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APPLICATION OF POWDERED DUTCH CHEESE IN WHEAT FLOUR BREAD TECHNOLOGY

Bakery products made from wheat flour occupy a leading position in the assortment. Consumption of such products in the amount of the daily norm (277 g) allows to provide a person's daily protein requirement by 40.0–43.0%. Wheat bread is a basic product in the diet of the majority of the population, therefore there is an objective need to expand its assortment with products with increased nutritional value, as well as to diversify its taste properties through the use of additional non-traditional raw materials.

The object of research is the technology of bread from wheat flour using powdered Dutch cheese to increase the nutritional value and consumer characteristics of the finished product.

It was established that powdered Dutch cheese is characterized by a good dissolution rate, low tendency to lump formation and a whiteness index corresponding to high-grade flour. The chemical composition of dry hard cheese is mainly represented by protein and fat, which will contribute to the enrichment of bakery products with milk proteins and milk fat.

It was established that according to the complex quality indicator, the optimal dosage of powdered Dutch cheese in the recipe for wheat flour bread is 4.0% by weight of flour. At such a dosage, a bright color of the crust of the product and a lighter color of the crumb are noted compared to the control. The bread acquires a pleasant creamy taste and aroma.

It was established that in the case of dosing powdered Dutch cheese in an amount of 4.0% by weight of flour, the fermentation process is intensified, gluten is weakened, it becomes loose and a strong weakening of the dough is observed during proofing. This is the basis for reducing the duration of dough ripening.

As a result of the research, a recipe for "Cheese" bread was developed, which has an extended shelf life and a lower value of crumb porosity, compared to the control by 21.8% – in the case of storage for 72 hours and provides the human body's need (women aged 18–29 years, I group of labor intensity) for proteins by 14.3% and fats 2 times more compared to the control sample.

Keywords: *wheat flour bread, powdered Dutch cheese, consumer properties, taste, nutritional value.*

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1. Introduction

Bread is an integral part of the diet of people around the world. Annual bread production exceeds 9 billion units [1]. It provides the human body with carbohydrates, dietary fiber, vitamins and minerals that meet the recommended dietary allowances.

During the production process of bread, its taste, aroma and structural characteristics are formed, and its shelf life is also determined. These indicators are subject to deterioration in the case of the production of bakery products using accelerated technologies, common today in the bakery industry, and during storage due to the processes of rancidity.

The taste of bread is one of the most important organoleptic parameters that the consumer evaluates through its sensory perception. That is why improving the taste characteristics of bakery products by adding appropriate ingredients and additives is becoming an increasingly relevant direction for manufacturers [2].

Flavor compounds in bakery products are formed as a result of enzymatic processes during fermentation and the Maillard reaction during baking. The transformation of the main components of the dough system into amino acids, peptides, volatile fatty acids, reducing sugars and their interaction with the formation of complex flavor and aroma compositions determine the consumer appeal of the finished product [3].

The bakery market is represented by a wide range of products with various flavor characteristics, which are achieved using mainly raw materials of plant origin: malt extracts, spices, seasonings, dried vegetables, fruits, etc. Given the increasing consumer demands for nutritional value, organoleptic and functional properties of bakery products, it is relevant to expand the raw material base with ingredients of animal origin, in particular milk processing products.

Milk processing products are promising ingredients for use in bakery products, as they combine high nutritional value and a positive effect on the physiological indicators of consumers. They are characterized by a low glycemic index ($GI < 55$), contain protein with a balanced composition of essential amino acids and a high degree of digestibility [4–6].

The positive effect of whey on the quality of bakery products is well known and confirmed by research and production practice. Partial or complete replacement of water used for kneading dough with whey allows to achieve an increase in the specific volume of products, as well as improvement of their taste, aroma and structure [7–9]. Whey is a by-product in the production of protein dairy products. Depending on the technology and type of the main product, whey can be casein, curd and whey after the production of sourdough cheese, obtained as a result of lactic acid fermentation or acid coagulation of proteins [10].

The chemical composition of whey is characterized by a high lactose content (up to 70% of total dry matter) and a low but functionally important protein content (approximately 0.7–1.0% of dry matter by weight) [11]. Freshly produced whey has a limited shelf life (only a few hours), so the industry prefers dry whey or concentrated whey products, which are more technologically stable, economically feasible, and convenient to use [12].

Such whey products in dry form are:
- sweet milk (from cheese) whey;
- whey with a reduced lactose content;
- demineralized whey with a demineralization of 40–90%;
- whey permeate (whey with a reduced protein content);
- whey protein concentrates (WPC) with a protein content of 25–80%;
- whey protein isolates (WPI, protein content 90%);
- lactose; other special types of whey and calcium-enriched whey products [13, 14].

The use of whey products in bakery product formulations provides them with technological advantages due to improved crust color due to enhanced Maillard reaction, the appearance of a pronounced milky flavor and aroma, an increase in the specific volume of products and their shelf life. The economic efficiency of using these products lies in the possibility of partial replacement of expensive ingredients, such as eggs, fat, sugar, powdered milk, with whey products with similar functional properties. Whey proteins increase the biological value of bakery products due to their high content of the amino acid lysine, which is depleted in wheat protein. As a result of combining whey and wheat proteins, the amino acid composition of bread is optimized [15].

In the production of bakery products, whey protein concentrates with a protein content of 34, 50 or 80% (WPC 34, WPC 50, WPC 80) are most often used in the amount of, respectively, 1–5% and 1–4% by weight of flour. The use of WPC 34, due to the lowest calcium concentration, allows to obtain products with a soft crumb.

Calcium ions in whey products play a significant role in the process of staling of bakery products. Whey protein chains bound by calcium ions are located between starch chains, slowing down its retrogradation. An increase in the lactose content in the dough also extends the shelf life of baked goods, which is explained by better fat emulsification. In addition, lactose crystals in finished products exhibit moisture-retaining ability [16].

When using whey protein concentrates in the recipe of bakery products, the duration of dough kneading should be increased. Whey proteins bind water differently than flour proteins, so the water consumption for dough kneading may change. When using whey permeate, an increase in the dosage of yeast may be required. To increase the specific volume of products, whey products with an increased lactose content (permeate) in an amount of 2–6% by weight of flour or with an increased protein content (WPC) [9].

Cheese is widely used in the food industry due to its distinctive taste, rich aroma and high nutritional value. However, there are a number of limitations to the direct use of cheese as an ingredient in food products, namely, the intensity of the cheese flavor may not be stable due to seasonal fluctuations in the composition of milk, excessive fat content and increased production costs. In this regard, the use of raw material alternatives based on processed cheeses, cheese powders, fermented protein products is gaining popularity in technological practice [17].

Cheese powder is an effective alternative to traditional cheese, combining high functionality, ease of use and consistent quality. Cheese powder is used to enhance flavor characteristics and create a pronounced "cheese profile" in product categories such as cookies, snacks, baked goods, etc. The demand for powdered cheese is growing due to its advantages such as long shelf life, ease of use, low transportation costs and stability during storage [5]. The industrial availability of cheese powder as an ingredient in food products is high, so there is a tendency for its increased use [18]. In the study of the authors [19], the effect of spray-dried cheese obtained from mixed soy-cow milk and modified by enzymatic treatment on the properties of wheat dough and the aroma profile of bread was analyzed. The study was carried out at dosages of 0.1%, 0.5%, 1.0%, 1.5% and 2.0% (w/w). With increasing cheese dosage in the dough, a significant accumulation of free amino acids and peptides was observed, which act as precursors of flavor and aromatic compounds formed during baking. As a result of gas chromatographic analysis of bread after baking, a total of 118 volatile compounds were identified, among which aldehydes, alcohols, esters and organic acids dominated. The results obtained confirm that enzymatically modified cheese powder can be effectively used as a dough improver with simultaneous enhancement of the aromatic properties of finished bakery products.

Considering all of the above, in order to expand the range of bakery products in terms of flavor diversity and increase the nutritional value in terms of protein content, the priority direction is to expand research on the use of cheese powders in bakery product formulations.

The aim of research is to establish the influence of powdered Dutch cheese on the technological process and quality of bread made from wheat flour. This will allow producers to improve the consumer properties of wheat flour bread, namely its taste and aroma, and increase its nutritional value, which will contribute to increasing the competitiveness of these products in the market.

2. Materials and Methods

The object of research is the technology of bread from wheat flour using powdered Dutch cheese to increase the nutritional value and consumer characteristics of the finished product.

The subject of research is powdered Dutch cheese, bread quality indicators, including those that characterize consumer properties.

The assessment of the influence of powdered Dutch cheese on the quality of bread from wheat flour was carried out using the method of trial laboratory baking. The comparative assessment was carried out with wheat bread, which is made from premium wheat flour and served as a control. The recipe for premium wheat bread is given in the literature [20]:
- premium wheat flour – 100 kg;
- hressed baking yeast – 3.0 kg;
- table salt – 1.5 kg.

The test laboratory baking was carried out using the unmixed dough preparation method. The mass fraction of moisture was 43.5%. The dough was prepared on a two-speed Esher dough mixer (Italy): at the first speed, kneading took place for 3 min, at the second speed – 8 min. During the test baking, the dough was fermented for 90 min, during the development of the recipe, the fermentation process was replaced by a resting process for 30 min. The dough was divided and rounded manually. The dough blanks were left to rise until ready in a proofing cabinet with the following parameters: the temperature in the proofing cabinet was 38 ± 2°C, the relative humidity was 78 ± 2%. Baking was carried out in a rotary oven at a temperature of 200–220°C with humidification of the baking chamber.

To determine the influence of powdered Dutch cheese on the nutritional value of finished products, colloidal processes of dough and on the structural and mechanical properties of dough, its physicochemical parameters were studied, which are given in Table 1.

The results of the comparative evaluation of powdered Dutch cheese and premium wheat flour showed that when used, bakery products will be enriched with proteins and fats. It was found that powdered Dutch cheese has a good degree of dissolution of up to 50.0%, which will lead to the accumulation of water-soluble substances in the dough and enrich the nutrient medium for yeast. Along with this, it has a fairly low tendency to form lumps (the degree of caking did not exceed 3%), and therefore, no additional technological operations will be required

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when used in the technology of bakery products. It was found that powdered Dutch cheese has a titrated acidity of 14.0°T, which can lead to an intensification of the dough ripening process. It was also found that powdered Dutch cheese has a whiteness at the level of premium flour.

Table 1

Chemical composition and special quality parameters of premium wheat flour and powdered Dutch cheese $n=3$, $p\geq0.95$, $\delta=3–5\%$

Name of indicators	Premium wheat flour	Powdered Dutch cheese
Moisture mass fraction, %	13.5	9.5
Protein mass fraction, %	10.3	40.3
Fat mass fraction, %	1.1	42.6
Unsaturated	0.2	24.5
Starch mass fraction, %	68.7	0
Dietary fiber mass fraction, %	0.1	0
Ash mass fraction insoluble in hydrochloric acid, %	0.5	6.9
Mineral substances, mg/100 g: Calcium	18	1124
Sodium	10	1405
Phosphorus	86	627
Solubility index, cm^3	–	0.2
Relative dissolution rate of dry powder, %	–	42.0
Degree of caking of dry powder, %, by sieve pore size 250 nm	–	2.9
Titrated acidity, °T	–	14.0
Titrated acidity, degrees	0.8	–
Whiteness, standard units	89.6	84.1

The complex quality indicator of finished products was calculated using the method of scoring the quality of bakery products [21]. The score included the following quality indicators: special quality indicators of bakery products (specific volume, dimensional stability, structural and mechanical properties of the crumb (during staleness) and organoleptic indicators (appearance, crust surface condition, porosity structure, taste, smell).

During the study of the influence of powdered Dutch cheese on the structural and mechanical properties of the dough, the elastic-elastic characteristics of the dough were studied on a farinograph of the Brabender company (Germany) [22]. The spreading of the dough ball during fermentation was determined by the change in diameter at a temperature of 30°C in a thermostat [23].

The determination of the mass fraction of gluten and its quality was carried out by generally accepted methods. The quality of gluten was determined by the resistance to compression deformation on the IDK-2 device, as well as by the extensibility over the ruler and the hydration capacity, which was calculated by determining the mass fraction of moisture in the gluten on OVT-1 device [22]. The gas-forming ability was determined by the volumetric method on the AG-1M device according to the generally accepted method [22]. Titrated acidity was controlled before and after fermentation of semi-finished products according to the generally accepted method [22]. The lifting force of the dough was determined by the duration of the rise of a 10 g dough ball in water at a temperature of 35–30°C in a thermostat [22].

The method for determining the crumb porosity consists in shaking in a conical flask with a volume of 250 cm^3 two parallelepipeds cut from the crumb of the product weighing 5 g each for 5 min on a vibrating shaker. The crumbs that broke off from the parallelepiped due to the friction of the two pieces are weighed on a scale and the crumb porosity, X, % to the mass of the crumb of the products is calculated using the formula

$$X=\frac{G_1}{G_2}\cdot100\ \%, \tag{1}$$

where G_1 – the mass of crumbs, g; G_2 – the mass of bread sample, g [24, 25].

To take into account the degree of influence of all organoleptic indicators on the quality of products, their evaluation was carried out according to a complex (group) quality indicator, using a 100-point scale. Each indicator was evaluated on a five-point scale taking into account the weighting factor of this indicator. The quality of the product was assessed by the sum of the points. The value of the weighting factor was established by the expert assessment method. The sum of these coefficients is a constant value and is equal to 20.

To establish the influence of powdered Dutch cheese on the browning degree of the bread crust during baking, the color of the crust and crumb was studied. The study was carried out according to the method described by the authors [25, 26] using a Chroma meter CR-200 (Minolta, Osaka, Japan) with the Hunter $L^*a^*b^*$ system. The lightness L^* describes the lightness of the sample with values from 0 (black) to 100 (white). The psychometric hue a^* describes the green ($-a^*$) and red ($+a^*$) of the scale, while the psychometric chromaticity b^* defines the blue ($-b^*$) and yellow ($+b^*$). The a^* and b^* indices are limited by the white calibration. The numerical value ΔE describes the total color difference and is determined by the formula

$$\Delta E=\sqrt{\left(L^*-L_0^*\right)^2+\left(a^*-a_0^*\right)^2+\left(b^*-b_0^*\right)^2}, \tag{2}$$

where L_0^*, a_0^*, b_0^* of the control sample, L^*, a^*, b^* of the experimental sample. Each indicator was measured at five points and averaged for calculation.

During staling, moisture migrates from the crumb of the products to the crust, therefore, the rate of formation of the subcrust layer, which is formed from the compacted crumb, is an indicator of the staling of bakery products. The transition of the crumb to the subcrust layer was determined by organoleptic analysis and this place was highlighted with a marker [24, 25].

The crust/crumb ratio was calculated as the mass of the crust, referred to the mass of the crumb in dry form according to the method given in [25, 27].

The nutritional value and provision of the daily norm of nutrients when consuming 277 g of bread were determined according to generally accepted methods [25, 28].

The results of experimental studies were subjected to statistical processing, implemented using standard Microsoft Office software packages.

3. Results and Discussion

The initial studies concerned the possibility of using powdered Dutch cheese in the technology of wheat flour bread by trial laboratory baking. Powdered Dutch cheese was dosed in an amount of 2.0; 4.0; 6.0 and 8.0% by weight of flour. The results of organoleptic evaluation of dough quality, physicochemical indicators of finished products and calculation of a complex indicator of finished product quality are given in Table 2 and Fig. 1.

The analysis of the organoleptic indicators of the dough showed that in the case of dosing powdered Dutch cheese more than 4.0% by weight of flour, the dough becomes sticky, both during kneading and after aging. It was established that the bread in the recipe of which powdered Dutch cheese is included in the amount of 4.0% by weight of flour has the highest complex quality indicator. The bright color of the crust of the product and the cream color of the crumb are noted compared to the control. The bread acquires a pleasant creamy taste and aroma. There is also a slight decrease in the specific volume and porosity of the products. Taking into account the obtained data on the influence of powdered Dutch cheese on the technological process and quality of bread from wheat flour, the dosage of 4% by weight of flour is rational. This will increase the nutritional and biological value of the products with the least negative impact on the specific volume of the products.

Table 2

The effect of powdered Dutch cheese on dough quality and physicochemical indicators of bread quality $n=3$, $p\geq0.95$, $\delta=3–5\%$

Indicator	Experimental samples				
	1	2	3	4	5
	Control (without additives)	powdered Dutch cheese, % by weight of flour			
		2.0	4.0	6.0	8.0
Organoleptic evaluation of dough					
State of dryness and structure of dough: after kneading	elastic, dry	more elastic compared to control, dry		more elastic compared to control, sticky	spreading, sticky
during processing	elastic		elastic, easy to work and roll	sticky when developed	sticky when developed
Physical and chemical quality indicators					
Specific volume, $cm^3/100$ g	344	345	343	342	336
Porosity, %	79	82	84	86	86
Dimension stability	0.5	0.52	0.50	0.48	0.44
Complex quality indicator	78.0	84.4	90.2	87.2	83.8

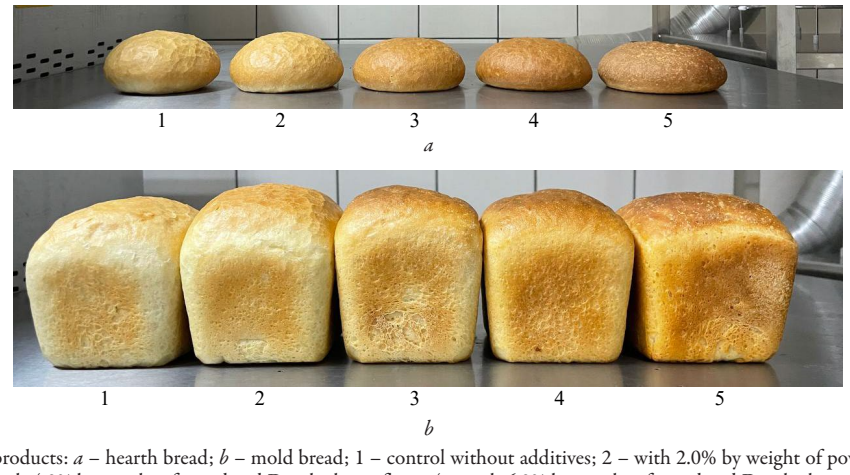

Fig. 1. Photo of finished products: *a* – hearth bread; *b* – mold bread; 1 – control without additives; 2 – with 2.0% by weight of powdered Dutch cheese flour; 3 – with 4.0% by weight of powdered Dutch cheese flour; 4 – with 6.0% by weight of powdered Dutch cheese flour; 5 – with 8.0% by weight of powdered Dutch cheese flour

Further studies were concerned with the scientific substantiation of the processes that occur in the dough at such a dosage.

The quantity and quality of gluten are the main prerequisite for the production of high-quality bakery products. The reduced quantity and quality of gluten are the main reason for the small volume of dough and bakery products even with normal gas-forming ability of flour, and therefore are one of the reasons for the staleness of bakery products. The effect of powdered Dutch cheese in the amount of 4.0% by weight of flour on the quantity and quality of dough gluten was studied. The results are presented in Table 3.

Table 3

Quantity and quality of gluten $n=3$, $p\geq0.95$, $\delta=3–5\%$

Quality indicators		Control	With powdered Dutch cheese
Gluten content:	wet, %	29.5	28.2
	dry, %	10.9	9.2
Gluten quality:	color	light	light
	stretchability	14.5	12.0
	elasticity	good	good
GDI, r. u.		64.3	61.6
Hydration capacity, %		194.5	186.6

As can be seen from Table 3, the addition of powdered Dutch cheese leads to a decrease in the content of raw and dry gluten. Obviously, this is due to the fact that powdered Dutch cheese does not participate in the formation of gluten. The hydration capacity of gluten proteins decreases due to the fact that the associative capacity of proteins of powdered Dutch cheese to water molecules is less pronounced than that of vegetable proteins, which leads to the redistribution of moisture. There is also a strengthening of gluten and a decrease in extensibility due to its weakening under the action of organic acids introduced with powdered Dutch cheese.

The following studies were concerned with establishing the influence of powdered Dutch cheese on the rheological properties of dough. The existing theoretical concept considers dough as a solid-liquid body that combines both elastic-elastic and visco-plastic properties. Its structure is determined by the composition and state of starch polymers, proteins, and cellulose, which hydrate in the presence of water, forming a colloidal system, as well as the content of low-molecular compounds, such as sugars, amino acids, and fats, which plasticize this system.

The elasticity of the dough inhibits the development of volume, but in already formed blanks it helps to preserve the correct shape. The elasticity of the dough determines the formation of a foam-like structure, which plays an important role in the processes of its fermentation, formation, and baking.

The elastic-elastic properties of the dough were determined using a farinograph from the Brabender company (Germany). The data obtained are given in Table 4.

As shown in Table 4, with the addition of 4.0% of powdered Dutch cheese to the flour mass, the water absorption capacity of the dough

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increases by 7.8%. It was found that the addition of powdered Dutch cheese to the dough system does not affect the duration of dough formation. In the case of using powdered Dutch cheese, the duration of dough stability is reduced, which leads to its weakening and a reduction in the duration of dough billets' standing. The obtained data correlate with the data obtained during the study of gluten quality.

Table 4

Effect of powdered Dutch cheese on the structural and mechanical properties of dough $n=3$, $p\geq0.95$, $\delta=3–5\%$

Indicators	Premium flour	Premium flour and 4.0% powdered Dutch cheese
Water absorption capacity, %	51.0	55.8
Dough formation time, min	2.0	2.0
Duration of dough formation, min	2.0	2.0
Stability, min	12.0	6.0
Dilution, units of volume, after 10 min after the start	50	80
Volume evaluation, units of volume	45	40

For a colloidal system, which is dough, visco-plastic properties are characteristic (along with elastic-elastic) during dough fermentation. During dough fermentation, residual deformation accumulates in it, i. e. irreversible deformation of viscous flow, which causes the displacement of dough layers relative to each other due to the destruction of the structural network. The ability of dough blanks to retain their shape, as well as the impossibility of forming loose products with a flat surface, depends on the shape-retaining ability. Indirect evidence of visco-plastic changes occurring in dough with powdered Dutch cheese of 4.0% by weight of flour may be the spreading of a dough ball. The results of the conducted studies are presented in Fig. 2.

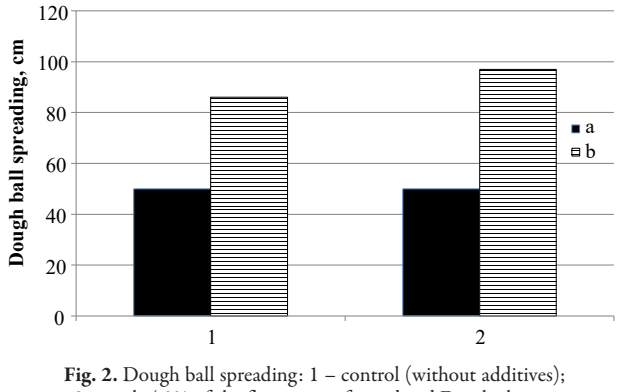


Fig. 2. Dough ball spreading: 1 – control (without additives); 2 – with 4.0% of the flour mass of powdered Dutch cheese; *a* – initial; *b* – 120 min

The data presented show that adding powdered Dutch cheese increases the spreading of the dough, which indicates its relaxation. Therefore, it is advisable to carry out the dough aging instead of the fermentation process, which will reduce the dough thinning.

The logical continuation of the research was to determine the effect of powdered Dutch cheese on the dough ripening process. The effect of powdered Dutch cheese on the intensity of alcoholic fermentation in the dough was concluded from the amount of carbon dioxide released during the aging and proofing of the dough. Considering that the dough is left to rest for 30 min, the duration of proofing of the dough blanks is approximately 50 min, therefore gas formation was determined for 120 min. The results of the studies are shown in Fig. 3.

Analysis of the research results showed (Fig. 3) that in dough with powdered Dutch cheese, gas formation significantly increases.

Analysis of the dynamics of gas formation in dough with an additive (Fig. 4) showed that when powdered Dutch cheese is added, a second extreme of the maximum intensity of dough fermentation is observed, which serves as the basis for reducing the duration of dough ripening.

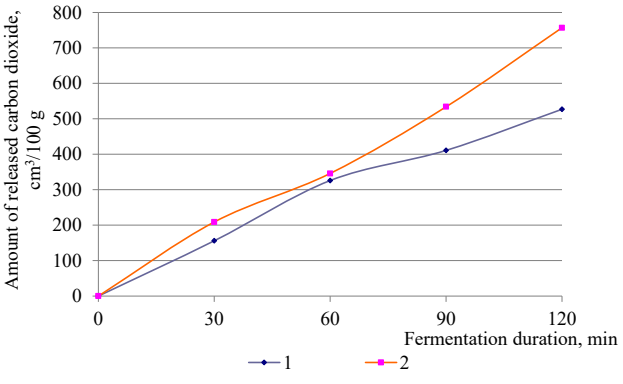


Fig. 3. Gas formation in dough: 1 – control (without additives); 2 – with 4.0% of the flour mass of powdered Dutch cheese

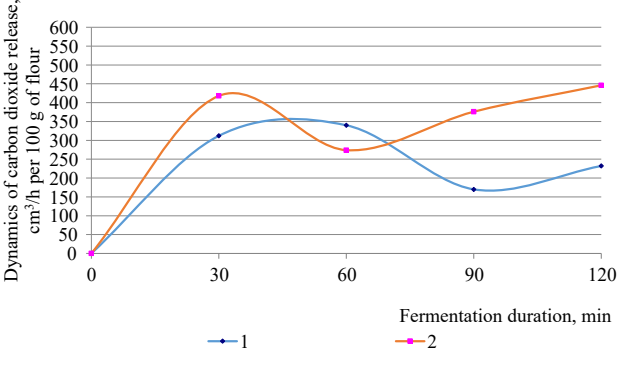


Fig. 4. Dynamics of gas formation: 1 – control (without additives); 2 – with 4.0% of the flour mass of powdered Dutch cheese

The results of studies on the influence of powdered Dutch cheese on the lifting force and acidity of the dough are given in Table 5.

Table 5

The influence of powdered Dutch cheese on the lifting force and acidity of the dough $n=3$, $p\geq0.95$, $\delta=3–5\%$

Indicators	Control without additives	Bread with 4.0% powdered Dutch cheese
Lifting force, min	22	18
Titrated acidity, deg	–	–
initial	0.8	0.8
final	1.2	2.2

It was found that the lifting force of semi-finished products when using powdered Dutch cheese decreases by 18% compared to the control. This is due to the introduction of additional nutrition for the yeast cell due to the increase in nitrogenous substances with powdered Dutch cheese.

During the fermentation of the dough, its acidity increases due to the accumulation of substances that have an acidic reaction, especially the accumulation of acids. Among the accumulated acids, lactic acid accounts for approximately 75%, other non-volatile acids – about 10%, volatile 18–20% of the acidity of the dough. The accumulation of acidic fermentation products is associated with the vital activity of lactic acid bacteria and yeast, which largely depends on the composition of the nutrient medium.

When powdered Dutch cheese is added to the dough, the initial acidity of the dough practically does not change, and the final one increases. This is obviously a consequence of the activation of enzymatic hydrolysis of flour biopolymers and an increase in the liquid phase of the dough of water-soluble hydrolysis products.

As a result of the theoretical and experimental studies, the "Cheese" bread was developed. To confirm the competitiveness of the developed product, consumer value was studied.

The most important indicators of consumer value are organoleptic indicators, namely: crust color, porosity structure, crumb elasticity, crumb chewiness and taste.

To compare organoleptic indicators, a quality polygon (profilogram) was constructed (Fig. 5).

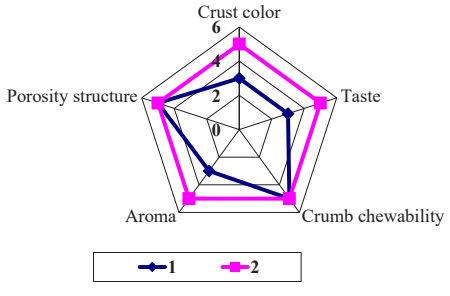


Fig. 5. Profile with quality polygons: 1 – wheat bread; 2 – "Cheese" bread

The average values of the calculation of the complex quality indicator are given in Fig. 5. Expert assessment showed that the use of powdered Dutch cheese contributes to the improvement of all quality indicators compared to the control. The taste and aroma properties and color of the crust are probably improved due to the accumulation of protein hydrolysis products that participate in the formation of taste and aroma.

As can be seen from the studies, the difference in the color of the products is very noticeable when using powdered Dutch cheese. Therefore, the color of the crust and crumb was studied using a digital colorimeter LS173, where the influence on such parameters as L^* (brightness $L^* = 0$ and $L^* = 100$ are taken as black and white, respectively), a^* (psychometric tone – from green (–) to red (+) in the ranges from –120–120), b^* (psychometric chromaticity – from blue (–) to yellow (+) in the ranges from –120–120) was determined, and the color change relative to the control sample ΔE^* was calculated [29]. The results of the studies are given in Table 6.

Table 6

Characteristics of bakery product samples in RGB color models, $n = 3$, $p \geq 0.95$, $\delta = 3–5\%$

Bakery product samples	Color characteristics			
	L_0^*	a_0^*	b_0^*	ΔE_0^*
Crust: wheat bread	61.10	10.79	23.84	–
"Cheese" bread	54.85	10.39	18.26	8.3
Crumb: wheat bread	68.56	0.26	8.64	–
"Cheese" bread	71.34	0.02	10.17	3.2

Analysis of the results showed that the control sample had a higher value of volatility L^* for the crust – 61.10, compared to the "Cheese" bread, which indicates greater ease of perception, and therefore lighter color, but the crumb of "Cheese" bread has a higher value of L^*, so the crumb of the products becomes lighter and goes into lighter colors compared to the control.

The authors of the scientific work [30] indicated that for bread made from wheat flour, the optimal value of volatility L^* lies in the ranges of 50–65, psychometric tone a^* – in the range of 14–18 and psychometric color b^* – 30–35. The obtained research results show that all color indicators are within these limits.

The value of psychometric tone a^* of the crust showed that both products have a red tint. The value of a^* of the crumb is almost zero, and therefore the crumb is characterized by a grayish color. The value of the psychometric color b^* of the crust and crumb showed that the use of powdered Dutch cheese reduces the intensity of the color due to the reduction of yellow pigments and the increase of blue ones.

Further studies were carried out to determine the influence of powdered Dutch cheese on the staling of bakery products.

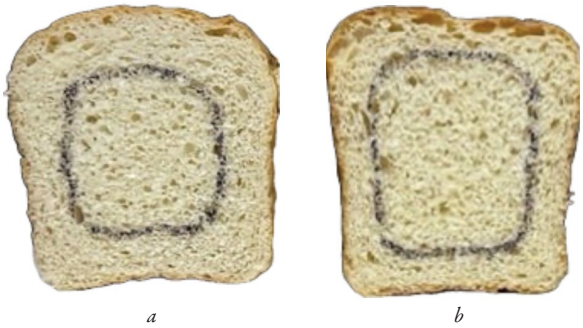
During storage of bread, a decrease in its quality indicators is noted, associated with the staling and drying. Bread becomes harder, brittle, its elasticity decreases, taste and aroma are lost.

Changes in the properties of bread during storage are associated with complex physicochemical, colloidal and biochemical processes occurring in the components of bread, and moisture loss.

Bread staleness is primarily associated with the processes of changing the state of starch, which during storage passes from an amorphous state to a crystalline one. Starch retrogradation occurs, which is associated with the aggregation of amylopectin and amylose molecules.

An important role in this process is played by the aging of gluten denatured during baking, which gives off moisture and, as a result, its hydration capacity decreases, which leads to a compaction of the crumb structure.

It is known that in multicomponent hard products, internal moisture migration occurs, the driving force is the relative humidity gradient between different parts of the product. The contrast between the crumb and the crispy crust is the result of the baking process, when the surface is exposed to higher temperatures than the crumb, as a result of which a relative humidity gradient and moisture content are created between the crust and the crumb, which causes the redistribution of moisture in the product. This is the reason for the softening of the crust and the hardening of the crumb and the formation of a thicker sub-crust layer. Therefore, it was advisable to investigate the effect of powdered Dutch cheese on the area of the formation of the sub-crust layer. The results of the studies show (Fig. 6) that during the storage process, when using powdered Dutch cheese, the sub-crust layer after 72 hours of storage is smaller compared to the sub-crust layer of the control product and is 1.1 and 1.6 for the control, respectively.



a *b*

Fig. 6. Formation of the subcrust layer after 72 hours of storage: *a* – wheat bread; *b* – "Cheese" bread

During storage, the physicomechanical properties of the crumb change, the pore walls lose their strength, which is accompanied by an increase in the crumb porosity. Therefore, to confirm the positive effect of powdered Dutch cheese on extending freshness, the porosity of the product's during storage was studied. The results of the studies are shown in Fig. 7.

The results of the studies show (Fig. 7) that the value of crumb porosity decreases when using powdered Dutch cheese compared to the control – by 24.0–27% under conditions of storage for 24 and 48 h and by 21.8% – in case of storage for 72 h.

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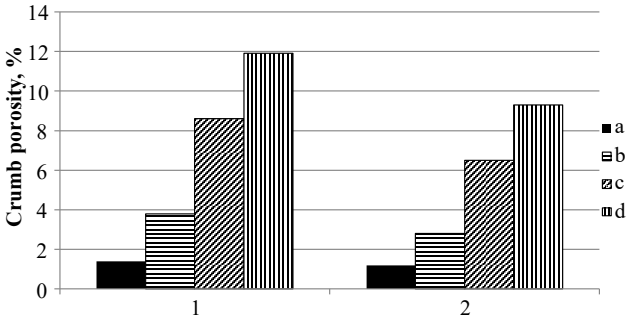

Fig. 7. Crumb porosity %: 1 – wheat bread; 2 – "Cheese" bread; *a* – after 4 h; *b* – after 24 h; *c* – after 48 h; *d* – after 72 h

The nutritional value of "Cheese" bread in comparison with wheat bread was estimated by calculating their chemical composition.

The calculations used the daily norm of bread consumption – 277 g, provided for by the "consumer basket" approved by the Cabinet of Ministers of Ukraine and the norms of physiological needs of the population in basic nutrients and energy. The calculation of the chemical composition is given in Table 7.

Table 7

Chemical composition of 100 g of "Cheese" bread

Nutrients	Wheat bread	"Cheese" bread	Change relative to control level, %
Protein, g	8.47	9.69	+14.4
Fat, g	1.04	2.33	+124.0
Carbohydrates, g	53.14	53.14	–
Ash, g	0.38	0.59	+55.3
Dietary fiber, g	2.65	2.65	–
Energy value, kcal	255.87	272.37	6.4

Based on the calculations, it was found that when adding powdered Dutch cheese in an amount of 4.0% to the mass of flour in the "Cheese" bread, the protein content increases by 14.4, fat content – almost 1.5 times compared to the control, and at the same time the carbohydrate content does not significantly increase the calorie content.

The calculation of ensuring the daily requirement of the body in dietary fiber when consuming the average daily norm of bakery products is given in Table 8.

Table 8

Providing the daily requirement for nutrients when consuming 277 g of finished products

Nutrients	Average daily requirement	Contains 277 g of bread		Covering daily requirement	
		wheat bread	"Cheese" bread	wheat bread	"Cheese" bread
Protein, g	67	23.46	26.84	35.0	40.0
Fat, g	68	2.88	6.45	4.2	9.4
Carbohydrates, g	392.00	147.19	147.19	37.5	37.5
Dietary fiber	30.0	7.34	7.34	24.5	24.5

Thus, the developed "Cheese" bread provides the human body's need (women aged 18–29, I group of labor intensity) for proteins by 14.3% and fats by 2 times more, compared to the control sample.

Practical significance. The conducted studies open up prospects for expanding the range of wheat flour bread with improved taste characteristics due to the use of a natural ingredient of powdered Dutch cheese.

Research limitations. It is worth noting the limitations of raw materials, since powdered Dutch cheese is imported to Ukraine, therefore, for each batch it is necessary to set a quality indicator to confirm which type of cheese the powdered cheese is made from.

Impact of martial law conditions. The war in Ukraine forces bakery manufacturers to respond to the increase in the cost of raw materials, both local and imported, and disruption of logistics, which slows down the expansion of the product range.

Prospects for further research. The subject of further research is monitoring the baking industry with the aim of expanding the range of competitive bakery products that will satisfy all segments of consumers in terms of nutritional value and consumer properties.

4. Conclusions

During the study, technological and functional properties as a promising ingredient in the production of bakery products were established for the first time. It was found that this product is characterized by a high dissolution rate, low tendency to clumping and a high whiteness index, comparable to premium flour, which is important for ensuring the homogeneity of the dough structure and the stability of the quality of products.

According to the results of the analysis of powdered Dutch cheese, it was established that this product is characterized by a high dissolution rate, low tendency to clumping and a high whiteness index. This is important for ensuring the homogeneity of the dough structure and the stability of the quality of products.

The chemical composition of powdered Dutch cheese, rich in proteins and milk fat, allows for the effective enrichment of bakery products with nutrients of animal origin, improving their nutritional value.

The scientific novelty of the study lies in establishing the optimal dosage of powdered Dutch cheese – 4.0% by weight of flour, at which the highest complex index of bread quality is achieved. It was found that when powdered Dutch cheese is included in the recipe of wheat bread, the highest comprehensive quality indicator of the products is achieved at a dosage of 4.0% by weight of flour. It is at this dosage that an intense color of the crust, a light, uniform crumb, and a pleasant creamy taste and aroma are observed, which significantly improves the organoleptic appeal of the product.

It was found that the introduction of powdered Dutch cheese in an amount of 4.0% by weight of flour intensifies the fermentation processes, while at the same time contributing to the weakening of the gluten framework of the dough, as a result of which the latter becomes more friable and sensitive to mechanical stress. This opens up the possibility of reducing the duration of dough maturation, which is a technological advantage in the conditions of intensification of production processes.

Based on the conducted research, a recipe for "Cheese" bread was developed, which includes powdered cheese, which provides:

– extended shelf life of the product;
– reduction of crumb fragility by 21.8% after 72 hours of storage compared to the control sample;
– increase in biological value: in particular, covering the daily requirement of a woman aged 18–29 years (I group of labor intensity) in proteins by 14.3%, and in fats – twice as much as in the control.

Thus, the obtained results have scientific novelty and high potential for practical application in the development of innovative bakery products with increased nutritional value, improved quality and expanded functional properties that meet modern requirements for rational nutrition of the population.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, including financial, personal, authorship, or any other, that could affect the research and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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