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Accelerated technology of rye bread with improved quality and increased nutritional value

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Abstract. Accelerated bakery technologies do not always ensure high bread quality. The taste and smell of bread is less pronounced when compared with the traditionally prepared bread and it is quickly subjected to microbial spoilage. The aim of the research was to develop an improved composite mixture for the accelerated technology of rye bread, which would improve its quality, nutritional value, extend shelf life and microbiological stability. Rowan powder (botanical species *Sorbus aucuparia*) as unconventional raw ingredients of high nutritional and biological value was used. Rowan powder has high acidity (40 degrees or 5.7% in terms of malic acid) and contains a wide range of organic acids, including volatile acids (2–3%) and preservative acids (such as sorbic acid), as well as other micro- and macronutrients. New acidifying additive with rowan powder was created. The optimal dosage of rowan powder in the new acidifying additive by 13% per 100 kg of flour allows bread making with higher specific volume, acidity and porosity of the crumb compared with the control sample. The research proves that rowan powder usage in the accelerated bread technology improves its organoleptic and physico-chemical indicators and also increases the content of dietary fiber, vitamins and minerals. The content of fibers in custard bread with rowan powder was 1.85 times higher than in the control sample. The rowan powder usage has a positive effect on the preservation of bread freshness during its storage. The rowan powder usage slows down the custard bread mould disease.

Key words: bread, rye, rowan powder.

INTRODUCTION

Bread made from rye flour or its mixture with wheat flour, including custard bread with scalded flour (like Swedish bread Sillabröd), is traditionally one of the main food products of the Russian population living in the North-West, Central and North-East regions, Belarus, Ukraine, Lithuania, Latvia, Estonia, as well as in Germany, Poland, Finland, Austria and other countries (Fuckerer et al., 2016). It is well-known that bread with rye flour, including custard bread, is technologically impossible to prepare without acidifying dough (Birch, 2013; Fuckerer et al., 2016; Gagiu et al., 2017). This is due to the peculiarities of rye flour (Tatham & Shewry, 1991; Wrigley & Bushuk, 2010; Ficco et al., 2018). The protein content of rye grain is similar to that of wheat. But rye flour proteins do not form a gluten skeleton like bread wheat (Shewry et al., 1997; Shewry et al., 2002; Tosi et al., 2011) and durum wheat proteins (Carrillo et al., 1990; Pogna et al., 1990; Palumbo et al., 2002).

The monomeric gluten proteins of rye are called secalins (equivalent to wheat gliadins) and the polymeric gluten proteins (polypeptides or subunits) take the generic name of glutelin (equivalent to wheat glutenin). The secalins of rye comprise four major groups of proteins, three of which are closely related to groups of wheat and barley prolamins (Tatham & Shewry, 1991; Wrigley & Bushuk, 2010; Ficco et al., 2018). Wheat flour protein is an important component having an influence on the quality of pasta and bread. The glutenin and gliadin proteins, the types present and their ratio influence dough properties. The disulfide bonds presented in the wheat gluten structure contribute to the process of dough formation through the process of disulfide-sulfhydryl exchange. Tyrosine bonds also form in wheat doughs during the processes of mixing and baking, contributing to the structure of the gluten network (Tilley et al., 2001; Sissons, 2008). Increasing of the number of high molecular weight glutenin subunits to obtain more varied dough properties improve the breadmaking properties of wheat and durum flour (Žilić et al., 2011). The rheological properties of gluten are needed not only for bread production, but also in the wider range of foods that can only be made from wheat, viz., noodles, pasta, pocket breads, pastries, cookies, and other products.

Rye have slightly less than wheat of the nitrogen-rich amino acids, such as glutamine and proline. Rye flour have a similar or higher content of gluten than wheat flour and the rye protein is forming gluten on wetting, but its resistance to stretching of the resulting dough is less than wheat gluten. Machine processing of rye dough is more difficult than for wheat dough due to the stickiness of rye dough. The resulting baked rye loaf is poorer in volume, with coarser crumb structure, but the distinctive flavour of rye makes it especially attractive to many customers (Cauvain et al., 2005; Wrigley & Bushuk, 2010).

That is why the starch, pentosans and dextrins of rye flour play a major role in the formation of crumb structure. An increase in acidity in the dough contributes to their swelling, which leads to the increase in the viscosity of the rye dough, its gas-holding capacity, the decrease in stickiness and hardenability of the crumb due to inactivation of the α-amylase. Biological or chemical methods are used for acidification. The most common ways are the usage of sourdough or of organic acids (Kosovan, 2008; Wrigley & Bushuk, 2010).

Traditional sourdough rye custard bread technology consists of several stages such as flour scalding and saccharification, sourdough and dough (Kosovan, 2008). So it is laborious and economically unprofitable, especially in the conditions of small enterprises. Artisan bakeries and bakeries working in discrete conditions are forced to move to an accelerated production method. Accelerated production is possible if complex acidifying additives and improvers are used (Kosovan, 2008; Lambert-Merete et al., 2010; Gagiu et al., 2017; Gioia et al., 2017). The quality of the rye custard bread produced in the accelerated way is worse than the one of the traditional bread. It does not have harmonious and traditional taste and smell, typical for rye bread made with scalded flour (like Swedish bread Sillabröd), because the substances involved in the formation of taste and smell accumulate in the sourdough fermentation process (Jensen et al., 2011; Onishi et al., 2011; Plessas et al., 2011; Demin et al., 2013). Such bread lacks aromatic substances and thus has weak, empty smell and taste.

The disadvantages of accelerated bread production technology include many other factors. It includes low content of vitamins, minerals, dietary fiber in finished products; the lack of guarantees in obtaining stable quality products, lower quality of bread. Crumb bread can be crumbling. This bread has low resistance to microbiological spoilage and short shelf-life. Consequently, accelerated technology bread does not meet the food security doctrine. That is why the main task for scientists and bakers is to improve the quality of bread prepared in an accelerated way and to make it useful. Therefore, introducing new biologically valuable components into the bread recipe is an important task (Corsetti et al., 2000; Dubrovskaya et al., 2017).

Due to the inconvenience of using biological starters in discrete conditions, it is necessary to use acidifying additives containing citric acid, as a rule, which may have a negative effect on health. For example, citric acid in an acidifying additive may cause an allergic reaction in people who are sensitive to acetylsalicylic acid or have asthma (Sweis & Cressey, 2018).

Accelerated technology of rye bread using acidifying additives and extruded flour was created at Saint-Petersburg branch of State Research Institute of Baking Industry (Kosovan, 2008). Flour eliminates the stage of flour scalding and saccharification. But bread prepared acceleratedly with this additive has a faint smell and taste and is quickly subjected to molding. To acceleratedly produced custard bread with a more pronounced smell and taste, it is advisable to use raw materials that not only participate in the formation of a harmonious taste and smell but also lead to an increase in the quality and nutritional value of the bread (Wieser, 2007; Dubrovskaya, 2012).

The aim of the research was to develop an improved composite mixture for the accelerated technology of rye bread, which would improve its quality, nutritional value, extend shelf-life and microbiological stability.

The powder from the fruit of the rowan (botanical species *Sorbus aucuparia)* was used as an enriching additive. Rowan powder has high acidity (40 degrees or 5.7% in terms of malic acid), has rich biochemical composition, as well as a significant amount of dietary fiber (56.3–59.9%) and volatile acids (2–3%) (Dubrovskaya, 2012).

MATERIALS AND METHODS

Characteristic of ingredients

The powder from the fruit of the ordinary rowan (botanical species *Sorbus aucuparia)* was used.

Rowan powder was obtained from the fruits of rowan *Sorbus aucuparia*. The rowan fruits were dried in a vacuum drier (SVK-1/4) at a temperature 58 ± 2 °C to a moisture content of 8–10%. The dried rowan fruits were ground into powder by knife mills. Particle size was 560–1,000 μm.

The biochemical composition of rowan powder used as an acidifying additive was investigated.

A new acidifying additive with extruded rye flour and rowan powder was developed. When developing a new additive, the following components were varied: rowan powder, extruded rye flour, fermented and unfermented rye malt, coriander. Formulation of acidifying additive is presented in Table 1.

Table 1. Formulation used to prepare different acidifying additive types

Ingredients, g	Control	Samples						
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Extruded rye flour	60.0	65.0	56.0	47.0	34.0	25.0	17.0	9.0
Fermented malt	25.0	20.0	20.0	20.0	20.0	25.0	20.0	20.0
Unfermented malt	9.0	-	-	-	4.0	-	4.0	4.0
Coriander	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Citric acid	3.5	-	-	-	-	-	-	-
Rowan powder	-	13.0	22.0	31.0	40.0	48.0	57.0	65.0
Total	100							

Bread making procedure

The optimal amount of rowan powder in the recipe of dry complex brewing was determined as a result of test laboratory baking of custard rye-wheat bread. The dough was made from following ingredients (g per 100 g total amount of flour): rye flour (45.0), wheat flour baking first grade (35.0), new acidifying additive (20.0) salt (1.5), white sugar (4.0) and yeast (1.2). Water was added in an amount to ensure the humidity of the dough 48.5%–49.0%. All the components were mixed in a kneading machine Ankarsrum Original Assistant (Sweden) at a speed of 200 rpm for 15 minutes. After mixing, dough was fermented at a temperature of 30 ± 2 °C for 90 minutes. Then, dough pieces shaped into 310 g loaves, placed in baking forms, and leavened at a 35–40 °C until the volume was twice that of the initial volume. The leavened dough samples were cooked in an oven SvebaDahlen (Sweden) at the temperature at 180 °C for 28 minutes with steam for 6 seconds. The control was bread on a well-known acidifying additive with extruded flour, developed by the St. Petersburg branch of State Research Institute of Baking Industry, which was used in the same amount.

Analysis of the biochemical composition of rowan powder

The analysis of the biochemical composition of the powder of mountain ash was performed using gas-liquid chromatography with mass spectrometry (GC–MS) on an Agilent 6850 chromatograph (USA). Acidity was determined according to State Standard of the Russian Federation (GOST R 52061–2003). The content of vitamins was determined in accordance with different State Standards of the Russian Federation and by special methods. Ascorbic acid was determined by photometric method (State Standard of the Russian Federation GOST 24556–89 P). The method is based on the extraction of vitamin C with metaphosphoric acid or acetic acid mixture and metaphosphoric acids, the reduction of ascorbic sodium 2.6-dichlorophenolindophenolate sodium acid, followed by extraction with an organic solvent (amyl acetate, butyl acetate or xylene) an excess of 2.6-dichlorophenolindophenol sodium and photometric measurement of organic extract at a wavelength of 500 nm.

ß-carotene (provitamin A) was determined by Murri's colorimetric method, based on photometric determination of the mass concentration of carotene in a solution obtained after extraction of carotene from products with an organic solvent and purified from related dyes using column chromatography. Tocopherol was determined by photoelectric colorimetric method (Skurikhin, 1991).

Vitamin B_1 (thiamine chloride hydrochloride) and vitamin B_2 (riboflavin) in food products, food raw materials and dietary supplements were determined by the method based on acid and enzymatic hydrolysis of the sample, as a result of which the release of related forms of vitamins occurs (Method M 04–56–2009). To determine the mass fraction of vitamin B_1, the resulting hydrolyzate is purified with isobutanol. Under the action of potassium-synergistic potassium in an alkaline medium, vitamin B_1 is oxidized to thiochrome, which is extracted with isobutanoll, and the fluorescence intensity of the resulting extract is measured using a FLUORAT®–02 fluid analyzer. To determine the mass fraction of vitamin B_2, the fluorescence intensity of the hydrolyzate is measured using a FLUORAT®–02 fluid analyzer. Then, to assess the influence of fluorescent impurities, riboflavin thiourea luminescence is quenched. The concentration of vitamin B_2 is calculated by the difference in values before and after extinguishing.

The dough assessment

Mass proportion of moisture of the dry microbial composition and of the sourdough was determined by drying at a temperature of 130 °C during 40 minutes in drier SHS-1M. The lifting capacity was determined by the rate of floating up of the 10 g of dough shaped in the ball with humidity of 45% in a glass of water with a temperature of 32 °C. The increase in volume was calculated by the ratio of the final volume to the initial volume multiplied by 100% (Puchkova, 2004). Acidity was determined by titration, using 0.1 N solution of NaOH (State Standard of the Russian Federation GOST 5670–96, 1996).

The gas-forming and gas-holding capacity of the dough was determined using a F3 Chopin Reofermentometer. Samples of the test weighing 315 g were placed on the bottom of the drum, preheated to 28.5 °C. A piston with a load of 2,000 g (4 plates of 500 g each) was installed on the dough and the system was tightly closed with a lid. The duration of the experiment was 90 minutes. The essence of the method is that the pressure generated by the dough in the fermentation process is alternately released into the atmosphere through a soda lime cartridge that retains carbon dioxide, the gas holding capacity of the test is estimated from the volume of which, expressed in cm^3. The rise of the dough in the fermentation process is estimated by the movement of the piston, which is mounted directly on the dough. During the analysis, two coordinate systems are displayed on the instrument display. On one (top) the dough rise dynamics are drawn in mm, on the second (bottom) – the dynamics of change in gas-forming ability and gas-holding capacity of dough in mm of water column.

Assessment of baked bread

Assessment of quality

The assessment of bread quality levels was carried out in relation to the following properties: organoleptic appearance (shape, surface, crumb color), condition of crumb (porosity and texture), taste and smell; physic-chemical and physical – the mass proportion of moisture was determined by drying at a temperature of 130 °C during 45 minutes in drier (SHS-1M, Russia), acidity was determined by titration, using a 0.1 N solution of NaOH (State Standard of the Russian Federation, 1996), porosity was determined as the ratio of pore volume to the total volume of products, pore volume – as the difference between the volume of product and the volume of non-porous mass, specific volume – as the ratio of product volume to 100 g of bread, compressibility was determined on the automatic penetrometer Labor (Hungary). The swelling of the crumb was determined by the amount of water absorbed by the crumb of bakery products for a certain period of time (Goryacheva, 1983).

The chemical composition of the bread was obtained by calculation (Kosovan, 2008), taking into account the content of nutrients in the used raw materials accordingly (Skurikhin & Tutelyan, 2002).

Sensory evaluation

The panel of 10 non-specialists was used to evaluate the sensory characteristics of the bread. Then, they were asked to evaluate separately appearance (shape, surface, crumb color) and the crumb (color, smell, taste, chewiness and porosity). The ranking scale ranged from 1 to 5 (5-like extremely, 4.5-like very much, 4-like moderately, 3.5-like slightly, 3-neither like not dislike, 2.5-dislike slightly, 2-dislike moderately, 1.5-dislike very much, 1-dislike extremely).

Mould spoilage assessment

The impact of the sourdough and rowan powder on mould disease of custard bread was investigated. Sterile bread slices were contaminated by a pure culture of the mould *Penicillium chrysogenum.* Immediately after baking in the oven opening, the loaves were packed into sterile paper, placed in a sterile room, and cooled to a temperature of between 25–28 °C. After cooling the bread was cut in a sterile environment, with slices being taken at a size of 3.5 × 6.5 cm and at a thickness of 0.3–0.4 cm. The slices were placed in sterile Petri dishes. An aqueous suspension of a pure culture of the mould, *Penicillium chrysogenum*, was prepared for the infection of slices of bread. The biomaterial of *Penicillium chrysogenum* was transferred from a tube containing a pure culture of mould grown on malt agar to 1 mL of sterile water using 'Tween-80' and was thoroughly suspended. The suspension was inoculated into each slice of bread in three shots using a microbiological needle. Petri dishes with infected slices were incubated at a temperature of 25 ± 1 °C until the first signs appeared of a growth of mould colonies Dubrovskaya, 2018).

Statistical analysis of the data

When analyzing the results of experiments, standard approaches of probability theory and mathematical statistics were used: One-way ANOVA to test the hypothesis of equality of averages of several independent samples, Tukey tests (for a posteriori quality control of conclusions) and the Dunnett test for assessing the relationship with the test sample, paired t- test for samples with different variances to test the hypothesis of the difference between the two means.

RESULTS AND DISCUSSION

It was established that rowan powder contains vitamins, minerals, as well as a significant amount of dietary fiber, carbohydrates and volatile acids (Table 2). This allows suggesting that rowan powder will increase the nutritional value of bread.

Rowan powder had a high acidity (40 degrees or 5.7% in terms of malic acid), acidifying additives. The effect of the quantity of rowan powder in the composition of new acidifying additive with extruded flour on the quality of custard bread was investigated (Table 3). With increasing dosage of rowan powder, the acidity of dough and bread increases. The specific volume of bread with rowan powder was slightly higher than that of the control bread. Increasing the dosage of the rowan powder to 15% (Sample 7) leads to a decrease in specific volume compared with other samples, but it is comparable with the control. It was established that the optimal amount of rowan powder in the composition of new acidifying additive is 11 and 13% of rowan powder per 100 kg of flour in the dough (Samples 5 and 6). With such a content of rowan powder, the analyzed parameters increase in comparison with the control sample.

Table 2. Rowan powder nutrient content

Vitamins:	Range
Ascorbic acid, mg 100 g^{-1}	40–65
Vitamin A, mg·100 g^{-1}	0.12–0.16
Vitamin E, mg kg^{-1}	7.9–9.2
Vitamin B_1, mg 100 g^{-1}	0.028–0.029
Vitamin B_2, mg 100 g^{-1}	0.37–0.434
Mineral substances:	
Potassium, mg 100 g^{-1}	780–980
Calcium, mg 100 g^{-1}	260–300
Iron, mg·100 g^{-1}	4.8–25.4
Manganese, mg 100 g^{-1}	5.9–6.7
Copper, mg 100 g^{-1}	0.4–0.5
Zinc, mg 100 g^{-1}	1.02–1.07
Selenium, μg kg^{-1}	16.8–17.3
Dietary fiber, g 100 g^{-1}	56.3–59.9
Carbohydrates, g 100 g^{-1}	26–30
Volatile acids, g 100 g^{-1}	2–3

Table 3. Physical and chemical indicators of dough and bread*

Indicators	Samples*								
Dough:	control	No.1	No.2	No.3	No.4	No.5	No.6	No.7	F
Acidity, degrees N	10.5 ± 0.5	5.5 ± 0.3	6.7 ± 0.3	7.3 ± 0.4	8.1 ± 0.4	9.1 ± 0.5	10.5 ± 0.5	10.5 ± 0.5	33.3
Lifting capacity, min.	10.0 ± 0.5	8.0 ± 0.4	8.0 ± 0.4	8.0 ± 0.4	9.0 ± 0.4	9.0 ± 0.4	10.0 ± 0.4	11.0 ± 0.6	12.3
Bread:									
Acidity, degrees N	5.0 ± 0.3	3.6 ± 0.2	3.8 ± 0.2	4.4 ± 0.2	5.0 ± 0.5	6.2 ± 0.3	6.8 ± 0.3	7.0 ± 0.4	25.2
Porosity, %	60 ± 3.0	60 ± 3.0	62 ± 3.0	62 ± 3.0	63 ± 3.0	64 ± 3.0	65 ± 3.0	65 ± 3.0	0.72[a]
Specific volume, cm^3 g^{-1}	1.7 ± 0.1	2.0 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	1.8 ± 0.1	1.8 ± 0.1	1.7 ± 0.1	1.5[a]
Compressibility, units of the device	19 ± 1.0	20 ± 1.0	20 ± 1.0	19 ± 1.0	19 ± 1.0	20 ± 1.0	20 ± 1.0	19 ± 1.0	0.41[a]

*The letter (a) means acceptance of the hypothesis (a slight difference in the results at the level of 0.05); calculated value of the F-criterion does not exceed the tabular value of the F-criterion - 2.66.

The acid-forming and gas-holding capacity of the dough with an acidifying additive containing 13% rowan powder (Sample No.7) was studied (Table 4).

It was found that the amount of gas released in the test sample on a new acidifying additive with rowan powder is reduced by 10.8% relative to the control sample (Fig. 1). The decrease in the total volume of gas released in the sample being analyzed is directly related to the high acidity of the rowan powder used. It is known that high acidity inhibits the activity of yeast.

Table 4. Dough characteristics*

Indicators	Control	Sample No.7	t*
Total volume of released CO_2, cm^3	962 ± 48	858 ± 43	2.03[a]
Volume of CO_2 retained, cm^3	864 ± 43	776 ± 39	2.01[a]
Gas retention coefficient, %	89.8 ± 4.5	90.4 ± 4.5	0.11[a]

*The letter (a) means acceptance of the hypothesis (a slight difference in the results at the level of 0.05), the calculated value of the t-test does not exceed the tabular value of the Student's t-test (from 2.77 to 4.3).

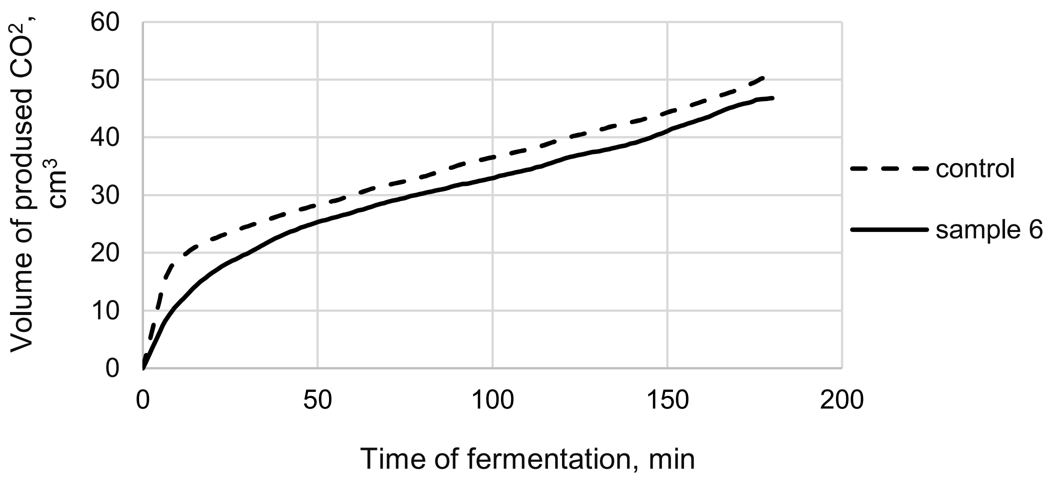

Figure 1. Dynamics of gas formation in the dough.

It was established that the gas holding coefficient in the dough samples was higher than in the control one (Fig. 2). This indicates a small amount of lost CO_2, which is also explained by the presence of rowan powder. The gas is retained in the dough due to the presence of pectic substances with a high degree of esterification in the rowan powder. Pectic substances of the powder make the dough stronger and more elastic, increasing its water-absorbing ability. Consequently, the specific volume of the experimental samples should be higher than that of the control, which is confirmed by physico-chemical and organoleptic characteristics (Tables 4, 5).

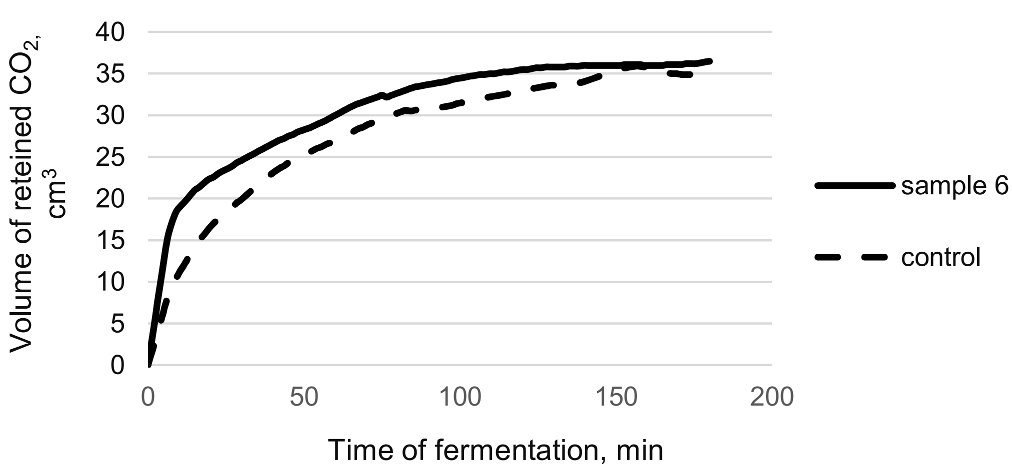

Figure 2. Dynamics of gas containment in the dough.

The sensory characteristics of custard rye-wheat bread were investigated (Table 5). The positive effect of rowan powder on sensory characteristics was found. It is established that increasing dosage (from 7 to 15%) in the composition of the acidifying additive leads to the improvement in the elasticity and color of the crumb, as well as the smell and taste of custard bread. It has been established that increasing the amount of rowan powder in a mixture is impractical, since the taste of the bread becomes sour and the smell is pronounced fruity. At the same time, we found out that the optimum content of a mountain rowan powder had samples 5 and 6.

It was established that the rowan powder in the acidifying additive improves the organoleptic and physic-chemical characteristics of the custard bread and increases the nutritional value.

Table 5. Sensory characteristics of custard bread

Indicators	Samples								
	control	No.1	No.2	No.3	No.4	No.5	No.6	No.7	F*
Crust:									
Shape	4.80 ± 0.18	4.83 ± 0.23	4.77 ± 0.22	4.77 ± 0.22	4.80 ± 0.21	4.82 ± 0.32	4.82 ± 0.32	4.82 ± 0.32	0.05[a]
Surface	4.80 ± 0.18	4.83 ± 0.23	4.77 ± 0.22	4.77 ± 0.22	4.80 ± 0.21	4.82 ± 0.32	4.82 ± 0.32	4.82 ± 0.32	0.01[a]
Color	3.20 ± 0.16	3.19 ± 0.19	3.89 ± 0.04	4.09 ± 0.12	4.73 ± 0.11	4.90 ± 0.15	4.90 ± 0.15	4.79 ± 0.12	9.8
Crumb:									
Color	3.49 ± 0.38	3.5 ± 0.10	3.64 ± 0.14	4.80 ± 0.21	4.83 ± 0.27	4.72 ± 0.32	4.72 ± 0.82	3.24 ± 0.12	6.06
Odour	2.08 ± 0.18	2.87 ± 0.28	2.92 ± 0.23	3.91 ± 0.06	4.11 ± 0.12	4.79 ± 0.12	4.90 ± 0.15	2.88 ± 0.28	45.4
Taste	2.22 ± 0.11	2.75 ± 0.18	2.95 ± 0.18	3.19 ± 0.19	3.43 ± 0.23	4.01 ± 0.04	4.09 ± 0.04	4.01 ± 0.18	38.2
Chewiness	3.19 ± 0.19	3.34 ± 0.29	3.25 ± 0.15	3.89 ± 0.14	4.01 ± 0.10	3.92 ± 0.05	4.05 ± 0.09	4.01 ± 0.10	9.94
Porosity	4.59 ± 0.23	4.65 ± 0.31	4.64 ± 0.25	4.69 ± 0.38	4.49 ± 0.22	4.57 ± 0.28	4.48 ± 0.38	4.39 ± 0.32	0.17[a]

*The letter (a) means acceptance of the hypothesis (a slight difference in the results at the level of 0.05); calculated value of the F-criterion does not exceed the tabular value of the F-criterion - 2.66.

Table 6 shows the effect of a rowan powder on increasing the nutritional value of custard bread and on meeting the daily need for nutritional components necessary for the normal development of the body.

The greatest impact of rowan powder was on the content of dietary fiber. Its content increased in 1.85 times relative to the control. Also, there is a decrease in the total content of digestible carbohydrates by reducing the digestible carbohydrates by 11.6%, which will have a positive impact on human health. When using rowan powder the content of vitamins and minerals, increased. Vitamins A, E and ascorbic acid were also found in the bread with rowan powder (Table 4). At the same time, the maximum degree of satisfaction of daily need was observed for vitamins A and E (11% and 13%, respectively).

Table 6. Content of basic nutrients in bread

Substances	Daily needs	Control	Sample No.6	t*
Proteins, g	75	6.6	6.4	3.57
Fat, g	83	1.1	1.0	0.6[a]
Digestible carbohydrates, g	365	43.0	38.0	4.05[a]
Dietary fiber, g	30	5.7	10.6	20.2
Ash, g		1.6	2.0	2.18[a]
Vitamins, mg 100 g^{-1}:				
vitamin C	70	-	1.4	
vitamin A	0.1	-	0.011	
vitamin E	10	-	1.26	
vitamin B_1	1.5	0.127	0.129	0.68[a]
vitamin B_2	1.8	0.06	0.095	0.18[a]
vitamin PP	20	0.76	0.79	0.5[a]
Mineral substances, mg 100 g^{-1}:				
Sodium	5,000	389	400.18	1.13[a]
Magnesium	400	35.5	42.47	12.24
Potassium	3,500	175	236.62	10.1
Calcium	1,000	23	48.55	45.8
Phosphorus	1,000	107.5	137.13	30.83
Iron	14	2.5	3.0	1.81[a]
Selenium	0.07	-	0.00015	
Manganese	7.5	-	0.52	
Zinc	15	-	0.09	

*The letter (a) means acceptance of the hypothesis (a slight difference in the results at the level of 0.05); calculated value of the t-test does not exceed the tabular value of the Student's t-test (from 2.77 to 4.3).

The total ash content also increased, respectively, by 17% and amounted to 1.6 g 100 g^{-1} in the control sample, and 2.0 g 100g^{-1} in the experimental sample. The most significant impact rowan powder had on the enrichment of custard bread with phosphorus, magnesium, satisfying the daily requirement of 21%, 13% and 11%, respectively. In addition, manganese and selenium were not found in the control bread, but they were found in sample with rowan powder.

The use of rowan powder in the recipe of custard bread leads to an increase in its consumer advantages and quality.

However, during storage, the quality of bread begins to decline due to the processes of staling and drying. The process of staling is irreversible, but it can be slowed down. Therefore, the next stage of research was to study the effect of new additive on changes in moisture, structural and mechanical properties and swelling of the crumb of custard rye-wheat bread during its storage.

It was established that the loss of moisture during storage was less in the sample with rowan powder. Moisture content in control bread decreased by 1.2% compared to its initial value, and in the experimental one only by 0.6% during storage period (Fig. 3).

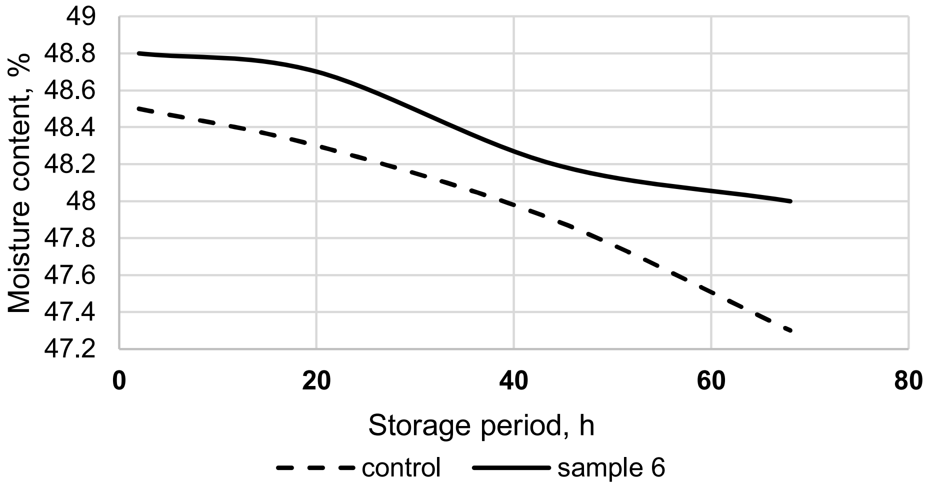

Figure 3. The change in moisture content of the crumb during the storage.

The compressibility of the bread crumb was examined (Fig. 4). It was found that the sample with rowan powder had the best compressibility throughout the entire storage period for 68 hours. The compressibility of the crumb of the control sample, compared to the sample with rowan powder, decreases with greater speed, especially during 20 hours of storage. By the end of storage, the compressibility of the control bread decreased by 57%, and that of bread with rowan powder decreased only by 37%. Such a pattern is associated with an increase in the mechanical strength of the pore walls, slowing down the process of drying and staling.

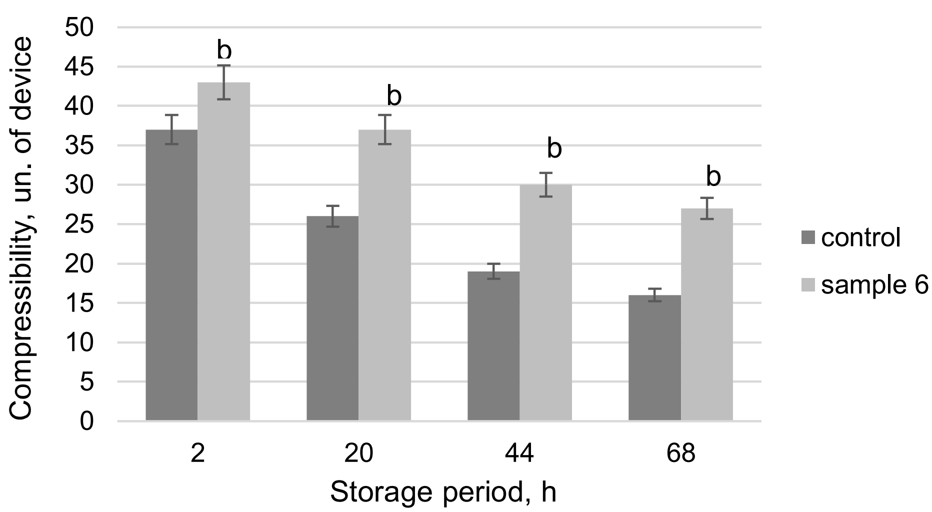

Figure 4. Crush compressibility during bread storage*.

* The letter (b) means the rejection of the hypothesis (a significant difference in the results at the level of 0.05), the calculated value of the t-value criterion is the tabular value of the t-student criterion.

When studying swelling, its decrease during storage was established (Fig. 5). Changes in the swelling index of the samples of custard bread under study occur most intensively also during 20 hours of storage. This is probably due to a decrease in the ability of colloidal substances to absorb water by compacting the structure of starch and proteins during their aging. The swelling capacity of the control bread was less than that of the samples with rowan powder during the storage period. At the same time, the swelling of the control decreased by 1.5% from the initial value (from 4.1%), and the swelling of bread with rowan powder decreased only by 1.2% (from 4.8%). That may be due to the high fiber content in bread with rowan powder, which has a high swelling index. Rowan powder has high water absorption capacity due to the high content of pectin with the high degree of esterification - 85%.

Thus, this studies have shown that the use of rowan powder in an acidifying additive has a positive effect on the preservation of freshness during storage of custard rye-wheat bread prepared in an accelerated way. The use of rowan powder leads to an improvement in the structural-mechanical properties (compressibility, swelling) of the bread prototype. The result can be explained by the fact that it is difficult to release free moisture during the storage of bread due to the influence of the rowan powder, which has a high water absorption capacity, caused by the content of pectin with a high degree of esterification (above 85%).

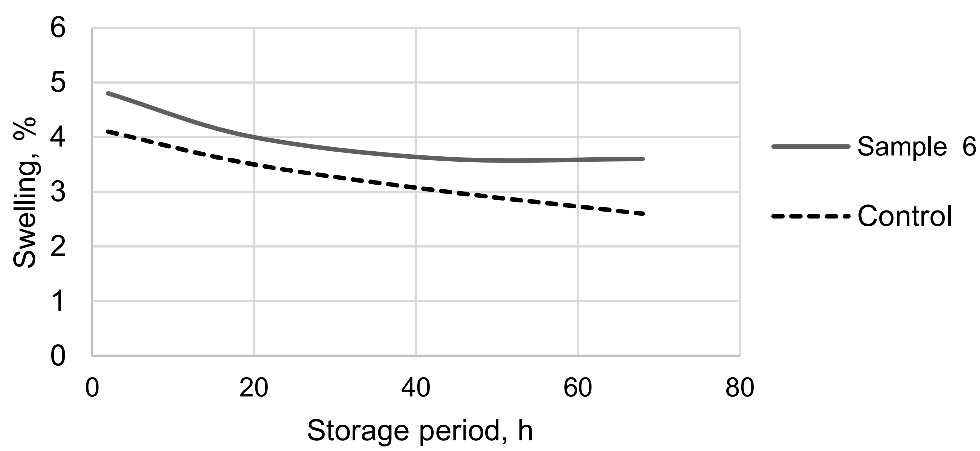

Figure 5. Change in the swelling of the crumb during the storage of bread.

The effect of the rowan powder on the custard bread resistance to the moulds was established. It was found out that in the control bread slices, contaminated by *Penicillium chrysogenum*, the growth of mould colonies was observed in 48 hours, and in samples 7 was not observed during 7 days storage until total slice staling. The usage of the rowan powder allowed slowing down the custard bread mould disease.

CONCLUSIONS

To improve the quality and nutritional value of custard rye-wheat bread produced in an accelerated technology, new acidifying additive with rowan powder was created. The value of rowan powder is that it contains biologically active substances. The optimal dosage of rowan powder in the new acidifying additive was revealed (13% per 100 kg of flour in the dough). It was established experimentally that the use of rowan powder in the accelerated bread technology improves its organoleptic and physico-chemical indicators, and also increases the content of dietary fiber (in 1.85 times), total ash content (by 17%), vitamins and minerals. The compressibility of the control bread decreased by

57%, and that of bread with rowan powder decreased only by 37% during storage, so it confirmed that the rowan powder usage had a positive effect on the preservation of bread freshness during its storage. Therefore, the use of rowan powder allows delaying the release of free moisture and slowing down the staling. The rowan powder usage (13% per 100 kg of flour in the dough) also allowed slowing down the custard bread mould disease.

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