Composite wheat-amaranth flour baking properties and bread freshness

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Composite wheat-amaranth flour baking properties and bread freshness

S Yr Mykolenko, E B Aliiev* and V Yr Dudin

Dnipro State Agrarian and Economic University, 25, Voroshylova str., Dnipro, 49027, Ukraine

*aliev@meta.ua

Abstract. The study has reviled the benefits of amaranth groat flour application into wheat bread making towards enhancing the technological efficiency and the quality of the bread, prolonging the freshness of the product without artificial improvers involved in the formulations. Paying attention to textural characteristics of the wheat-amaranth bread during its shelf-life, amaranth groat flour as a derived product of amaranth grain processing presented a positive impact on the change of textural properties of the bread crumb during wheat-amaranth bread shelf-life. The effect of ranging 5–30% substitution of common wheat high-grade flour by the amaranth flour derived from partially defatted amaranth grain was investigated and the complex organoleptic quality of the bread made of the composite flour reached the highest level at 15% of the amaranth flour in the formulation. The technological parameters of bread making such as the duration of proofing, shape stability, specific volume, crumb porosity, baking and drying losses, when wheat high-grade flour was partially replaced by the amaranth grain-derived milling product showed better performance for the bread enriched by the amaranth flour at higher substitution level approving the wider application of the pseudocereal flour in the food industry. The freshness of the bread made of the composite flour is related to the textural characteristics of the crumb which tend to change drastically due to styling. The amaranth groat flour application into the wheat bread formulation led to changes in compressive force and tension of the crumb, the stress value at relative strain $\varepsilon = 25\%$, the elastic modulus, and the statical elastic hysteresis index. The resulting application of the amaranth groat flour into bread formulation allowed to ensure a 2-2.5-fold increase in the freshness of wheat bread with a 15% amaranth groat flour content when providing higher comprehensive quality of the product.

1. Introduction

Bread is a staple food all around the world. The nutritional value of bread and bakery products due to their daily consumption has a significant influence on human health, being the cornerstone to posing a risk to diseases of affluence, such as diabetes, obesity and atherosclerosis. Recently, global trends of a healthy diet have been faced with high consumer expectations regarding the sensory properties of food products [1]. Moreover, sustainability in food chains requires particular attention to seeking alternative and more environmentally friendly sources, processes and food systems. Climate change in recent decades has prompted to look for non-traditional food resources, e.g. cereal and pseudocereal crops, especially drought-resistant and undemanding soil quality, which can replace wheat, rye, and corn [2–4]. Under the influence of global trends and state policy, agribusiness and the food industry are increasingly inclined to the need of providing manufacturers with a sustainable approach to processing food and reducing waste along the food chain [5]. It is known that the majority of waste from bakery products is related to the last stage of the food chain. Styling of bread is the main reason to accumulate waste due to losing the freshness of the product and decreasing sustainability of the food chain [6]. Therefore, the use of improvers to prolong the freshness of bread is a widespread practice, which often goes beyond the principles of healthy food production.

Amaranth is a promising crop, which, despite its long cultivation history in Polynesian cultures, has not yet received wide use as a source in the food industry of the XXI century [7]. This is mainly associated with the lack of agricultural techniques, insufficient awareness of the population about its nutritional value and limited research and developments on the effective use of amaranth processing products in the food industry. Amaranth grain among cereals and pseudocereals is unique due to its high content of squalene (4–8 %), proteins (13–18 %) and its precious amino acid composition close to the ideal protein requirements, explicitly high content of lysine, dietary fibers (8–18 %), which are closer rather to vegetables and fruits than to cereals [8]. Amaranth grain-derived products are a unique plant-based source of squalene, which is triterpene and precursor of steroids, exhibiting anti-carcinogenic, immunomodulating, and antioxidant biological activity. This way, the introduction of amaranth grain-derived products to food might be extremely beneficial to the nutritional value of the product. The main fraction of amaranth protein is presented by globulins and albumins, which are abundant in essential amino acids, but the absence of gluten in amaranth grain-derived products also affects technological qualities, for instance, related to baking properties of the flour, triggering deterioration of rheological characteristics of the dough, which should be optimal to obtain the product of high quality. Moreover, an additional influential factor contributing to the change of technological behaviour of the dough including amaranth grain-derived products is small-sized amaranth starch and the presence of alfa-amylase inhibitor [9].

Due to its complete absence of gluten, Amaranth flour can only be used as a partial substitute of wheat flour in traditional wheat bread formulations [10]. The baking qualities of composite wheat-amaranth mixtures depend significantly on both the grain processing and the varietal characteristics of amaranth grain [11]. However, most of the research works that investigated composite mixtures with amaranth grain-derived products in bread making were devoted to the use of whole grain flour [12]. This approach does not address sustainability and efficiency along the food chain, because the fatty acid composition of amaranth grain includes linolenic acid, which can quickly oxidize and lead to high product rancidity, turning them into food waste. Moreover, the fat content in amaranth grain overpasses cereals [13]. Dehulling and cold-pressing of amaranth grain allow an additional concentration of squalene in the amaranth oil. Therefore, defatted amaranth grain-derived products as baking ingredients are more promising to use in composite flour formulations. This applies to amaranth flour, mainly consisting of amaranth grain perisperm, which does not contain fat. Studies on the baking properties of composite wheat-amaranth flour made from amaranth groats are scarce [14], and the effect of such baking ingredients on the freshness and staling of bread remains unexplored. Therefore, the study aimed to determine the impact of amaranth groat-derived product as an ingredient of wheat-amaranth composite flour on the quality emphasising the changes of the bread crumb textural properties during storage.

2. Materials and methods

2.1. Materials

Wheat high-grade flour was purchased from the market (Dnipro, Ukraine), with the following characteristics: moisture content of 14 %, wet gluten content of 26 %, and gluten deformation index (GDI) of 65 units. Amaranth flour was provided by the Association of Amaranth Grain Producers and Processors (Dnipro, Ukraine). This flour was produced from debranned amaranth flour as a milled product of polished amaranth grain with germ and pericarp removed (Karlivka, Ukraine). During the research, the flour was stored at a temperature of +4–+10 °C for 2–3 months. Individual indicators of the quality of wheat and amaranth flour and the composite flours are given in Table. 1. Compressed fresh yeast (Lviv, Ukraine) and salt (Artemivsk, Ukraine) were also used for trials.

Table 1. Quality characteristics of wheat, amaranth flours and composite mixtures.

Flour (%)	Moisture content, %	Whiteness, units	Falling number, s	Titratable acidity, mL 0.1N NaOH
Wheat high-grade flour (100)	14.7±0.14	59.1±0.02	503±2	3.0±0.28
Amaranth groat flour (100)	11.7±0.14	12.9±0.03	61±1	9.5±0.42
Wheat-amaranth composite flour (95:5)	14.7±0.14	54.3±0.03	502±18	2.8±0.28
Wheat-amaranth composite flour (90:10)	14.7±0.14	49.3±0.04	516±8	3.3±0.14
Wheat-amaranth composite flour (85:15)	14.4±0.06	44.3±0.04	516±4	3.1±0.14
Wheat-amaranth composite flour (80:20)	14.4±0.57	38.7±0.03	499±12	3.3±0.14
Wheat-amaranth composite flour (75:25)	14.1±0.14	36.8±0.04	475±6	3.9±0.14
Wheat-amaranth composite flour (70:30)	13.7±0.42	40.4±0.04	453±9	4.3±0.14

2.2. Baking trial tests

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 the wheat and the amaranth flour at a ratio of 100:0 (control), 95:5, 90:10, 85:15, 80:20, 75:25, and 70:30. Thus, amaranth flour content (α) varied in the following concentration range of 0–30% with a step of 5%. The amount of water needed for the formation of the dough was determined based on the moisture content of the flour. Compressed baker's yeast (5 g) and salt (1.5 g) were added to the formulation. The fermentation of the dough was for 170 minutes at 31±1°C. The loaves were baked after proofing, the duration of which varied depending on the test sample (T_e, min), in a laboratory oven with the humidification of the baking chamber at 220–230 °C for 30 minutes. After 4–6 hours, the organoleptic, and physicochemical quality characteristics of the bread were determined.

2.3. Bread quality characteristics

Baking loss (ω) was determined as the ratio of the weight of hot bread, determined immediately after removing the loaf from the oven, to the mass of cooled bread after 4 hours of storage at room temperature, expressed in %.

Drying loss (φ) was determined as the ratio of the weight of cooled bread after 4 hours of storage at room temperature to the weight of bread after 24 hours of storage at room temperature, expressed in %.

The total loss of bread weight was determined as baking and drying losses together, expressed in %.

The specific volume of bread (ρ) was measured according to the AACC Method 10-05.01 as the volume of displaced rapeseed about the weight of the bread, g/ml.

Shape retention (H:B) was defined as the ratio of the height to the width of the central part of the bread [12].

The porosity of the bread crumb (δ) was determined according to the common method [15] using Zhuravlev's device, and expressed in %.

The moisture content of the crumb (W) was determined by the air-oven method as a loss in weight of 5 g of crushed bread crumb taken from the central part of the loaf according to AACC Method 44-15.02 and expressed in %.

To measure the titratable acidity (TA, °), 25 g of the crushed bread crumb taken from the central part of the loaf was placed in a flask having a capacity of 500 ml, where 250 ml of water of 20 ºC was added. The flask was closed with a plug and vigorously shaken for 2 min, settled for 10 min, shaken for 2 min and settled again for 8 min. Then the solution was filtered, 50 ml of the filtrate were taken with a pipette and transferred to two 150 ml conical flasks, 2-3 drops of phenolphthalein solution were added, and titration was carried out with 0.1 N solution of sodium hydroxide till the appearance of light pink colour was observed for 1 min.

The titratable acidity was calculated with the use of the following formula:

$$TA=2V \tag{1}$$

where V is the volume of 0.1 N solution of sodium hydroxide used for the titration.

The complex quality of the loaf was determined by taking into account sensory characteristics, particularly crust colour, crust surface condition, crumb colour, crumb porosity structure, crumb rheological properties, flavour, taste, and crumb chewability, expressed on a five-point scale [15] taking into account the significance of the criteria. The organoleptic evaluation was carried out by a panel group of 7 employees of the Faculty of Engineering and Technology, Dnipro State Agrarian and Economic University.

The trials were performed in 3–5 repetitions. Statistical analyses were performed in MS Excel.

The textural characteristics of the bread were determined after 24 and 48 hours of storage of the samples at room temperature according to the following indicators: the dynamics of changes in compressive force and tension, the stress value at relative strain $\varepsilon = 25\%$, the elastic modulus, the static elastic hysteresis index.

The elastic characteristics of the product were determined according to the developed methodology, which includes the following stages:

1. A loaf of bread is cut crosswise into parts 25 mm thick.
2. Parts of bread products are alternately placed on a flat horizontal surface (work table) in the area under the cylindrical indenter (diameter of 21 mm, area of the working surface $S = 3.464 \cdot 10^{-4}$ m^2), which is fixed on a strain gauge that moves in a vertical plane. The strain gauge with the indenter attached to it must be calibrated and correspond to a force of 0 N in a state of rest.
3. The maximum value of the compressive force F_{max} (H) is set, and the largest value of the relative deformation ε_{max} (%) is required.
4. Next, the indenter starts to descend uniformly straight at a speed of 10 mm/s from the upper point. When a part of the bread crumb is reached, the force on the strain gauge begins to increase from 0 N. This moment is recorded as the beginning of the measurement process. At this point, the value of the layer thickness of the part of the bread product X (mm) is determined on the condition that the work table corresponds to the origin of coordinates 0 mm.
5. During the measurement process, the value of time t (ms), absolute deformation Δx (mm) and compression force F (N) are determined.
6. Upon reaching the value of absolute deformation $\Delta x \geq \varepsilon_{max} \cdot X/100$ (mm) or force $F \geq F_{max}$ (H), the indenter stops.
7. Next, the indenter starts to move upwards uniformly and in a straight line at a speed of 10 mm/s. At the same time, the determination of the time value t (ms), the absolute deformation Δx (mm) and the compressive force F (N) continues.
8. All received data are stored in the database.
9. Further, the textural properties of the bread crumb are calculated based on the obtained data. Thus, the compressive force F (H) is converted into tension σ (kPa) according to the formula

$$\sigma = \frac{F}{1000 \cdot S} = 2.887 \cdot F \tag{2}$$

and stored in the database.

10. From the database, the stress value at relative strain $\varepsilon = 25\%$ is rotated and fixed (Fig. 2) as the textural characteristic of the product σ.
11. The elastic modulus of the product E (kPa) is determined by the formula (Fig. 1):

$$E = \frac{100 \cdot \sigma(\varepsilon = 25\%)}{25} = 4 \cdot \sigma(\varepsilon = 25\%). \tag{3}$$

12. Based on the obtained dependences σ (ε), which are presented in the form of elastic hysteresis, their area (static elastic hysteresis index) S (kPa·%) is determined by the formula (Fig. 1)

$$S = \sum_{i=1}^{\frac{\varepsilon_{max}}{\Delta\varepsilon_i}} \left(\sigma_{up\,i} - \sigma_{down\,i}\right)\Delta\varepsilon_i = \sum_{i=1}^{10\varepsilon_{max}} 0.1\left(\sigma_{up\,i} - \sigma_{down\,i}\right). \tag{4}$$

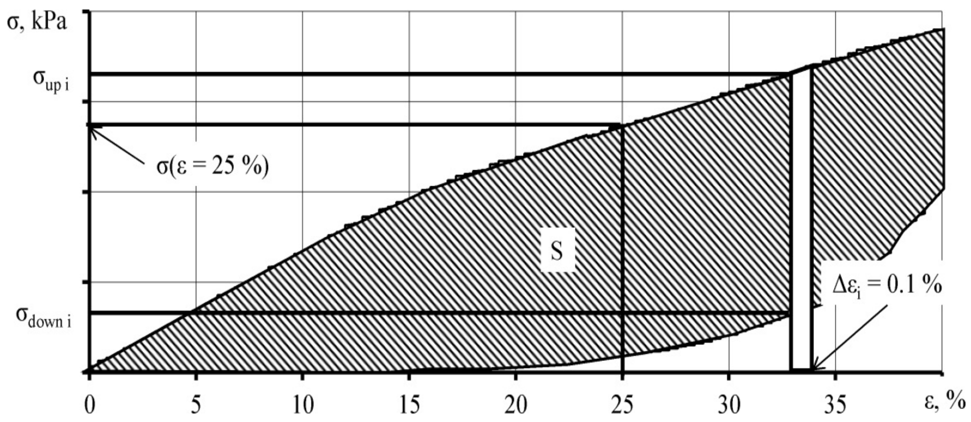
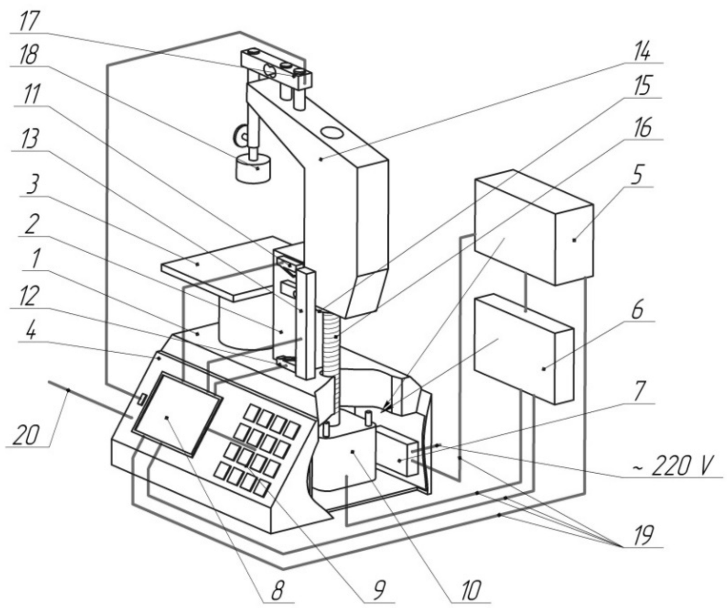


Figure 1. Bread crumb tension and relative deformation.

To implement the abovementioned methodology and to measure the textural characteristics of bakery products, a device for automatic determination was constructed. The structural and technological scheme and general view of the device for automatic measurement of the food textural properties are shown in Figure 2.



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1 – bed, 2 – guide, 3 – work table, 4 – box, 5 – power supply unit, 6 – stepper motor driver, 7 – outlet with switch, 8 – control unit with LCD, 9 – keyboard, 10 – stepper motor, 11 – upper limit switch, 12 – lower limit switch, 13 – linear variable resistor, 14 – tripod, 15 – nut with raceways for balls, 16 – threaded shaft, 17 – strain gauge, 18 – cylindrical indenter, 19 – electrical wires, 20 – USB output

Figure 2. Structural and technological scheme (a) and general view (b) of the device for automatic measurement of food textural properties.

3. Results and discussion

The unique chemical composition of amaranth grain makes it an attractive food source for applying amaranth grain-derived products into bread formulations based on different mixtures of wheat and amaranth flour. Table 2, Figure 1 show that in this way technological properties, as well as physical and chemical characteristics of bread, were found to show significantly different performance concerning the increase of the amaranth flour in the product. For instance, significantly decreased proofing of the dough highlighted that it can be reduced in 2 or 4 times when the amaranth flour content exceeded 15 and 30% respectively, which is in agreement with previous findings [16]. Despite intensified proofing, the total loss in the weight of bread demonstrated the tendency to increase with 25-30% of amaranth flour content in the bread formulation due to higher drying loss.

Table 2. Quality of wheat-amaranth bread.

Characteristic	Amaranth flour content, %						
	0	5	10	15	20	25	30
Technological properties							
Duration of proofing T_e, min	140±3	70±2	70±2	70±2	35±1	35±1	40±1
Baking loss ω, %	14.4±0.8	13.3±1.4	13.5±1.3	14.4±1.1	15.1±0.6	16.1±2.1	16.6±1.4
Drying loss φ, %	0.73±0.16	2.42±0.25	2.25±0.13	1.14±0.24	0.63±0.05	0.59±0.15	0.36±0.18
Total loss, %	15.1±0.7	15.7±0.1	15.8±1.1	15.6±1.4	15.7±0.6	16.7±1.9	17.0±1.6
Physical and chemical characteristics							
Specific volume ρ, g/cm^3	2.39±0.06	2.43±0.11	2.75±0.12	3.09±0.22	3.47±0.13	3.33±0.20	3.28±0.18
Shape stability H:B	0.33±0.09	0.45±0.02	0.43±0.02	0.46±0.02	0.37±0.08	0.34±0.04	0.14±0.08
Crumb moisture content W, %	42.3±1.3	43.0±0.8	42.5±1.3	42.8±0.8	42.8±0.8	42.8±0.8	42.0±1.5
Titratable acidity TA, °	1.1±0.1	1.4±0.2	1.5±0.2	1.8±0.2	2.0±0.3	2.0±0.3	2.0±0.3
Crumb porosity δ, %	70.6±1.7	74.5±2.1	75.6±1.6	76.4±3.6	76.7±1.1	80.4±2.6	79.8±3.1
Complex quality Q, units	71.0±1.7	88.4±2.4	94.3±2.8	97.8±2.9	93.3±2.5	82.2±1.9	69.0±1.5
Texture characteristics							
Stress value at relative strain σ (25 %), kPa	53.4±2.8	36.4±1.6	34.5±1.5	23.7±2.4	21.6±1.6	15.6±0.7	9.2±1.6
Elastic modulus E, kPa	212.8±11.0	145.4±6.4	138.2±5.9	94.9±9.5	86.3±6.5	62.3±2.7	36.9±6.4
Static elastic hysteresis index S, kPa·%	1412±81	989±86	965±70	668±70	634±48	454±28	286±48

Sensory properties play a crucial role in the acceptance of food by customers, and thus sensory radar (Figure 4) reveals the most important properties of bread on wheat-amaranth composite flour such as crust colour and appearance; crumb colour, structure, and chewiness; aroma and taste of the product. Therefore, the application of the amaranth flour could substantially affect the quality of the bread evaluated by the customer when the amaranth flour content in the composite mixtures reached 20% and more: crust appearance and aroma were the most sensitive attributes of the product deteriorated with the increase of the amaranth flour content in the formulations.

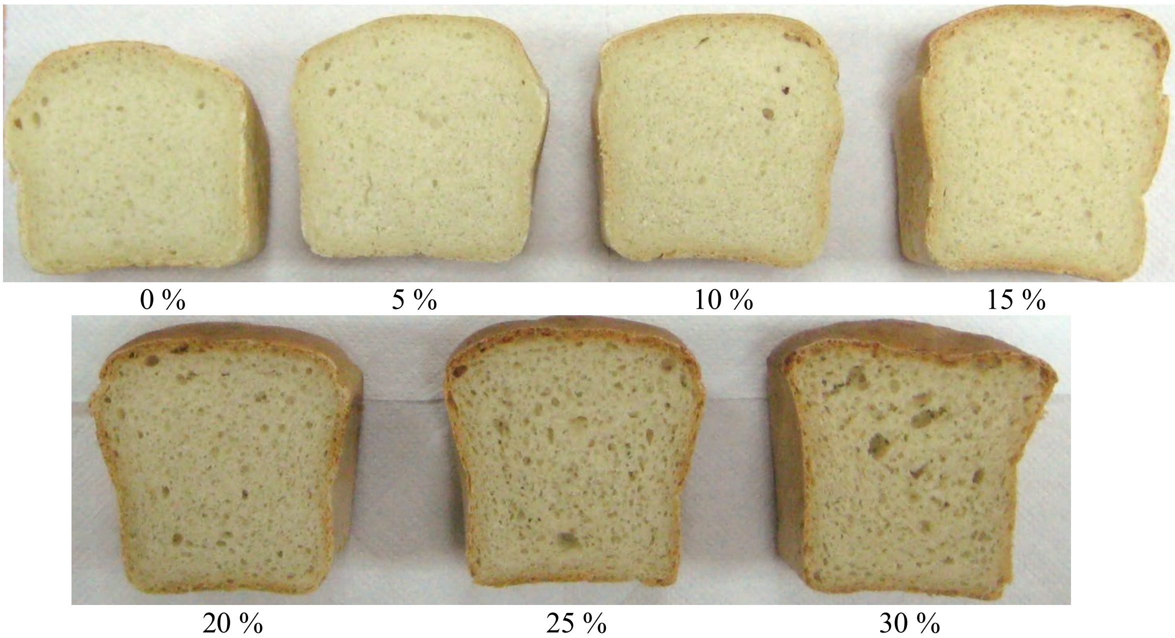

Figure 3. Wheat-amaranth bread with 0 (control), 5, 10, 15, 20, 25, 30 % of amaranth flour substitution.

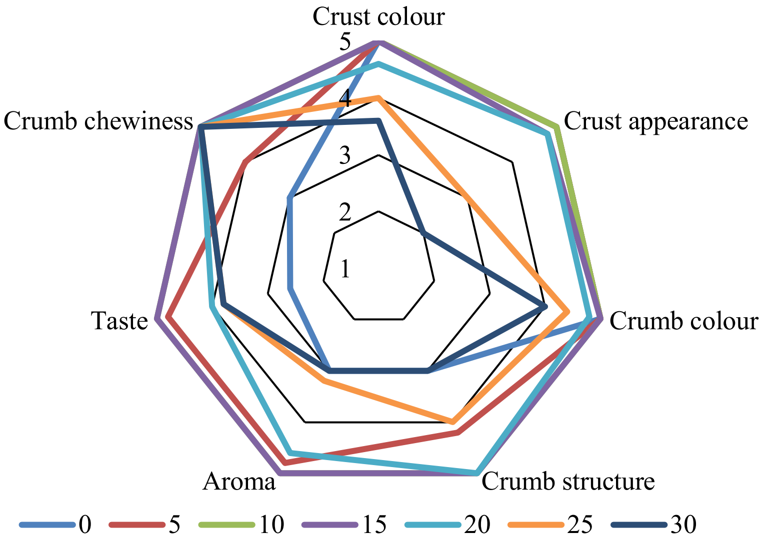

Figure 4. Sensory radar chart of wheat-amaranth bread with 0 (control), 5, 10, 15, 20, 25, and 30 % of amaranth flour.

The graphical interpretation of the obtained relations (Table 2) is shown in Figures 5-7. Thus, the increase in the amaranth flour content α led to a change in the quality characteristics of the bread. Hence, the complex organoleptic index was the highest (Q = 97.8 points) for the bread with 15 % of the amaranth flour. In turn, the baking loss ω, crumb porosity δ, and titratable acidity increased along with higher amaranth flour content. The opposite pattern was observed for proofing duration T_e, drying loss φ, and shape stability H:B of the loaf.

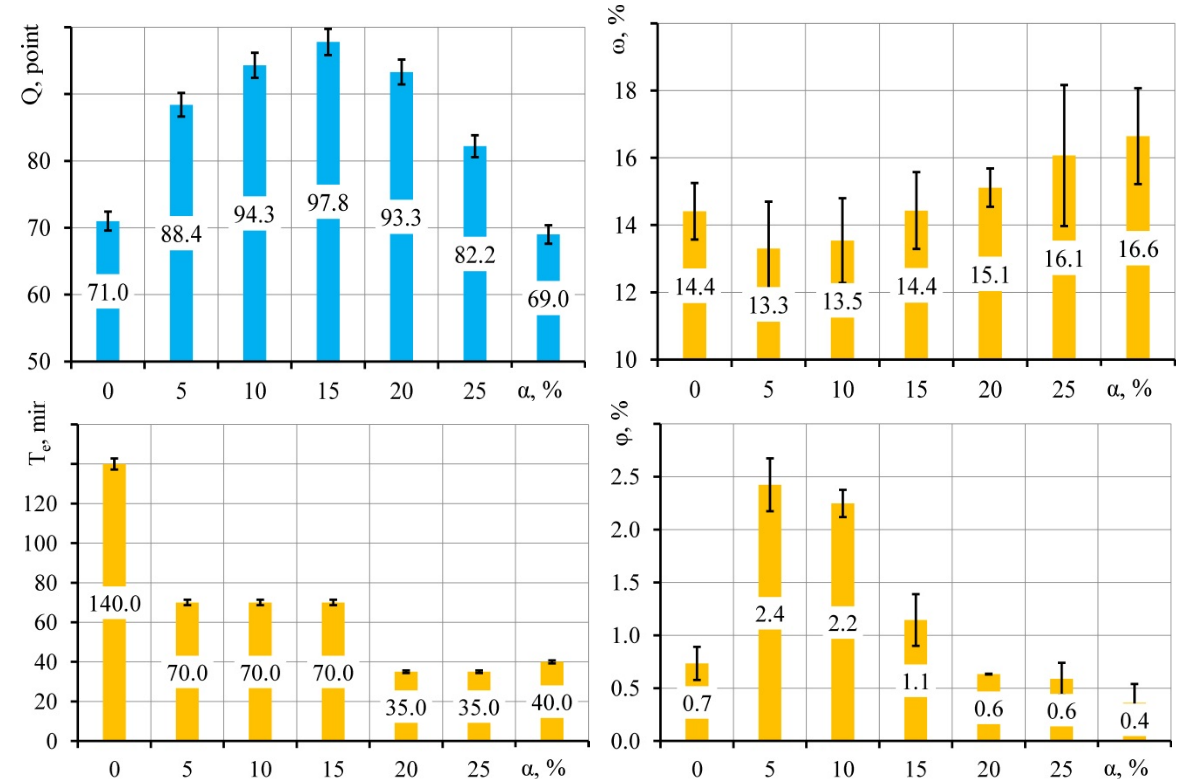

Figure 5. Effect of amaranth flour content α on bread complex organoleptic score Q, baking loss ω, duration of proofing T_e, drying loss φ.

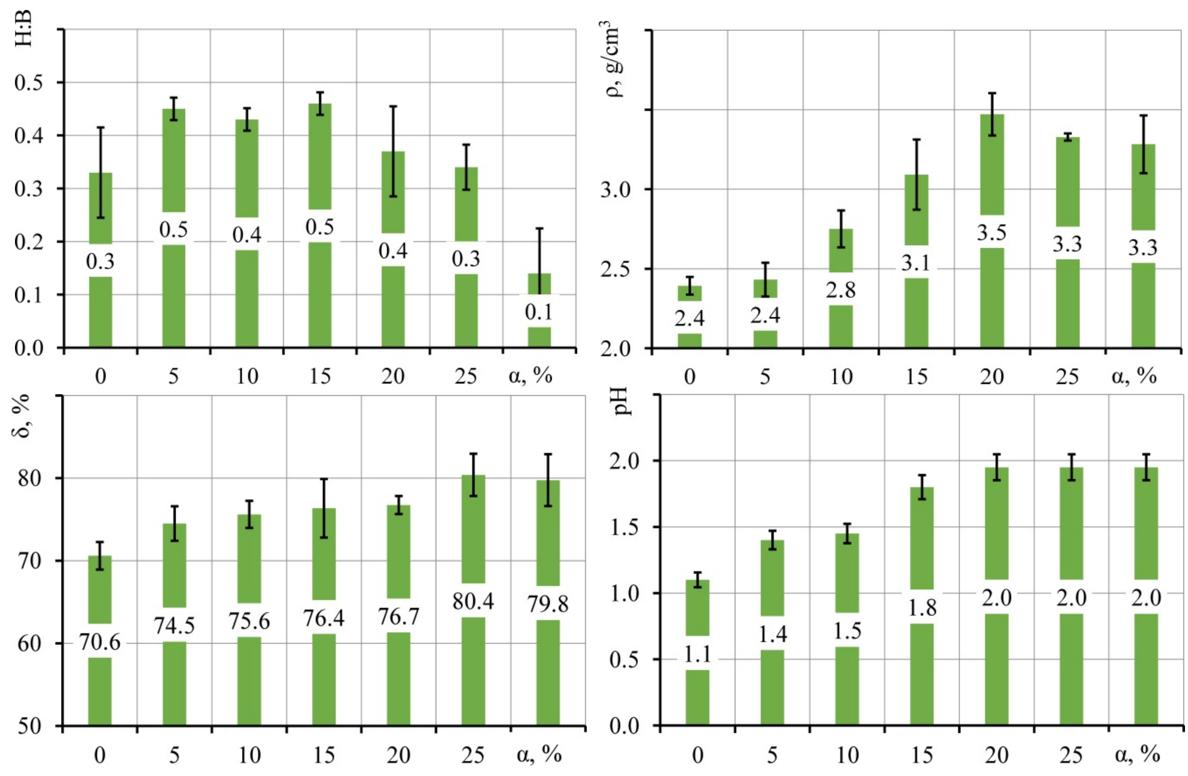

Figure 6. Effect of amaranth flour content α on bread shape stability H: B, specific volume ρ, crumb porosity δ, titratable acidity TA.

Figure 7 presents the dependences of changes in the elastic strength of fresh bread crumb F(t) on time t and the tension of fresh bread crumb σ (ε) on its relative deformation ε with different content of amaranth flour α in the bread formulations. The dependence of the fresh wheat-amaranth bread tension on its relative deformation σ(ε) was presented in the form of elastic hysteresis. When the amaranth flour content α increased, the hysteresis area decreased, which is confirmed by Figure 8, e.g. by the static elastic hysteresis index. A similar pattern was observed for the elastic modulus E and the stress at relative strain σ (25%). So, a decrease in their values was demonstrated with an increase in amaranth flour content α. Obviously, this was related to higher crumb porosity δ and the specific volume ρ of the products.

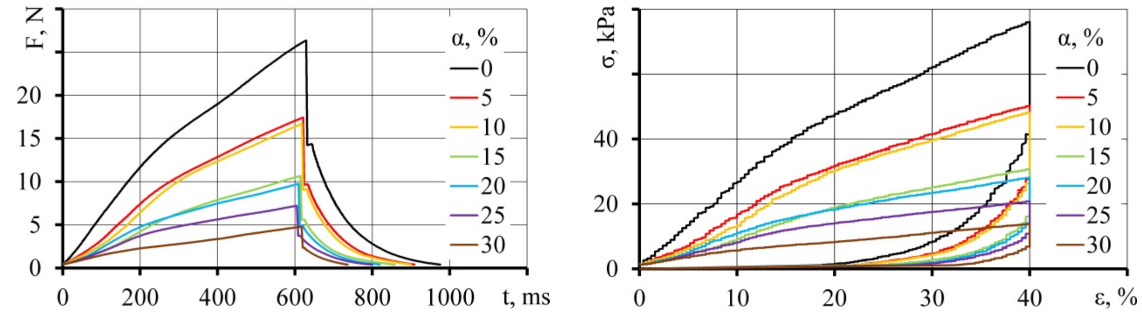

Figure 7. Dynamics of changes in elastic strength of fresh bread crumb F(t) and tension of fresh bread σ (ε) depending on amaranth flour content α.

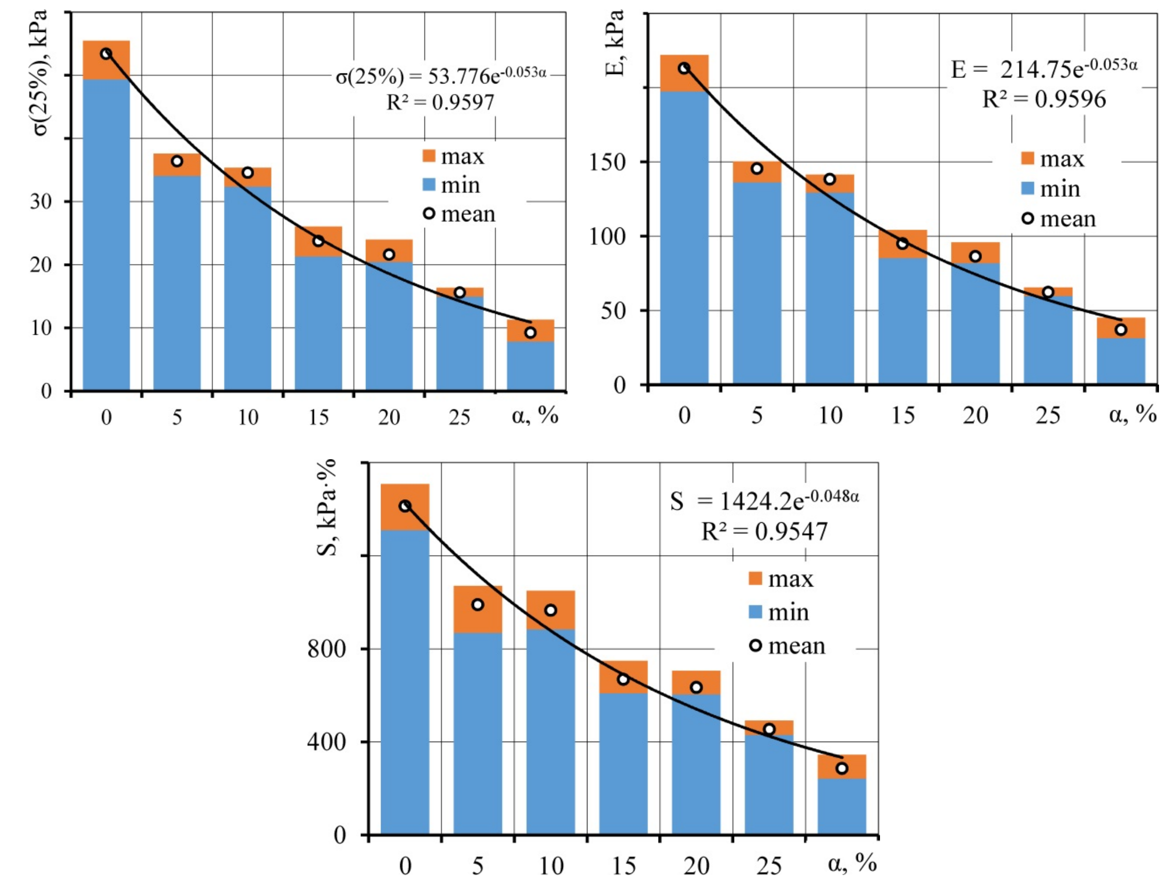

Figure 8. Stress value at relative strain σ (25%), elastic modulus E and static elastic hysteresis index S depending on amaranth flour content α.

Moreover, the results of changes in the crumb textural properties of the bread produced on different wheat-amaranth composite flour were obtained after 2 storage days of the products without access to oxygen under ambient conditions. A comparative assessment of the textural changes of the bread crumb is given in Table 3, Figures 9–11.

Table 3. Textural characteristics of bread with different amaranth flour content during storage.

Storage, hours	Amaranth flour content α, %						
	0	5	10	15	20	25	30
Stress value at relative strain σ (25%), kPa							
24	53.4±2.8	36.4±1.6	34.5±1.5	23.7±2.4	21.6±1.6	15.6±0.7	9.2±1.6
48	95.8±3.2	65.3±2.8	63.7±2.8	43.0±2.6	35.0±1.8	27.5±1.7	17.4±0.9
Elastic modulus E, kPa							
24	212.8±11.0	145.4±6.4	138.2±5.9	94.9±9.5	86.3±6.5	62.3±2.7	36.9±6.4
48	382.6±12.1	261.4±10.2	254.9±7.8	172.0±10.1	139.9±8.2	110.1±4.3	69.8±4.9
Static elastic hysteresis index S, kPa·%							
24	1412±81	989±86	965±70	668±70	634±48	454±28	286±48
48	2733±101	1807±99	1810±80	1239±82	1067±66	827±35	576±34

Figures 9–11 demonstrate that during the storage of the wheat-amaranth bread, the textural properties changed drastically. Thus, in 2 days, the stress value at relative strain σ (25%) and the elastic modulus E increased by 1.8–1.9 times, when the static elastic hysteresis index S accelerated by 1.9–2.0 times. Such a change in the textural properties of the wheat-amaranth bread indicated its styling and related changes in the crumb microstructure. It should be noted that the presence of amaranth flour led to a decrease in the stress value at relative strain (25%) and the elastic modulus E, which was probably associated with lower starch retrogradation and softer structure of the crumb when gluten content decreased with higher amaranth flour substitution.

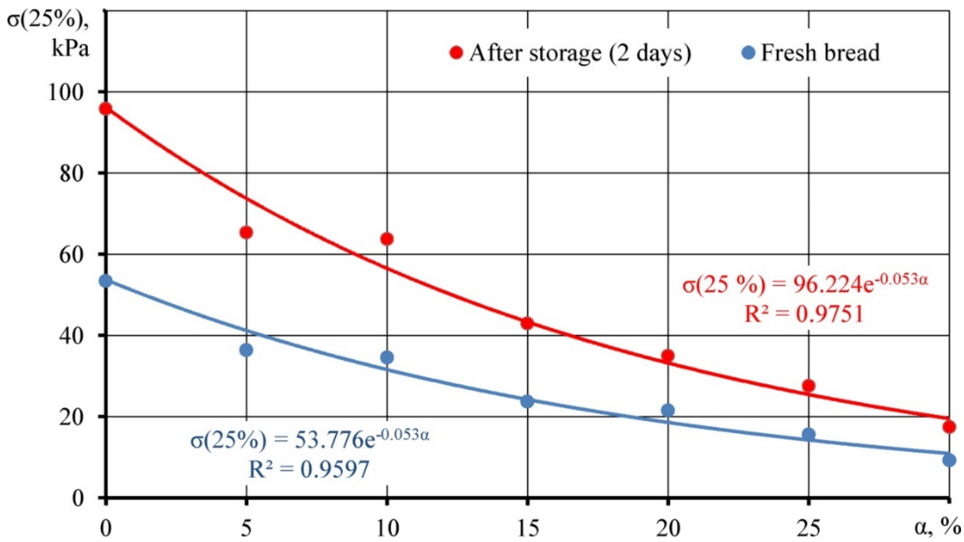

Figure 9. Effect of amaranth flour content α on stress value at relative strain σ (25%) of wheat-amaranth bread during storage.

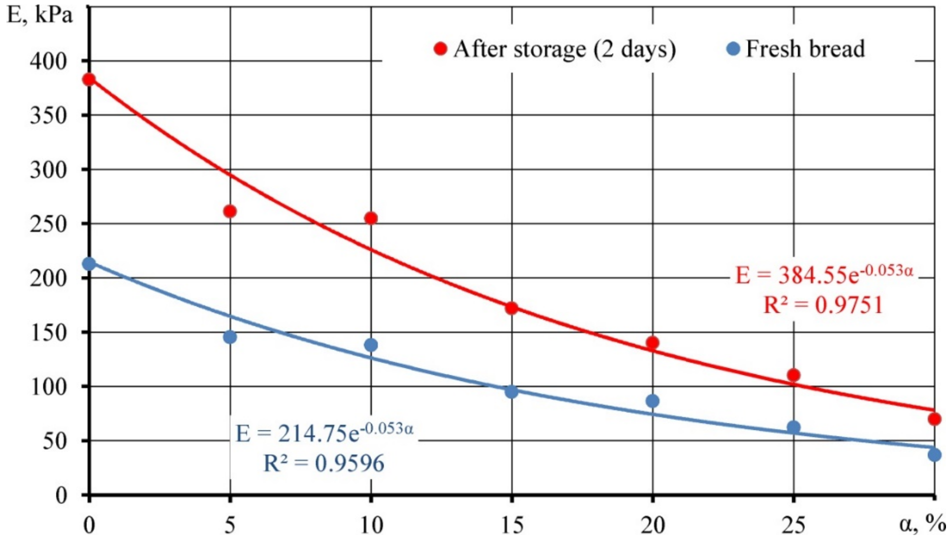

Figure 10. Effect of amaranth flour content α on elastic modulus E of wheat-amaranth bread during storage.

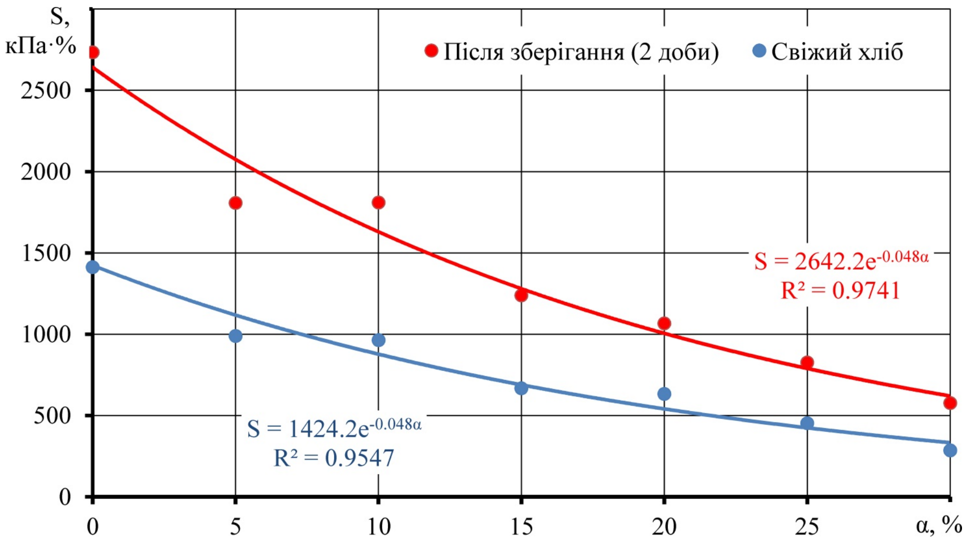

Figure 11. Effect of amaranth flour content α on static elastic hysteresis index S of wheat-amaranth bread duration storage.

The obtained results of the study are in agreement with the research [14] and the reported properties of another amaranth grain-derived products [11–13]. Therefore, amaranth flour application in the bread formulation could make a considerable change to the textural properties of the wheat-amaranth bread, possibly prolonging its shelf life without the deterioration of the bread quality when the wheat flour was 15 % substituted by the amaranth groat flour.

4. Conclusion

The benefits of applying amaranth flour to wheat bread were proved in terms of improving processing efficiency and bread quality, thereby prolonging product freshness without including artificial improvers in the formulations. Taking into account the textural properties of wheat amaranth bread during storage, amaranth groat flour as a product of the grain processing showed a positive impact on changes in the textural properties during storage of the wheat-amaranth bread.

Amaranth flour produced from debranned amaranth grain as an ingredient of wheat-amaranth composite flour improved the organoleptic, and physicochemical properties of the bread at 15–20% content in the mixture. This way higher complex organoleptic scores and decreasing the duration of proofing in bread making were reached without the deterioration of the quality. Despite intensified proofing, the total loss in the weight of bread, and titratable acidity demonstrated an increase when the amaranth flour content exceeded 25–30%.

Changes in the elastic strength of the fresh bread F(t) as a function of time t and the tension of fresh bread σ (ε) as a function of its relative deformation ε for different content of amaranth flour α revealed the formation of the softer structure of the product enriched with the amaranth groat flour. The area of static elastic hysteresis decreased with a higher concentration of the amaranth flour in the wheat-amaranth bread. Application of the amaranth groat flour in the bread formulations could contribute to the freshness of wheat-amaranth during storage enhancing the quality and nutritional value of the product.

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