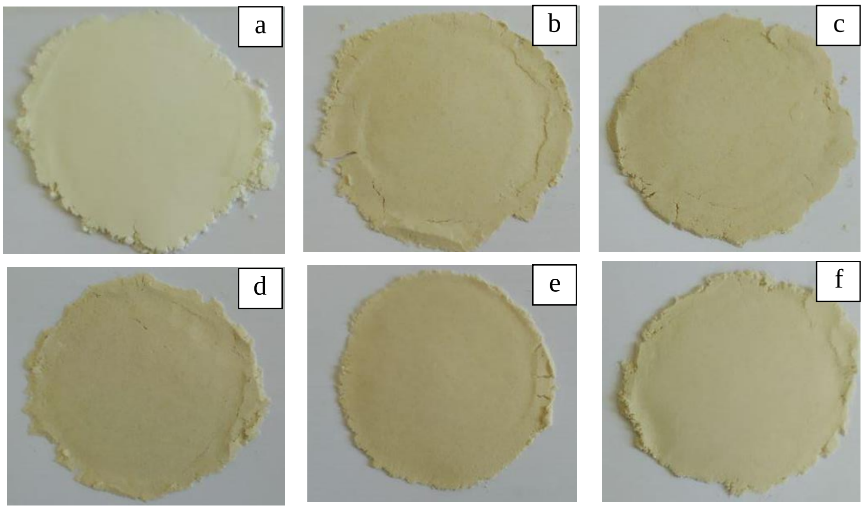

Fig. 1. Patent wheat flour (a) in comparison with full-fat amaranth flour from the variety Kharkivsky-1 (b), Liera (c), Sem (d); amaranth flour from flakes (e); amaranth flour from groats (f)

After dough kneading, the dough was fermented at 31±1°C for 200minutes, and every 20, 80, 140, 200 minutes, a 50g sample was taken to wash wet gluten from. Wet gluten was washed out manually, then the gluten deformation index was determined by a device IDK-3M according to GOST 27839. Laboratory bread baking tests were performed according to the standard method (GOST 27669) when kneading the dough with 200 g of flour. Wheat-amaranth composite flours were prepared as mixtures of wheat flour and amaranth flour at the ratios 95:5, 85:15, 75:25. The amount of water needed for dough formation was determined based on the moisture content of the flour. Compressed baker's yeast (5g) and salt (1.5g) were added according to the formulation. The dough was fermented in a thermostat at 31±1°C for 170minutes. The loaves were baked in a laboratory oven, with the baking chamber humidified at 220-230°C for 30 minutes.

The bread samples were analysed for specific volume and shape stability. The general quality of a loaf was determined based on the sensory characteristics like crust colour, crust condition, crumb colour, crumb porosity structure, crumb rheological properties, smell, taste, and crumb chewability, and rated on a five-point scale. The moisture content, total titratable acidity, and porosity of crumb were analysed according to DSTU 7045:2009. The trials were performed in 3-5 repetitions.

Statistical analyses were performed using MS Excel and STATISTICA. Pearson correlation analysis was performed at $p<0.05$. Cluster analysis was carried out by the method of agglomerative hierarchical clustering (Ward's method).

Results of the research and their discussion

The amaranth flours under study differ in the processing methods, which could include defatting and/or debranning, as well as in the varietal characteristics of amaranth grain. Particle size distribution of the flours is shown in Fig. 2. The full-fat amaranth flours of different grain varieties have almost the same particle size, mostly 150 to 240µm. The DAG flour had more particles of larger size (160-240µm), while the biggest DAF flour fraction included the particles varying between 130 and 150µm.

Therefore, the amaranth flours studied had the particles of smaller size compared to the results of the previous studies [10,11]. This must have been because of the difference between the processing methods used previously and the ones applied in the current research. Unlike it is in patent wheat flour, the fraction of particles smaller than 130 µm only makes up 4-5% of the amaranth flours under study.

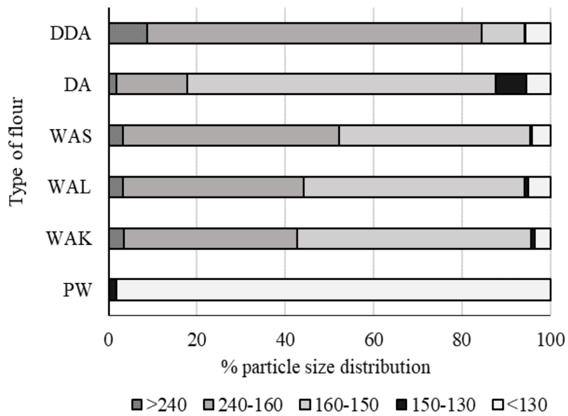

Fig. 2. Granularity of different amaranth flours in comparison with patent wheat flour

Table 1 presents some physicochemical properties of the amaranth flours under study which are important for bread making. All types of the amaranth flour are characterised by lower moisture content compared to patent wheat flour, which is in agreement with the studies by Z. Kucheruk and N. Shmalko [12,14].

Table 1 – Physicochemical properties of different amaranth flours

Type	Moisture content, %		Water absorption capacity, %		Whiteness index, units		Autolytic activity, %		Total titratable acidity, ml of 0.1 N NaOH	
	MD	SD	MD	SD	MD	SD	MD	SD	MD	SD
PW	14.0	0.0	58.9	1.9	63,2	0.1	10.5	0.3	3.2	0.0
FFK	9.7	0.2	72.2	1.9	15,6	0.6	31.8	0.5	11.8	0.0
FFL	9.8	0.1	68.9	1.9	3,5	0.6	33.2	0.6	15.0	0.0
FFS	9.9	0.2	67.8	1.0	4,4	0.4	36.8	0.8	13.0	0.0
DAF	10.6	0.3	86.7	3.3	9,5	0.3	64.2	0.7	8.7	0.1
DAG	9.2	0.1	69.4	1.0	20,4	0.3	50.3	0.8	14.9	0.1

Note. MD – mean deviation, SD – standard deviation in 3–5 repetitions

The samples of FFL and FFS (full-fat amaranth flour with a higher fat content) showed slightly reduced water absorption capacity compared to the FFK flour, which is obviously due to the varietal characteristics of amaranth grain.

Whiteness index of the amaranth flours was significantly lower than that of the wheat one, which depends on both the varietal characteristics of the processed amaranth grain and the processing method. The whole amaranth grain of the Kharkivsky-1 variety (FFK) and amaranth flour from groats (DAG) had the highest whiteness indices among the amaranth flour samples studied.Autolytic activity of all the amaranth flours studied was significantly higher than that of the wheat flour, which is in agreement with the previous study [13]. In particular, defatted amaranth flours (DAF and DAG), which are starchier, is autolysed more easily. Amaranth starch is known to have small-sized granules (0.5–3 μm) and low amylose content (2–12%) [28]. Smaller starch granules have a higher water absorption capacity and ability to swell, lower gelatinisation temperature, and higher stability during freezing [29]. The total titratable acidity of amaranth flour was also significantly higher than the acidity of patent wheat flour. This is due to higher protein content in amaranth flours and especially to their higher content of fats, which are mainly represented by polyunsaturated fatty acids. Correlation analysis has shown that the water absorption capacity of the flour samples significantly correlated with their autolytic activity (+0.885), whereas the acidity of the flours studied negatively correlated with their moisture (-0.939) and the whiteness index (-0.814). Hence, a higher moisture content is associated with a lower fat and protein content of the flours considered. The whiteness index apparently depends on the starch content of the flours studied, and the presence of outer layers of amaranth grains contributes to an increase in amylolytic enzymes in the flour.

The flour samples studied can be divided into two separate clusters (Fig. 3). The first cluster includes all gluten-free amaranth flours, while the second one is represented by patent wheat flour with the lowest similarity by the physicochemical properties. Furthermore, the first cluster falls into three subclusters: in the first subcluster, a separate subgroup is formed by the full-fat amaranth flours among which FFL and FFS have the highest intra-cluster similarity. So, the full-fat amaranth flour of the variety Kharkivsky-1 was different from other full-fat amaranth flours. The second and third subclusters were formed by the defatted flours DAF and DAG, and the last one is the least similar to the other types of amaranth flour in its quality characteristics.

Incorporation of the gluten-free amaranth flours also affected the gluten resilience during fermentation of the dough made from the composite flour where wheat is mixed with different amaranth flours (Fig. 4). Relaxation of the gluten with a decrease in its resilience was observed in all samples studied. However, the full-fat amaranth flours FFL and FFS along with the amaranth flour from flakes DAF showed lower relaxation of the gluten. In contrast, a rapid decrease in the elasticity was shown by the sample with amaranth flour from groats DAG. This is apparently due to the interaction of amaranth grain perisperm proteinases with wheat gluten. Replacing patent wheat flour with the amaranth flours FFL, FFS, and DAF caused strengthening of the dough gluten during fermentation. This agrees with the works [16,17], where similar gluten behaviour was related to using full-fat amaranth flour and amaranth bran.

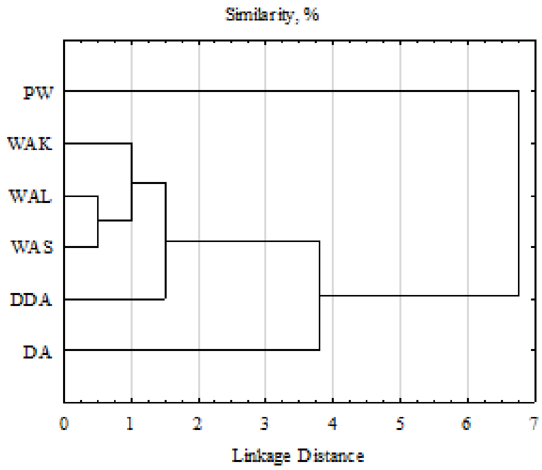

Fig. 3. Cluster analysis of flours

Bread from flour with 5, 15, 25% of amaranth flour has shown lower loaf shape retention, while its specific volume and porosity increased (Table 2). Obviously, reduction in the shape stability was caused by the deterioration of the dough's gas retention due to a decrease in gluten in samples with amaranth flour, which is in agreement with the previous works [18, 22, 24, 26].

Table 2 – Quality characteristics of wheat-amaranth bread

Flour composite, %	Specific volume, g/cm^3		Shape stability, H:D		Complex quality, points		Total titratable acidity, ml of 0.1 N NaOH		Porosity, %	
	MD	SD	MD	SD	MD	SD	MD	SD	MD	SD
PW	1.70	0.10	0.56	0.01	87	0	1.6	0,1	68	1
5FFK+95PW	2.17	0.03	0.46	0.01	88	0	1.4	0,1	73	0
5FFL +95PW	2.20	0.02	0.45	0.01	85	0	1.6	0,0	74	0
5FFS+95 PW	2.15	0.09	0.45	0.02	88	1	1.3	0,0	73	1
5DAF+95 PW	3.27	0.40	0.43	0.02	89	0	1.3	0,1	77	3
5DAG+95 PW	2.18	0.07	0.46	0.02	89	0	1.6	0,1	73	0
15FFK+85PW	1.82	0.20	0.56	0.01	88	0	1.4	0,1	73	0
15FFL+85PW	1.60	0.02	0.42	0.01	83	0	1.7	0,0	77	0
15FFS+85PW	2.03	0.45	0.41	0.02	86	1	1.4	0,0	72	0
15DAF+85PW	2.85	0.30	0.39	0.02	89	0	1.7	0,1	80	3
15DAG+85PW	2.47	0.08	0.46	0.02	89	0	1.6	0,0	77	1
25FFK+75PW	1.83	0.00	0.44	0.02	78	2	2.2	0,0	74	1
25FFL+75PW	2.06	0.02	0.46	0.02	77	4	2.2	0,0	74	1
25FFS+75PW	2.12	0.07	0.45	0.02	78	3	2.2	0,0	74	2
25DAF+75PW	2.12	0.02	0.37	0.03	82	1	2.4	0.1	75	2
25DAG+75 PW	2.51	0.06	0.39	0.02	85	1	2.8	0.0	79	0

Note. MD – mean deviation, SD – standard deviation in 3-5 repetitions

The amount of amaranth flour in the flour mixture is a key factor determining the bread quality. Increasing the share of amaranth flour in the bread formulations from 5 to 25% reduces the general bread quality, especially when using full-fat amaranth flour no matter what amaranth variety it is made from. In this case, the crumb structure and the taste of bread deteriorate, while its titratable acidity increases from 1.6 to 2.2–2.8ml of 0.1N NaOH. It should be noted that the specific volume and porosity of bread when using the full-fat amaranth flour increase by 1.1–1.3 and 1.1 times respectively.Inclusion of DAF in bread formulations leads to an increase in the specific volume and the porosity by, respectively, 1.3–1.9 and 1.1–1.2 times. The specific volume and the porosity of the samples with DAG increased by 1.3–1.5 and 1.1–1.2 times respectively. These results disagree with those in other works [10,26], where the use of amaranth flour led to a decrease in the porosity, specific volume, and overall quality of bread made using amaranth flour. This might be due to the dispersivity of the products studied and their different chemical composition determined, in particular, by the varietal characteristics of amaranth grain. Only A.Zueva et al [23] observed an insignificant increase in the bread porosity, but at much lower inclusion of full-fat amaranth flour into bread formulations (4%).

The correlation of the complex quality of the studied bread samples with their specific volume was positive (+0.540), and it was negative with their acidity (-0.685). In turn, the shape stability was negatively correlated with the porosity (-0.598), but the specific volume and the porosity had a positive correlation (+0.533). So, the correlation of these quality characteristics in the wheat-amaranth bread samples has shown the average strength of the relationship. Cluster analysis of the bread quality characteristics has allowed distinguishing four separate clusters of the samples studied (Fig. 5).

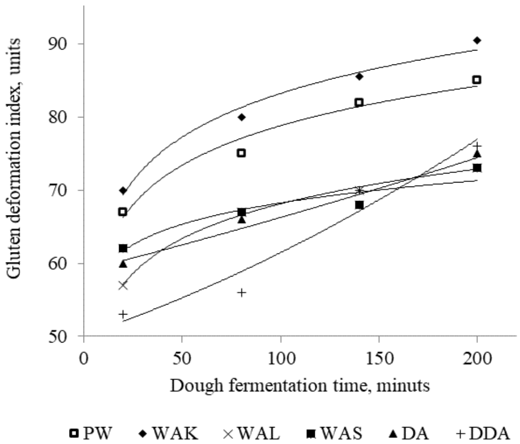

Fig. 4. Effect of different amaranth flours on gluten resilience

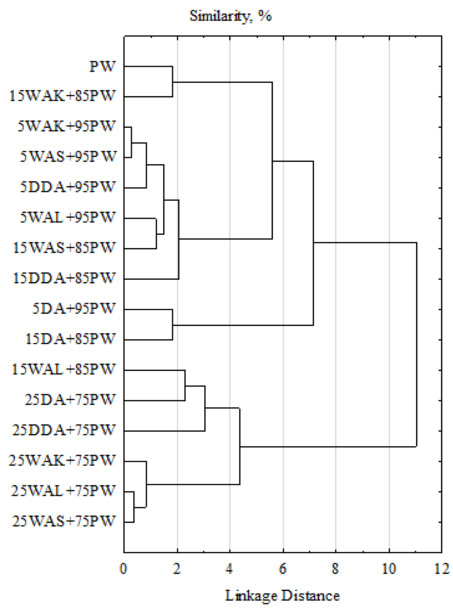

Fig. 5. Cluster analysis of the wheat-amaranth bread samples

The first cluster was formed of wheat bread (control) and the sample with 15% of FFK. The second cluster was comprised of the samples with 5–15% inclusion of amaranth flour of different types. The third cluster included the samples containing 5–15% of DAF with the quality parameters least similar to those of the above-mentioned samples. The last cluster included the samples of bread where 25% of wheat flour were replaced with amaranth flour of different types and the samples with 15% of FFL. Thus, the last cluster comprised the bread samples of the poorest quality. These are the bread samples containing the full-fat flours listed in the descending order of their sensory characteristics: FFK→FFS→FFL. The decrease in the quality manifests itself in the appearance of a specific odour and taste, in the poor overall quality of bread, especially when using the full-fat amaranth flour of the variety Liera (FFL). Therefore, to make bread, it will be the most practical to take the full-fat amaranth flour of the variety Kharkivsky-1 (FFK) and defatted flours from flakes and groats (DAF, DAG), which are by-products of processing amaranth grain into oil. These amaranth flours, when used to replace 5–15% of wheat flour in a wheat-amaranth flour mixture, improve the quality of bread by enriching it with bioactive compounds.

Conclusion

The amaranth flours have a 1.3–1.5 times lower moisture content, 1.2–1.5 times higher water absorption capacity, and larger particle size in comparison with patent wheat flour. The amaranth variety significantly affects the whiteness index of full-fat amaranth flours; the highest was that of the Kharkivsky-1 flour. By their whiteness index, the amaranth flours descend in the following order: DAG→FFK→DAF→FFS→FFL. The flours from the amaranth by-products DAF and DAG show the highest autolytic activity. This indicates the high activity of amylolytic enzymes and accumulation of water-soluble carbohydrates in the course of boiling the water-flour suspension. Due to their higher content of fats, proteins, and fibre, amaranth flours have higher titratable acidity than patent wheat flour has. The water absorption capacity of the flours studied was positively correlated with the autolytic activity (+0.885), whereas the total titratable acidity negatively correlated with the moisture (-0.939) and the whiteness index (-0.814) of the flour.

Inclusion of the full-fat amaranth flour of the varieties Liera and Sem or the amaranth flour from flakes in wheat-amaranth dough significantly strengthens the gluten during dough fermentation. Replacing 5 to 25% of wheat flour with amaranth flour in bread formulations increases the specific volume and the porosity of the crumb, but reduces the shape stability. The general quality of bread correlates positively with the specific volume (+0.540) and negatively with the acidity (-0.685) at $p<0.05$. In turn, the shape stability is negatively correlated with the porosity (-0.598), but the specific volume and the porosity have a positive correlation (+0.533). Bread with 5, 15, 25% of full-fat amaranth flour have shown a 1.3–1.9 and 1.1–1.2-fold increase in the specific volume and the porosity respectively. Amaranth flour from flakes included in bread formulations increases the specific volume and the porosity by 1.3-1.9 and 1.1–1.2 times respectively, while using amaranth flour from groats shows a 1.3–1.5 and 1.1–1.2-fold increase, as compared with wheat bread. The bread samples with full-fat amaranth flours descend in their sensory characteristics in the following order: FFK→FFS→FFL.

The physicochemical characteristics of full-fat amaranth flour depende on the varietal characteristics of the amaranth grain. Moreover, the quality of full-fat amaranth flours differs significantly from the quality of amaranth by-products. The full-fat amaranth flour from Kharkivsky-1 (FFK), defatted flour from flakes (DAF), and defatted and debranned flour from groats (DAG) are the most acceptable for bread-making by their baking properties. Wheat-amaranth composite flours with 5-15% of FFK, DAF, DAG improve the quality and nutritional value of bread enriching it with lysine, squalene, bioactive peptides, dietary fibre, and essential minerals.

The rheological properties of the wheat-amaranth dough should be studied in order to give scientific substantiation of the processes that determine the dough behaviour in the bread technology. The next steps should be measurement of the content of bioactive compounds in Ukrainian varieties of amaranth grain and assessment of the nutritional benefits of bakery goods made from different products of its processing.

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ХЛІБОПЕКАРСЬКІ ВЛАСТИВОСТІ РІЗНИХ ВИДІВ АМАРАНТОВОГО БОРОШНА ЯК СКЛАДОВОЇ ПШЕНИЧНОГО ХЛІБА

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Анотація. Технологічні характеристики амарантового повножирового борошна залежать від сортових особливостей зерна амаранту української селекції і суттєво відрізняються від амарантового знежиреного борошна з пластівців і з крупи. Порівняно з пшеничним борошном вищого сорту, амарантове характеризується нижчою вологістю, вищою водопоглинальною здатністю і автолітичною активністю. Сорт амаранту *Amaranthus hypochondriacus* суттєво впливає на білість повножирового борошна, найбільш світлим з яких є борошно із зерна сорту Харківський-1. За рахунок більшого вмісту жиру і білків, клітковини амарантове борошно відрізняється вищою кислотністю. Водопоглинальна здатність борошна позитивно корелює з автолітичною активністю (+0.885). Кислотність негативно корелює з вологістю (-0.939) і білістю (–0.814) борошна. Хліб, виготовлений із заміною 5, 15, 25% пшеничного борошна вищого сорту на амарантове борошно різних видів, характеризується збільшеним питомим об'ємом виробів, зниженою формостійкістю хліба, збільшеною пористістю м'якушки. Статистично достовірною ($p<0.05$) є кореляція комплексної якості досліджуваних зразків хліба з питомим об'ємом (+0.540) та негативною з кислотністю (-0.685). Формостійкість негативно корелює з пористістю (-0.598), а питомий об'єм і пористість мають позитивний кореляційний зв'язок (+0.533). Питомий об'єм і пористість хліба при застосуванні амарантового повножирового борошна зростають у 1.1-1.3 і 1.1 разів відповідно. Використання знежиреного борошна з пластівців призводить до збільшення питомого об'єму виробів у 1.3-1.9, пористості – на 1.1-1.2 разів, з крупи – у 1.3-1.5 і 1.1-1.2 разів відповідно. Зразки хліба з 25% дозуванням амарантового борошна усіх досліджених видів і вироби з 15% повножирового борошна із зерна сорту Лєра характеризуються найнижчими споживчими якостями. Доведено, що використання 5-15% повножирового борошна із зерна амаранту сорту Харківський-1 та знежиреного борошна з пластівців і з крупи як побічних продуктів переробки зерна амаранту на олію підвищує якість хліба і дозволяє поліпшити його поживну цінність.

Ключові слова: *Amaranthus hypochondriacus*, амарантове повножирове борошно, амарантове знежирене борошно з пластівців, амарантове знежирене борошно з крупи, пшеничний хліб, хлібопекарські властивості.

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