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IMPROVING THE CONSUMER PROPERTIES OF CUPCAKES ENRICHED WITH A FOOD ADDITIVE OF COMBINED COMPOSITION

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Abstract. The study focused on optimizing the formulation and improving the production technology of a flour-based confectionery product– cupcakes enriched with a combined food additive based on iron oxide nanoparticles ($FeO \times Fe_2O_3$ NPs) and Laminaria (Laminaria sp.), developed using an innovative technology. The combined food additive (CFA) was created using dry powders of iron oxide nanoparticles and Laminaria SP powder in a weight ratio of 15:85. This additive was designed both as a technological improver and a nutritional fortifier for incorporation into rye cupcakes. The additive is a finely dispersed brown powder with a particle size of approximately 0.2 mm. Its main component, Laminaria, is a brown seaweed that serves as a natural source of macro- and microelements, proteins, vitamins, and other biologically active compounds that contribute to enhancing the nutritional composition of food products. The second component is a mixed oxide of divalent and trivalent iron ($FeO \times Fe_2O_3$ NPs)—a fine dark brown powder with particle sizes of 70–80 nm, odorless and tasteless, possessing a broad range of functional and technological properties. During the recipe development, the optimal ratio of ingredients for cupcakes preparation was determined. It was found that the optimal concentration of CFA is 1.0% of the flour weight, which improved the nutritional value of the final product and provided it with the necessary functional and technological properties. The study also investigated the physicochemical and sensory characteristics of the final product, including: the effect of the combined food additive on gluten properties; dough development and gas formation; the influence of the additive on the structural and mechanical properties of the dough; and its impact on the physicochemical and organoleptic quality indicators of the cupcakes.

Keywords: cupcakes, flour products, raw materials, combined food additive (CFA), nutritional value, recipe, development.

Introduction. Formulation of the problem

The health of both individuals and the nation as a whole significantly depends on the quality of nutrition. A rational and balanced diet is one of the key factors determining work capacity, life expectancy, and the preservation of a nation's gene pool. In today's context, the issue of healthy eating has gained priority and is considered an important aspect of state policy in many developed countries, including the United States, Australia, and Germany. For Ukraine, improving the population's nutrition is also an extremely relevant issue. Recent research in the field of nutrition science has revealed a direct link between the levels of certain nutrients in food and human health. This has led to the development of a new approach to nutrition, viewing it as a tool for disease prevention and a supportive element in the treatment of various conditions. Flour-based confectionery products have a significant drawback – they almost completely lack essential nutrients. Therefore, improving their quality and nutritional value, as well as expanding their range through enrichment with essential components and functional ingredients, remains a highly important and relevant task [1, 2].

Analysis of recent research and publications

One of the significant contemporary trends in the food industry is the development of functional foods with health-promoting properties based on staple products such as flour-based confectionery products. Fortification of such foods increasingly relies on plant-based bioactive compounds. Seaweeds, in particular, are recognized as one of the most promising resources due to their exceptional adaptability, rapid growth rates, and sustainable production [3, 4]. This is further supported by data from the Food and Agriculture Organization, which reports a more than threefold increase in global seaweed production over the past 20 years [5].

Among seaweeds, brown algae (Phaeophyceae or Phaeophyta) occupy a distinguished position. They are among the most extensively consumed types of algae in the human diet [6]. In addition to their nutritional value, brown algae serve critical technological functions in the food industry, including stabilization and thickening. Moreover, due to their rich content of bioactive compounds with diverse therapeutic properties, they are actively utilized in the production of nutraceuticals and pharmaceutical preparations, as outlined in various reviews [7].

Brown algae are notable for their content of valuable nutrients, including sulfated polysaccharides (such as alginates, fucoidans, and kelp polysaccharides), proteins, minerals, vitamins, dietary fibers, fatty acids, pigments, polyphenols, and polyunsaturated fatty acids [8, 9]. Furthermore, they serve as an important natural source of iodine and its organic compounds [10, 11].

One of the most notable representatives of brown algae is Laminaria, commonly known as kelp, comprising more than thirty species. Laminaria is considered a valuable dietary product due to its low caloric content (7–10 kcal/100 g), minimal fat content (0.9–6.5% dry weight), and low sugar levels (approximately 1.0–3.0%) [12, 13]. These nutritional characteristics highlight its potential as a fortifying agent in the development of highly nutritious functional food products.

Another significant trend in contemporary food technology is the application of nanotechnologies. This approach is widely recognized as a positive and rapidly expanding innovation [14, 15]. The novel and unique functional properties of nanomaterials drive this growth, impacting all stages of food production–from enhancing sensory qualities during product development to improving the safety and stability of foods during transportation and storage. Particularly noteworthy are metal and metal oxide nanoparticles, which exhibit substantial potential both in the creation of innovative food products and in food packaging technologies. Previous studies [16, 17, 18] have demonstrated the feasibility of using iron oxide nanoparticles (IONPs) as a food additive, imparting specific functional and technological properties. Incorporation of IONPs into food formulations, particularly in bakery products, has been shown to enhance surface activity of structural builders, increase effective viscosity, improve water-holding and water-binding capacities, and provide antioxidant and emulsifying effects.

In recent years, complex food additives (CFAs) have shown promising potential in food production due to their unique properties and broad nutritional profile. The effectiveness of ultrafine complex food additives in innovative food technologies is determined by their functional and technological characteristics, which result from their rich chemical composition, high dispersity, surface activity, structure, and specific physicochemical parameters [17, 18, 19, 20].

In a number of studies, the authors studied examined the impact of dried kelp powder on the baking qualities of wheat flour and dough. It was found that incorporating kelp powder into wheat flour enhances gluten strength, with higher dosages further reinforcing this effect. Additionally, the inclusion of kelp powder in the dough significantly increased its acidity and moisture content, proportional to the amount added. Overall, the results suggest that kelp powder can improve the nutritional profile of flour-based products without compromising their baking quality.

Further analysis revealed that increasing the concentration of kelp powder led to a reduction in gluten content, while simultaneously enhancing the dough's rheological properties, particularly its elasticity. These improvements are attributed to the high water-binding capacity of pectic substances present in kelp.

Optimal production conditions for new flour-based confectionery items with improved taste and consumer appeal were also identified. The ideal formulation includes a 5% substitution of flour with kelp powder [21, 22, 23, 24].

We have proposed a combined food additive (CFA) based on brown seaweed Laminaria sp. and iron oxide nanoparticles (FeO× Fe2O3 NPs), developed using an innovative technology [25]. This additive is a high-dispersity brown powder with a particle size of approximately 0.2 mm.

The first component of the additive, brown seaweed Laminaria, is a unique natural source of macro- and microelements, proteins, vitamins, and other biologically active substances [9, 26], significantly enhancing the nutritional profile of food products.

The second component, FeO×Fe2O3 nanoparticles, is a uniform, fine-dispersed dark brown powder with a particle size of 70–80 nm, and no taste or odor. It has a spinel structure, with Fe^{2+} and Fe^{3+} cations occupying the lattice sites, featuring free 3d orbitals and playing a role in structural formation. These nanoparticles possess a chemically active surface layer, are characterized by cluster affinity, amphiphilicity, and a sufficiently high ζ-potential (33–44 mV). FeO× Fe2O3 NPs adjust the surface activity of structuring agents and affect the effective viscosity of colloidal-dispersed systems, contributing to structure formation and the development of a stable food matrix on both micro and macro levels [11, 16, 18, 25].

Moreover, the iron-containing component of the CFA demonstrates antioxidant properties due to the reducing action of Fe^{2+} and exhibits bacteriostatic effects, which slow down oxidative and microbial spoilage in food products. These nanoparticles can partially dissolve in the gastrointestinal tract, enhancing the biological value of the additive by increasing the availability of iron [26, 27, 28, 29].

The iron-containing component maintains stable physicochemical properties across the full temperature and pH range used in food processing. It offers a wide range of functional and technological properties, including structuring, stabilizing, sorptive, hydrating, water- and fat-binding, water- and fat-holding, and fat-emulsifying abilities. In other words, it has high functional and technological potential for use in food products [11, 27, 28, 29].

Thus, the complex food additive based on Laminaria sp. and FeO×Fe2O3 nanoparticles holds great promise for application in various food items, particularly in the development of bakery and culinary products with improved consumer properties.

An example of realizing the functional and technological benefits of this seaweed-iron additive (SIA) is the proposed technology for cupcakes enriched with this complex, combined additive.

The purpose and tasks of the research. Improving the technology of cupcakes by introducing into the recipe a food additive based on brown algae kelp (Laminaria sp.) and iron oxide nanoparticles (FeO×Fe2O3 NPs), obtained using innovative technology. o achieve the set goal, the following aspects were determined:

1. the optimal amount of food additive to improve the functional and technological properties of the dough and increase the nutritional and biological value of the finished products;
2. the effect of the combined food additive on the properties of gluten;
3. dough development and gas formation;
4. the effect of the combined food additive on the structural and mechanical properties of the dough;
5. the effect of the combined food additive on the physicochemical and organoleptic quality indicators of cupcakes.

Research materials and methods

In the production of cupcakes, the combined food additive was added in quantities of 0.5, 1.0 and 1.5% of the flour weight. The physical and textural characteristics of the dough and finished cupcakes were assessed using standard methods. A sensory analysis of the cupcakes enriched with the CFA was carried out to compare them with the classic recipe.

To create model samples of cupcakes, the methodology described in [30, 31] was used. The development process included technological analyses with sensory and analytical evaluation. The recipes of experimental cupcake samples using a food additive based on brown algae kelp (Laminaria sp.) and iron oxide nanoparticles (FeO×Fe2O3NPs) in the amount of 0.5%, 1.0% and 1.5% by weight of the flour mixture in powder form are given in Table 1.

The main raw ingredients of the experimental cupcakes samples were as follows: premium wheat flour (PWG), Enlil milling complex, Ukraine; medium rye flour (MRF), LLC "August-Kiy", Ukraine; combined food additive, LLC "NAUTECH PLUS", Ukraine; refined sunflower oil, TM "Oliwia", Ukraine; liquid pasteurized egg melange, TM "Ovostar", Ukraine; baking powder, TM "Eco", Ukraine; dark cocoa powder (20–22 %), TM "DeZaan", Netherlands; ground cinnamon, Sri Lanka; white sugar "Shchedra Torbinka", Ukraine. Table 1 presents the recipe compositions of the experimental cupcakes' samples.

To make cupcakes, let's use the classic cupcake production technology (Fig. 1), which is described in.

The basic scheme for cupcakes production includes the sifting of dry ingredients, mixing with liquid ingredients, placing the batter into molds, baking, and cooling. Specifically, premium wheat flour (PWG), the combined food additive, medium rye flour (MRF), cocoa powder, and ground cinnamon are sifted, followed by the addition of baking powder and the combined food additive. These ingredients are mixed for τ=(1...2) min using a hand mixer (Kenwood HMP10.000WH, Reading, UK) at a speed of n=160 rpm.

Refined sunflower oil is combined with liquid pasteurized egg melange, sugar is added, and the mixture is stirred for τ=(1...2) minutes at a speed of n=160 rpm. The liquid and dry mixtures are then combined, and the dough is kneaded for τ=(2.5...3.0) minutes at a speed of n = 350 rpm.

The prepared dough is poured into molds, filling them to 2/3 of their volume, and baked in a preheated electric baking cabinet (SHPE-1, Ukraine) for τ=(20...25) minutes at a temperature of t=(180...200)°C. After baking, the cupcakes are cooled in the molds to a temperature of 20...25°C and then removed.

After 60 minutes of cooling, the cupcakes are stored in airtight plastic bags to prevent moisture loss. The experimental cupcake samples (1–BC, 2–B1, 3–B2, 4–B3) were analyzed using physicochemical methods; nutritional characteristics and sensory indicators were also evaluated. Additionally, a texture profile analysis (TPA) was conducted.

Table 1 – **Recipe compositions of cupcake prototypes**

Name of raw material	Net weight, g/100.0 g of product				
	Dry matter (DM), g	Sample 1 – control	Sample 2 – with 0.5 % combined food additive	Sample 3 – with 1.0 % combined food additive	Sample 4 – with 1.5 % combined food additive
Premium wheat flour (PWG)	86–87 %	41.34±1.50	38.79±1.50	36.25±1.50	33.70±1.50
Combined food additive (CFA)	99,8 %	–	0.25±0.15	0.51±0.15	0.76±0.15
Medium rye flour (MRF)	85–86 %	9.57±0.95	11.82±0.95	14.15±0.95	16.45±0.95
White sugar	99.8–100 %	45.02±1.65	45.02±1.65	45.02±1.65	45.02±1.65
Refined sunflower oil	99.8–100 %	5.60±0.20	5.60±0.20	5.60±0.20	5.60±0.20
Liquid egg melange	26–27 %	1.89±0.15	1.89±0.15	1.89±0.15	1.89±0.15
Baking powder	99.8–100 %	0.15±0.01	0.15±0.01	0.15±0.01	0.15±0.01
Cocoa powder	90–95 %	1.52±0.10	1.52±0.10	1.52±0.10	1.52±0.10
Ground cinnamon	90–95 %	0.31±0.02	0.31±0.02	0.31±0.02	0.31±0.02
Total		106.30±1.5	106.30±1.5	106.30±1.5	106.30±1.5
Final product		100.00±1.1	104.70±1.1	105.10±1.1	105.20±1.1

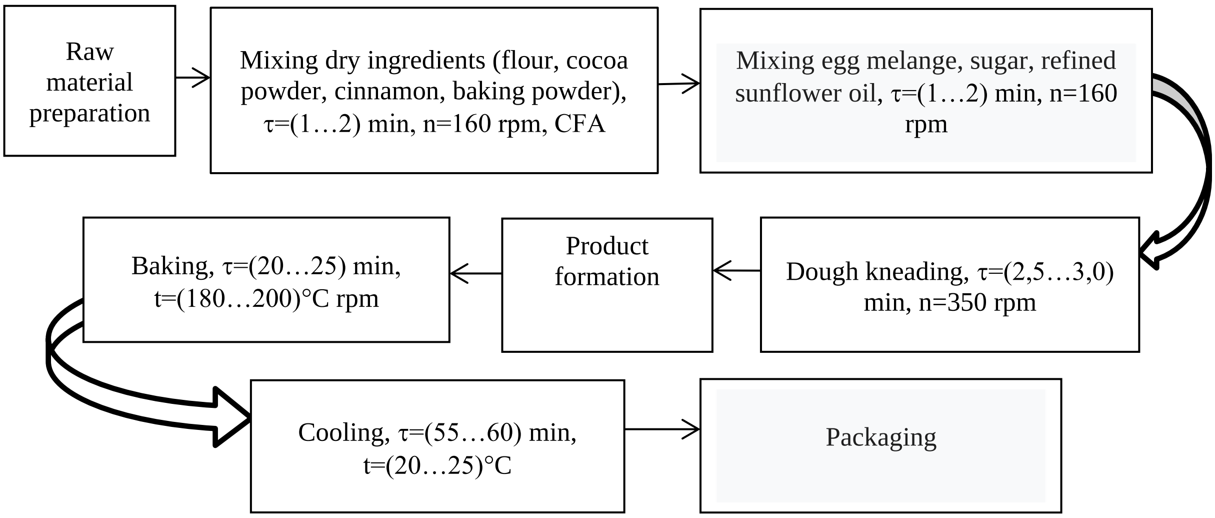

Fig. 1. Scheme of production of cupcakes

Physical characteristics

Dough Characterization

The influence of the combined food additive on gluten properties was evaluated by measuring the quantity of raw gluten, as well as its compressibility and extensibility, following the standardized procedures described by Drobot (2015). The dough's titratable acidity was analyzed using a volumetric titration method, employing 0.1 M sodium hydroxide as the titrant and phenolphthalein as the indicator. The acidity was reported in Neumann degrees. Two acidity levels were recorded: the initial acidity, measured immediately after dough preparation, and the final acidity, determined at the end of the fermentation process.

Dough Development and Gas Production

The dough development process and gas production were analyzed using using the Alveolab alveograph (CHOPIN Technologies, France) (ISO:27971) [32].

Based on real-time curves of dough development and gas release, the following parameters were quantified: total carbon dioxide volume released (Vt, mL), maximum dough height (Hm, mm), final dough height at the end of the test (h, mm), percentage drop in dough development ((Hm–h)/Hm, %), and the time to reach maximum dough height (T1, min). The dough's specific volume was assessed using data on its initial volume and the changes observed during fermentation, following the method by Drobot (2015). For this test, a 50 g dough sample was placed in a 250 mL cylinder and incubated in a thermostat at 30°C. Dough spreadability was evaluated by tracking the change in diameter of a 100 g dough ball over a 180-minute fermentation period at 30°C (Drobot, 2015). Yield stress (Pa) was calculated using penetration depth measurements obtained with a Labor penetrometer (LABOR machine s.r.o., Czech Republic).

The *adhesive strength of the dough* (to steel) in kPa was determined using the texture analyzer "Structurometer ST-1M" (Laboratory Equipment, Ukraine). The method is based on applying a load to a dough sample using a disk for a certain period of time, during which the deformation (h_e, mm) does not exceed a specified value. After that, the detachment force (F_det, N) of the disk from the tested mass is measured, and the adhesive strength in kPa is calculated as the ratio of the detachment force to the disk area. The study of the adhesive properties of the dough was carried out between solid steel surfaces (Lazorenko and Omelianchenko, 2013) [33, 34, 35].

The *dough cohesiveness* (CG, arbitrary units) was determined using the texture analyzer TA.XTplus (Stable Micro Systems, UK) according to the methodology described in studies (1, 2, 3), with a cylindrical probe P/36R (d = 36 mm), a polymer container (d = 50 mm, h = 40 mm), and the following test parameters: probe insertion speed – 1.0 mm/s, insertion depth – 20 mm, holding time at the lowest point – 1 s, return speed – 1.0 mm/s, number of repetitions – 3 measurements for each sample.

After kneading, the dough was allowed to rest for 5 minutes at a temperature of 22±2°C to stabilize its structure. Then, 100±2 g of dough was placed into each container, ensuring the top surface was leveled. Dough cohesiveness (CG, arbitrary units) was calculated using formula (1):

$$КГ = \frac{A_2}{A_1} \quad (1)$$

where A_1– area under the curve of the first cycle (penetration), mm²;

A_2 – area under the curve of the second cycle (probe detachment from the dough), mm² [33, 34, 35].

Bake loss and height cupcakes. Baking loss, the weight loss of the cupcakes during baking, %, was determined by the gravimetric method and calculated by the formula (1) :

$$Bakel\ loss(g/100g) = \frac{(Batter\ weight - Cupcake\ weight)g}{Batter\ weight(g)} \times 100 \quad (2)$$

The baking experiment was repeated twice on two different days.

The height of the cupcakes was determined using an electronic digital caliper Digital Caliper (Ripley, USA).

Texture Profile Analysis (TPA). The crumb texture of the cupcake samples was evaluated using a texture analyzer TA.HDplusC Texture Analyser (Stable Microsystems, Surrey, UK), equipped with a cylindrical probe (P/25) with a compression degree of 25% at a speed of 1 mm/s, according to the Bourne method [33]. They selected 10 different parts for 3 different batches. The samples were cut from the center of the product into squares of 2.0×2.0 cm and kept for 2.0 h at (20±2)ºC and relative humidity of 45-50% for standardization of water absorption before the dough. The texture characteristics were determined: hardness, adhesiveness, cohesiveness, elasticity (stability), chewing, elasticity according to the methodology [36, 37, 38].

To characterize the crumb structure, a classical method using the Zhuravlev device UOP-01 ("Termolab", Ukraine) and a digital image processing method were applied. The latter involved the use of an HP ScanJet Pro 4500 fn1 flatbed scanner ("Hewlett Packard", USA) with a resolution of 300 dpi, according to the methodology [2, 12]. Images of the crumb slice of the cupcake sample were analyzed using the Image J software, developed by the National Institutes of Health [39]. The software processes the digital image of the crumb slice by converting the color to grayscale and segmenting the regions into dark areas (gas phase – pores) and light areas (solid phase – solid particles). Next, the software determines the number and perimeter of the pores and calculates the area of spheres equivalent to each pore based on these parameters. Since the scanning resolution is known, it is easy to convert pixel dimensions to conventional units of porosity measurement, namely: Pore area (total pore area in cm² / total cupcake sample area in cm²). Pore density (number of pores per cm²). Specific pore perimeter (sum of all pore perimeters in mm / total cupcake sample area in cm²).

Sensorial evaluation

The sensory tests were hedonic and conducted by a tasting panel consisting of 15 experienced tasters who had more than two years of experience in sensory analysis of various food products, following ISO 8586:2012 and ISO 11132:2012 standards. The evaluation parameters were assessed according to the Score Card method and the recommendations of Grasso S. et al. [31]. The experimental cupcakes samples were prepared on the day of testing and stored in airtight polyethylene bags until evaluation. Drinking water was offered for mouth rinsing before each subsequent test, and the delay time between samples (to assess the aftereffect) was 30 seconds. The evaluated attributes were as follows: appearance: Related to visual perception (surface color, crumb color, crumb porosity); texture: associated with mechanoreceptor sensations (crumb consistency, elasticity); aroma: related to the sense of smell (egg, chocolate, fruity-citrus, cinnamon, sweet-spicy, nutty, spicy, pleasant marine); taste and flavor: taste – associated with taste perception, flavor – associated with taste, smell, and texture (egg, bitter, burnt, chocolate, fruity-citrus, sweet-spicy, sweet, salty-marine); mouthfeel: related to stickiness and dryness in the mouth; aftertaste: associated with the taste sensations of the cupcakes perceived immediately after removing the product from the mouth (salty-marine aftertaste). The values obtained from the participants were assessed using one-way analysis of variance (ANOVA) and expressed as the average value for each parameter on a 5-point scale.

Physicochemical analyses

Physicochemical analyses were conducted for the experimental cupcake samples (Samples 1...4). The moisture, protein, fat, and ash content were determined using the methods of the Association of Official Analytical Chemists (AOAC, 2002) [40]. The total carbohydrate content was calculated by the difference method: 100−(moisture+ash+protein+fat). The energy value of the cupcakes (kcal/100 g) was calculated using the computational method [41].

Statistical analysis

For the statistical analysis were used a one-factor analysis (ANOVA) for a series of parallel measurements at least 3. The data in tables represents the mean ± standard deviation. Value of $p<0.05$ was considered statistically significant. The Tukey's HSD test was used to determine significant difference between means. Basic statistic and ANOVA were performed using the statistical software package Minitab ver. 18.1 (Minitab Inc., USA).

Results of the research and their discussion

Dough Characteristics. One of the key technological factors influencing the quality of rye-wheat cupcekes is the gluten properties of wheat flour. Upon hydration, gluten proteins—primarily glutenin and gliadin–interact to form a viscoelastic, three-dimensional network (Wrigley et al., 2006). The quantity and functional quality of gluten significantly affect dough texture and its ability to retain carbon dioxide. The impact of the combined food additive on gluten characteristics is summairezed in Table.2.

Table 2 – Gluten characteristics

Indicator	Dough sample			
	BC	B1	B2	B3
Wet gluten, %	26.8 ±0.3^{a}	27.9±0.5^{b}	28.6±0.4^{bc}	29.4±0.3^{c}
Compressibility, CU	78±2^{a}	73±1^{b}	70±2^{c}	66±2^{cd}
Extensibility, cm	15.0±0.6^{a}	14.0±0.5^{b}	12.5±0.3^{c}	11.0±0.4^{d}

a-d Means within the same row with different superscripts are significantly different at $p<0.05$

Analysis of the data presented in Table 2 confirms an enhancement in both the quantity and quality of gluten upon the incorporation of the combined food additive (CFA) into the cupcakes formulation, regardless of the concentration used. Specifically, there is a statistically significant increase in wet gluten content ranging from 4% to 10% ($p<0.05$). Additionally, the inclusion of CFA resulted in a 7–18% improvement in compressibility and a 7–36% reduction in gluten extensibility across samples B1 to B3.

These effects are likely attributable to the capacity of iron oxide nanoparticles within the additive to form protein-ligand complexes (Tsykhanovska et al., 2022c, 2023), particularly with gluten proteins (Tsykhanovska et al., 2018). A contributing factor may also be the interaction between wheat flour proteins and algal polysaccharides (Fu et al., 2021). Overall, it is reasonable to suggest that the combined additive facilitates the formation of bonds between protein and carbohydrate molecules, thereby contributing to the development of a more structurally stable matrix.

Furthermore, the positive impact of CFA on the physicochemical and rheological properties of rye-wheat dough was confirmed through rheofermentometric analysis. The additive significantly enhanced the gas-forming capacity of the dough, as demonstrated. in Figure 2

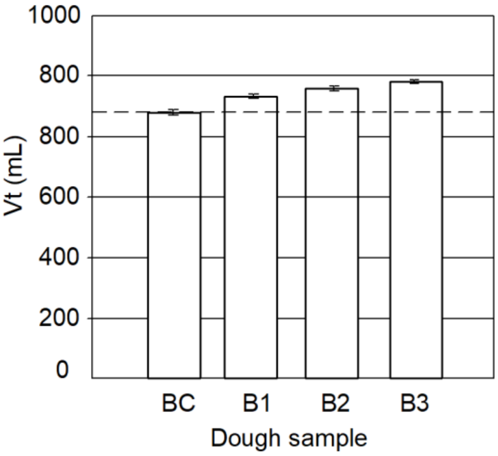

Fig.2. Total amount of CO_2 produced in the dough samples

The analysis of the gas release curve during dough fermentation indicates a 6–11% ($p<0.05$) increase in carbon dioxide production in the experimental samples compared to the control, depending on the additive concentration. This improvement in gas formation is likely associated with combined leavening: mechanical leavening — the cake batter formulation includes substances capable of forming an emulsion or foam structure (lecithin and egg white from melange), and chemical leavening — the dough is leavened by carbon dioxide and ammonia released during the decomposition of chemical leavening agents ($(NH_4)_2CO_3$, baking soda $NaHCO_3$, and Na_2CO_3, which decomposes into CO_2), especially during heating.

As shown in the dough development time curve (Figure 3), an increase in the additive concentration in the cupcakes formulation correlates with a reduction in the time required to reach maximum dough development (T1). Additionally, the maximum dough height (Hm) and the dough height at the end of fermentation (h) were 8.5–19.0% and 10.5–26.0%

higher, respectively, than those in the control sample (Figure 4).

A reduction in the decline of dough development, expressed as (Hm–h)/Hm, was also observed in samples B1–B3 with increasing levels of the additive. These results are attributed both to enhanced gas retention capacity – due to the strengthening of the gluten network – and to accelerated gas formation in the dough, as previously discussed.

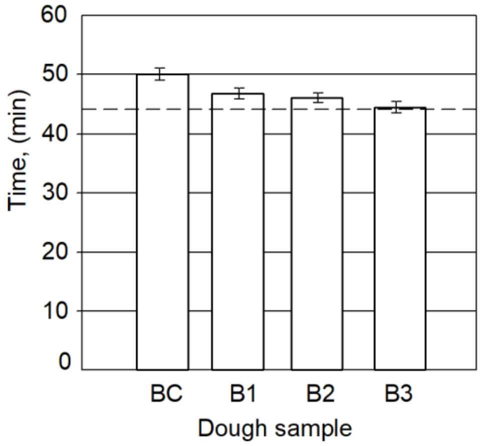

Fig.3. Time to maximum dough development T1

The incorporation of the combined food additive (CFA) into the rye-wheat dough formulation results in a slight reduction in both initial and final acidity levels by 0.1–0.3 degrees, which may be attributed to the amphoteric nature of iron nanoparticles (Table 3).

However, the observed reduction in acidity was not statistically significant ($p>0.05$), indicating the need for further investigation. Increasing the concentration of the additive from sample B1 to B3 led to notable changes in certain physical properties of the dough. As presented in Table 3, the spreadability index of rye-wheat dough decreased by 11–13% ($p<0.05$), likely due to the reinforcement of the wheat gluten network and enhanced water-retention capacity of the dough.

Furthermore, the specific volume of the dough increased by 6–13% ($p<0.05$), supporting the findings illustrated in Figures 3 and 4. This increase is attributed to improved gas retention resulting from gluten strengthening.

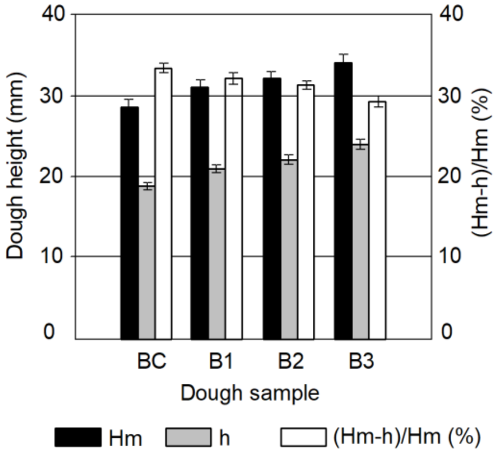

Fig. 4. Magnitudes of maximum dough height Hm, dough height h at the end of the measurement after 3 hour and decline in dough development (Hm-h)/Hm of the dough samples

The analysis of rheological properties also revealed a 6–12% ($p<0.05$) increase in yield stress in the dough samples containing the additive. This reflects the water-binding capabilities of the additive's components. Correspondingly, a reduction in adhesion strength to steel (used as a research-grade platinum analog) by 15–35% ($p<0.05$) was observed. These results align with previous studies (Różyło et al., 2017; Tsykhanovska et al., 2022a).

Sensorial evaluation. In order to substantiate the optimal amount of the combined food additive in the recipe, a sensory analysis of the experimental cupcakes samples was conducted, which is presented in Table 4.

Established (Table 4) that with partial replacement of wheat flour for the food supplement CFA in the amount of 0.5%; 1.0%; 1.5% of the weight of the flour brown the surface of the surface and the crumb (compared to the control) becomes somewhat saturated due to the pigment of fucoxatin brown color supplement combined food additive. Compared to the control improves the state of the crumb: consistency – (1.05–1.06) times, elasticity – (1.06–1.07) times and porosity – in (1.05–1.06) times, which is associated with structure-forming, water-holding, fat-holding, stabs. The combined food additive, which is consistent with the data of Table 5.

Table 3 – Physicochemical and rheological characteristics of rye-wheat dough

Indicator	Dough sample			
	BC	B1	B2	B3
Initial acidity, grades	6.9 ± 0.1^{a}	6.8 ± 0.3^{a}	6.7 ± 0.3^{a}	6.6 ± 0.2^{a}
Final acidity, grades	8.0 ± 0.4^{a}	7.9 ± 0.3^{a}	7.9 ± 0.2^{a}	7.8 ± 0.3^{a}
Spreading, mm	88.0 ± 1.2^{a}	84.0 ± 1.1^{b}	81.0 ± 1.0^{c}	78.0 ± 1.0^{d}
Specific volume, ml/g	2.48 ± 0.1^{a}	2.64 ± 0.11^{b}	2.72 ± 0.11^{c}	2.80 ± 0.12^{d}
Yield stress, Pa	452 ± 8^{a}	478 ± 9^{b}	492 ± 9^{c}	508 ± 7^{d}
Adhesive strength*, kPa	2.3 ± 0.1^{a}	2.0 ± 0.2^{b}	1.8 ± 0.2^{c}	1.7 ± 0.2^{cd}

a-d Means within the same row with different superscripts are significantly different at $p<0.05$.

*The value is determined using steel plates

Table 4 – Sensory analysis of cupcake samples

Parameters	**Descriptor**	**Intensity of characteristics of cupcake samples, score**				
		Standard	**Sample 1 – control**	**Sample 2**	**Sample 3**	**Sample 4**
Appearance	Surface color	5.0	4.90±0.06^{a}	4.96±0.06^{a}	5.00±0.07^{bc}	4.98±0.07^{c}
	Crumb color	5.0	4.92±0.06^{a}	4.94±0.06^{a}	5.00±0.0^{b}	4.96±0.06^{a}
	Crumb porosity	5.0	4.70±0.04^{a}	4.95±0.06^{b}	5.00±0.07^{cd}	5.00±0.07^{d}
	Crumb consistency	5.0	4,68±0,04^{a}	4.99±0.07^{b}	5.00±0.07^{cd}	5.00±0.07^{d}
	Crumb elasticity	5.0	4.67±0.04^{a}	4.99±0.07^{b}	5.00±0.07^{cd}	5.00±0.07^{d}
Aroma	Egg	1.0	1.00±0.01^{a}	0.760±0.008^{b}	0.740±0.008^{c}	0.720±0.007^{d}
	Chocolate	2.0	1.89±0.08^{a}	1.72±0.06^{b}	1.69±0.05^{c}	1.67±0.05^{d}
	Fruity-citrus	2.0	1.94±0.09^{a}	1.86±0.08^{bc}	1.81±0.07^{c}	1.78±0.07^{d}
	Cinnamon	2.0	2.21±0.06^{a}	2.10±0.06^{bc}	2.12±0.06^{c}	2.16±0.06^{a}
	Sweet	3.0	3.20±0.06^{a}	3.26±0.07^{bc}	3.29±0.08^{cd}	3.32±0.08^{d}
	Spicy	2.0	0.00	2.46±0.06^{a}	2.68±0.06^{b}	2.94±0.06^{c}
	Walnut	2.0	0.720±0.007^{a}	1.360±0.009^{b}	1.420±0.009^{c}	1.480±0.009^{d}
	Pleasant sea	5.0	4.80±0.05^{a}	4.94±0.06^{b}	5.00±0.07^{c}	4.96±0.06^{d}
Taste and Flavor	Egg	1.0	1.24±0.05^{a}	0.56±0.02^{b}	0.54±0.02^{c}	0.52±0.02^{d}
	Chocolate	2.0	1.99±0.08^{a}	1.75±0.06^{b}	1.73±0.05^{c}	1.57±0.05^{d}
	Spicy	2.0	0.00	2.37±0.06^{a}	2.58±0.06^{b}	2.84±0.06^{c}
	Bitter	1.0	0.00	0.00	0.00	0.32±0.01^{a}
	Brackish	1.0	0.00	0.00	0.0	0.140±0.005^{a}
	Fruity-citrus	2.0	1.92±0.09^{a}	1.86±0.08^{bc}	1.84±0.08^{c}	1.80±0.07^{d}
	Sweet	3.0	3.52±0.15^{a}	3.66±0.15^{b}	3.72±0.15^{c}	3.75±0.15^{d}
	Sweet-spicy	3.0	3.24±0.14^{a}	3.68±0.15^{b}	3.76±0.16^{c}	3.79±0.16^{d}
Mouthfeel	Stickiness	3.0	3.68±0.15^{a}	2.82±0.11^{b}	2.72±0.10^{c}	2.69±0.10^{d}
	Dryness	1.0	1.68±0.07^{a}	3.64±0.12^{b}	3.78±0.13^{c}	3.82±0.14^{d}
Aftertaste	Brackish-marine	1.0	0.36±0.01^{a}	1.22±0.01^{b}	1.30±0.01^{c}	1.36±0.01^{d}

Table 5 – Physical characteristics of cupcake samples, α≤0,05

Parameter	**Cupcake samples**			
	Sample 1 – control	**Sample 2**	**Sample 3**	**Sample 4**
Product weight loss during baking (g/100 g)	11.2±0.50^{a}	11.30±0.50^{a}	11.28±0.47^{a}	11.27±0.47^{a}
Product height (cm)	3.78±0.14^{a}	3.99±0.15^{a}	4.13±0.18^{a}	4.14±0.18^{a}
Hardness (g)	178.14±2.42^{a}	185.21±2.54^{ac}	188.44±2.58^{ab}	191.18±2.62^{bc}
Elasticity (%)	57.12±1.16^{a}	56.88±1.14^{a}	56.72±1.14^{a}	56.61±1.13^{a}
Adhesiveness (g/s)	76.53±2.02^{a}	78.03±2.02^{b}	78.69±2.04^{c}	78.82±2.06^{d}
Cohesion, g	0.243±0.001^{a}	0.248±0.001^{cd}	0.254±0.001^{bd}	0.257±0.001^{d}
Chewing, %	74.24±1.98^{a}	75.13±1.98^{b}	76.38±1.99^{cd}	76.94±1.99^{d}
Elasticity (resistance), g	0.066±0.008^{a}	0.069±0.009^{a}	0.071±0.010^{a}	0.072±0.011^{a}
Porosity density (number of pores/cm^{2})	1.92±0.08^{a}	2.78±0.11^{b}	4.76±0.19^{c}	5.64±0.21^{d}
Specific pore perimeter (mm/cm^{2})	12.02±0.56^{a}	9.09±0.44^{b}	6.11±0.28^{c}	5.03±0.21^{d}
Porosity area (cm^{2}/cm^{2})	0.0150±0.0005^{a}	0.0160±0.0005^{bc}	0.0170±0.0005^{cd}	0.0180±0.0005^{d}

Analysis of the data presented in Table 5 indicates that changes in cupcakes height, baking coefficient, and product yield following the incorporation of combined food additive at concentrations of 0.5%, 1.0%, and 1.5% (based on wheat flour weight) occur at a slower rate compared to the control. This effect is attributed to the structuring and stabilizing properties of the fine-dispersed combined food additive particles [42, 43].

Furthermore, the inclusion of the complex CFA enhances wheat gluten strength, likely due to electrostatic interactions between Fe_2O_3 nanoparticles and gluten proteins. This interaction improves the viscoelastic characteristics of the dough, enabling more effective entrapment of air bubbles during mixing and retention of CO^2 released by leavening agents [11].

Experimental samples enriched with combined food additive exhibited an increase in hardness by 4.0–7.3% relative to the control. This may be attributed to both the higher protein content and the Maillard reaction, which promotes polymerization and interaction between biopolymer molecules–proteins and polysaccharides–thereby strengthening the dough structure. In addition, from the analysis of the distribution of air bubbles by crumb volume (Fig. 5), it follows that the experimental cupcakes samples enriched with combined food additive have better crumb aeration compared to the control.

Nevertheless, in samples 2, 3, and 4, the concentration of combined food additive remains below the threshold associated with undesirable hardness, as defined by Regulation (EC) No 1924/2006 of the European Parliament and the Council. This is further supported by the high carbohydrate content of the product. Similar findings in other studies associate increased hardness with higher protein levels introduced through protein-rich ingredients [9, 15, 29], as well as elevated fiber content resulting from the use of raw plant-based materials [2, 33, 34].

A reduction in hardness by 4.0–7.3% and an increase in elasticity by 0.42±0.89% observed in sample 1 are associated with elevated water activity, which promotes the role of water molecules as plasticizers. In this context, water acts as a cross-linking inhibitor for biopolymer molecules (sugars and proteins). Notably, the addition of combined food additive at levels of 0.5%, 1.0%, and 1.5% leads to a slight decrease in elasticity in the final product, likely due to the complex-forming behavior of iron-containing nanoparticles in the combined food additive additive [16-18, 28, 29]. Nevertheless, cupcake samples 2 through 4 exhibit a light and adequately elastic crumb texture.

Previous studies have also reported reduced elasticity in baked goods (e.g., muffins, cupcakes) with increasing protein content due to the incorporation of plant-based ingredients [11, 17, 29]. The lower elasticity observed in samples 2–4 compared to the control (sample 1) correlates with a notable increase in pore density (Table 5), which rose by 1.45–2.94 times. Simultaneously, combined food additive addition resulted in a reduction in the specific pore perimeter by 1.32–2.39 times and an increase in pore area by 6.7–20.0%.

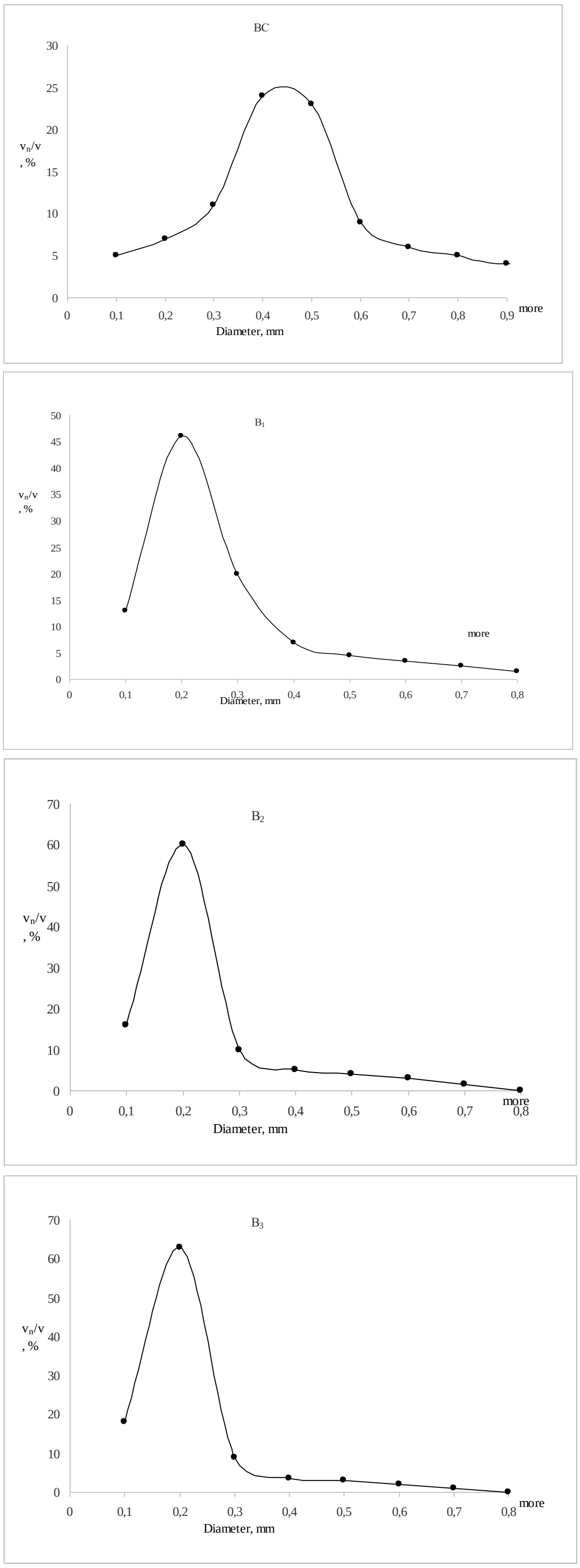

Fig.5. Pore size distribution in experimental cupcakes samples

This effect is attributed to the stabilizing and complex-forming capabilities of the combined food additive additive, whose iron oxide nanoparticles inhibit the coalescence and collapse of air bubbles, thereby maintaining a more dispersed pore structure [11].

Consequently, although cupcakes enriched with CFA exhibit slightly reduced crumb elasticity compared to the control, this does not negatively impact sensory attributes. Combined food additive addition at 0.5%, 1.0%, and 1.5% also led to a 1.96–3.0% increase in adhesiveness, due to enhanced moisture migration and the structuring properties of iron-containing nanoparticles, which intensify with higher combined food additive content.

Cohesiveness in samples 2–4 increased by 2.06–5.76%, likely resulting from the formation of intermolecular cross-links among proteins, carbohydrates, and lipids, which contribute to a more stable three-dimensional matrix. The combined increases in adhesiveness and cohesiveness led to a 1.21–3.62% rise in chewiness. Moreover, the resilience (springiness) of the cupcakes improved by 6.06–9.1%, attributed to the structural reinforcement facilitated by electrostatic interactions between Fe_2O_3 nanoparticles and biopolymer molecules, involving both hydrophobic and polar regions (ionogenic and ionized groups) [16-18, 28, 29].

It is important to highlight that the optimal combined food additive concentration was determined to be 1.0%. Increasing the content to 1.5% led to only marginal additional changes in physical properties. Based on physicochemical and sensory evaluations, a combined food additive mass fraction of 1.0% (relative to wheat flour) is recommended. Future studies will explore additional flour-based products incorporating other novel additives, with the goal of expanding the functional and technological applications of such ingredients while enhancing the nutritional value of the final products.

Physicochemical and nutritional analyses. The analysis of the chemical composition of the cupcakes (Table 6) shows the improvement of the biological and nutritional value of the finished product compared to control.

The addition of CFA to cupcakes enhances their nutritional value compared to the control sample. Specifically, the product is enriched with trace elements such as iodine (I), zinc (Zn), manganese (Mn), selenium (Se), cobalt (Co), bromine (Br), and vitamins A, C, and B8. Furthermore, increases are observed in the following components: iron (Fe) by 1.06 times, copper (Cu) by 1.1 times; macroelements by (2.51±0.71)%; vitamins by (1.42±0.32)%; ash by 1.41 times; protein by 1.05 times; carbohydrates by (2.55±0.45)%; fat by (0.010±0.001)%; and the caloric content of the final product by 8.18 kcal. These improvements are attributed to the rich chemical composition of the complex food additive (Biancarosa, I.). The optimal amount of CFA is 1.0% of the wheat flour weight, as this concentration does not negatively affect the texture of the cupcakes (Table 7)

Table 6 – Chemical composition, caloric content of prototypes of cupcakes, $\alpha \leq 0,05$

Nutrient	Cupcake samples	
	Control - BC	**Sample 3 - B2**
Macronutrients, g/100 g dry matter		
Water	47.0±0.4	48.0±0.4
Proteins	7.5±0.2	7.9±0.2
Fats	0.90±0.01	0.91±0.01
Sugars	1.05±0.01	1.10±0.01
Starch	19.2±0.3	20.6±0.3
Fiber	1.90±0.01	1.96±0.01
Organic acids	0.38±0.01	0.40±0.01
Ash	2.10±0.01	2.96±0.01
Mineral substances, mg/100 g dry matter		
Na	343.51±2.28	349.26±2.28
K	98.62±1.14	101.09±1.14
Ca	28.12±1.16	29.65±1.19
Mg	27.46±1.04	28.04±1.04
P	82.08±2.23	82.66±2.23
I	ND	0.02±0.1
Fe	3.22±0.02	3.41±0.02
S	ND	5.02±0.03
Zn	ND	0.05±0.01
Mn	ND	0.002±0.0
Cu	0.0010±0.0	0.0011±0.0
Se	ND	0.004±0.0
Co	ND	0.005±0.0
Br	ND	0.01±0.0
Water- and fat-soluble vitamins, mg/100 g dry matter		
A	ND	0.96±0.02
E	0.04±0.001	0.64±0.001
C	ND	0.85±0.02
B_1	0.17±0.01	0.19±0.01
B_2	0.06±0.001	0.08±0.001
B_3 (PP)	0.66±0.01	0.69±0.02
B_6	0.07±0.002	0.09±0.002
B_8	ND	1.21±0.02
B_9	8.56±0.04	8.68±0.04
B_{12}	0.002±0.0	0.003±0.0
Approximate calorie content, kcal/100 g	200.62±1.06	208.80±1.06

** The approximate calorie content and calories from protein were estimated using a calculation method based on the average values of proteins, fats, and carbohydrates in 100 g of the product.*

Table 7 analysis reveals that the changes in height, baking coefficient, and yield of cupcakes with CFA at concentrations of 0.5%, 1.0%, and 1.5% (based on wheat flour weight) progress more gradually compared to the control. This is attributed to the structuring and stabilizing effects of CFA fine-dispersed particles [40, 41].

Table 7 – Physical characteristics of cupcake samples, α≤0,05

Parameter	Cupcake samples			
	Sample 1 – control	**Sample 2**	**Sample 3**	**Sample 4**
Product weight loss during baking (g/100 g)	11.2 ± 0.50^{a}	11.30 ± 0.50^{a}	11.28 ± 0.47^{a}	11.27 ± 0.47^{a}
Baking coefficient (%)	9.8±0.4	6.1±0.4	3.7±0.4	2.5±0.4
Product height (cm)	3.78 ± 0.14^{a}	3.99 ± 0.15^{a}	4.13 ± 0.18^{a}	4.14 ± 0.18^{a}
Hardness (g)	178.14 ± 2.42^{a}	185.21 ± 2.54^{ac}	188.44 ± 2.58^{ab}	191.18 ± 2.62^{bc}
Elasticity (%)	57.12 ± 1.16^{a}	56.88 ± 1.14^{a}	56.72 ± 1.14^{a}	56.61 ± 1.13^{a}
Adhesiveness (g/s)	76.53 ± 2.02^{a}	78.03 ± 2.02^{b}	78.69 ± 2.04^{c}	78.82 ± 2.06^{d}
Cohesion, g	0.243 ± 0.001^{a}	0.248 ± 0.001^{cd}	0.254 ± 0.001^{bd}	0.257 ± 0.001^{d}
Chewing, %	74.24 ± 1.98^{a}	75.13 ± 1.98^{b}	76.38 ± 1.99^{cd}	76.94 ± 1.99^{d}
Elasticity (resistance), g	0.066 ± 0.008^{a}	0.069 ± 0.009^{a}	0.071 ± 0.010^{a}	0.072 ± 0.011^{a}
Porosity density (number of pores/cm^2)	1.92 ± 0.08^{a}	2.78 ± 0.11^{b}	4.76 ± 0.19^{c}	5.64 ± 0.21^{d}
Specific pore perimeter (mm/cm^2)	12.02 ± 0.56^{a}	9.09 ± 0.44^{b}	6.11 ± 0.28^{c}	5.03 ± 0.21^{d}
Porosity area (cm^2/cm^2)	0.0150 ± 0.0005^{a}	0.0160 ± 0.0005^{bc}	0.0170 ± 0.0005^{cd}	0.0180 ± 0.0005^{d}
Product output, %	118.4±1.1	122.4±1.1	124.1±1.1	125.7±1.1

Moreover, the inclusion of CFA strengthens wheat gluten through electrostatic interactions between Fe_3O_4 nanoparticles and gluten proteins. This enhances the dough's viscoelastic properties, improving its ability to retain air bubbles formed during mixing and CO^2 released by leavening agents [16]. The hardness of CFA-enriched samples increases by 4.0–7.3% compared to the control, due to a higher protein content and the Maillard reaction, which promotes polymerization and interactions among biopolymers (proteins and polysaccharides), thus reinforcing the structure.

However, in samples 2, 3, and 4, the level of CFA remains within acceptable limits, not exceeding hardness thresholds set by Regulation (EC) No 1924/2006 of the European Parliament and Council, especially considering the product's high carbohydrate content. Similar studies have also linked increased hardness to higher protein and fiber content when incorporating protein-rich or plant-based raw ingredients [16, 42].

In sample 1, a reduction in hardness by 4.0–7.3% and an increase in elasticity by (0.42±0.89)% are observed, likely due to higher water activity, where water molecules act as plasticizers, inhibiting cross-linking of biopolymers (sugars and proteins). Notably, introducing 0.5%, 1.0%, and 1.5% CFA results in a slight decrease in elasticity, attributed to the iron-containing nanoparticles' complex-forming effects [9, 31–33]. Still, experimental samples (2 to 4) maintain a sufficiently airy and elastic crumb structure.

As a result, cupcakes enriched with CFA exhibit slightly reduced crumb elasticity due to denser structure and larger pores, but without negatively affecting sensory perception. The addition of 0.5–1.5% CFA increases adhesiveness by 1.96–3.0%, likely due to improved product adhesion from the hydrating and structuring actions of iron-containing nanoparticles. This effect is also supported by internal moisture migration.

Cohesiveness rises by 2.06–5.76% in samples 2–4 compared to the control, due to cross-linking between proteins, carbohydrates, and lipids, forming a stable spatial matrix. Consequently, chewiness increases by 1.21–3.62%. CFA enrichment also enhances springiness (resilience) by 6.06–9.1%, attributed to strengthened and stabilized structure via electrostatic interactions between Fe_2O_3 nanoparticles and biopolymer macromolecules, involving both hydrophobic and polar groups [11, 16-18].

Approbation of research results. Research results can be implemented at food industry enterprises specializing in the production of flour-based confectionery products use a mixture of rye and wheat flour with the addition of food additives.

Conclusion

1. A combined food additive (CFA) was formulated using dry powders of iron oxide nanoparticles and *Laminaria sp* powder in a weight ratio of 15:85. This additive was developed as both a technological improver and a nutritional fortifier for incorporation into rye-wheat cupcakes.
2. The inclusion of CFA at concentrations of 0.5, 1.0%, 1.5% relative to flour weight (samples B1, B2, and B3) enhanced gluten quality. This was evidenced by a statistically significant increase in wet gluten content (4–10%), higher compressibility (7–18%), and reduced extensibility (7–36%) across the experimental cupcakes samples.

3. Gas release profiles during dough fermentation revealed a 6–11% ($p<0.05$) increase in carbon dioxide production in the CFA-enriched samples, which is probably related to combined loosening.

4. Dough development time curves demonstrated that increasing CFA content led to a reduction in the time required for maximum dough development. Additionally, the maximum dough height and the final height at the end of gas formation were elevated by 8.5–19.0% and 10.5–26.0%, respectively, compared to the control sample.

5. The optimal CFA concentration is 1.0%. At 1.5%, only minor changes in physical parameters occur compared to 1.0%. Therefore, based on physicochemical and sensory evaluations, 1.0% of wheat flour mass is considered the optimal dose.

6. Sensory Evaluation of Cupcakes with 1.0% CFA: Aroma and Flavor: Pleasant marine aroma with a subtle salty-sea taste. Appearance: Uniform shape with a domed, smooth surface free from cracks. Crumb Texture: Soft, elastic, resilient, non-sticky, and resistant to crumbling. Crumb Structure: Well-developed porosity with small, uniformly distributed, thin-walled air cells.

7. Enhancement of Chemical Composition and Nutritional Value: Chemical analysis of the experimental cupcake samples reveals a notable improvement in both biological and nutritional value compared to the control.

8. Nutritional Profile Enhancements: Microelement Enrichment: Iodine (I), Zinc (Zn), Manganese (Mn), Selenium (Se), Cobalt (Co), Bromine (Br). Vitamin Enrichment: Vitamins A, C, and B8. Increased Content of the Following Nutrients: Iron (Fe): Increased by 1.06 times; Copper (Cu): Increased by 1.1 times; Macroelements: Increased by (2.51±0.71)%; Vitamins: Increased by (1.42±0.32)%; Ash Content: Increased by 1.41 times; Carbohydrates: Increased by (2.55±0.45)%; Fat: Increased by (0.010±0.001)%; Caloric Value: Increased by 8.18 kcal

9. Future studies will explore other flour-based products incorporating various developed additives, aiming to broaden application potential, enhance dough functionality, and increase the nutritional value of finished products.

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ПОКРАЩЕННЯ СПОЖИВНИХ ВЛАСТИВОСТЕЙ КЕКСІВ, ЗБАГАЧЕНИХ ХАРЧОВОЮ ДОБАВКОЮ КОМБІНОВАНОГО СКЛАДУ

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Анотація. У дослідженні було оптимізовано рецептуру та вдосконалено технологію виготовлення борошняного кондитерського виробу – кексів, збагачених харчовою добавкою комбінованого складу на основі наночастинок оксидів заліза (НЧ FeO× Fe_2O_3) та ламінарії (Laminaria sp.), створеною за інноваційною технологією. Комбінована харчова добавка (CFA) була розроблена за допомогою сухих порошків наночастинок оксиду заліза та порошку Laminaria SP у співвідношенні ваги 15:85. Ця добавка була розроблена як технологічного імпровізованого, так і харчовим фортифікатором для включення в кекси з жита. Дана добавка є високодисперсним порошком бурого кольору з розміром частинок приблизно 0,2 мм. Основним компонентом добавки є ламінарія – бура водорість, що є природним джерелом макро- й мікроелементів, білків, вітамінів та інших біологічно активних сполук, які сприяють покращенню нутрієнтного складу харчової продукції. Другим компонентом виступає подвійний оксид дво- та тривалентного заліза (НЧ FeO× Fe_2O_3) – тонкодисперсний темно-коричневий порошок із частинками розміром 70–80 нм, що не має запаху і смаку, та якому властивий широкий спектр функціонально-технологічних властивостей. Під час розробки рецептури було визначено найкраще співвідношення інгредієнтів для приготування кексів. Встановлено, що оптимальна концентрація CFA становить 1,0% від маси борошна, що дозволило підвищити харчову цінність готових виробів і надати їм необхідних функціонально-технологічних властивостей. Також були досліджені фізико-хімічні та сенсорні характеристики готового продукту, а саме: вплив комбінованої харчової добавки на властивості клейковини; розвиток тіста і газоутворення; вплив комбінованої харчової добавки на структурно-механічні властивості тіста; вплив комбінованої харчової добавки на фізико-хімічні та органолептичні показники якості кексів.

Ключові слова: кекси, сировина, харчова добавка комбінованого складу, харчова цінність, споживні властивості, рецептура, технологія.

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