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ORIGINAL RESEARCH PAPER

RHEOLOGICAL INDICATORS OF WHEAT DOUGH WITH THE ADDITION OF LECITHIN AND ORGANIC PUMPKIN SEED MEAL FLOUR FOR BAKERY PRODUCTS

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Abstract

The aim of the study was to determine the influence of pumpkin seed meal flour mixed with phospholipids on the structural and mechanical properties of wheat flour dough. The particle size of wheat flour was mainly 119.7-135.4 µm, of pumpkin seed meal flour – 971.1-1242.0 µm and 196.0-221.6 µm. Wheat flour particles were characterized by an irregular, rather sharp shape with a wider surface. Pumpkin seed meal flour particles has larger size, a smooth surface, and many protein structures. The addition of lecithin to the recipe led to an increase in the storage modulus of the dough samples. It improved the elasticity of the dough. Replacing part of the wheat flour with pumpkin seed meal flour also increased the storage modulus and increased the deformation force necessary to break bonds and destroy such a dough system. The curves of the loss modulus also had an ascending character in proportion to the change in frequency. Replacing part of wheat flour with pumpkin seed meal flour in combination with lecithin changed the structural and mechanical properties of the dough system, such as elasticity and viscosity, resistance to deformation.

Keywords: pumpkin seed meal flour, sunflower lecithin, grain size composition, surface morphology, rheological indicators, bakery dough

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Introduction

During the last decade attention was paid to the aspects of healthy nutrition, the expansion of the range of products with health-improving properties, in particular, in view of the spread of diseases of the gastrointestinal tract. The World Health Organization recommends changing the ratio of the main nutrients that enter the body. Thus, it is necessary to increase the content of dietary fibers and complete proteins in the diet, and reduce the use of saturated fats (Stabnikova *et al.*, 2021). To correct the diet, it is worth paying attention to the intake of these nutrients with basic food products, one of which is bread.

In addition, the vector of achieving sustainable development in the production of food products is maintained throughout the world, which is one of the modern challenges of humanity and requires a holistic approach. Bread, as one of the main foods worldwide, has a significant impact on the sustainability of the food system (especially in terms of environmental impact), food security and food systems, and human health (Tendall *et al.,* 2015).

Bread made from wheat flour is devoid of high nutritional value due to insufficient protein, dietary fiber content, depleted composition of vitamins and minerals.

Animal protein is considered less environmentally sustainable than vegetable protein. Therefore, the use of raw materials rich in plant protein is desirable to maintain environmental stability, improve food safety, meet higher consumer demand, and decrease of protein-energy malnutrition (Langyan *et al.,* 2022).

The positive effect of dietary fiber on the intestinal microbiome, slowing down the course of metabolic diseases (obesity and diabetes), cardiovascular and autoimmune diseases was also established (Ioniță-Mîndrican *et al.,* 2022).

Promising raw materials for correcting the recipe of wheat bread are pumpkin seed products, in particular pulp, fiber, pumpkin oil considering rather high content of vegetable protein (about 40-44%) and dietary fibers (about 12-15%) (Jurgita *et al*., 2014), flour (Shevchenko *et al.,* 2022).

The effect of replacing 15%, 30%, 50% of wheat flour with boiled pumpkin pulp on sensory indicators and quality characteristics of bread was studied. By increasing the amount of pumpkin pulp in the recipe of wheat bread, an increase in the content of ash and crude fiber, in water absorption and the final moisture content of the bread was observed. It also increased the elasticity and porosity of bread. The use of semi-finished products – pumpkin juice and puree contributed to the improvement of the sensory indicators of wheat flour bread (Păucean *et al.,* 2014).

Due to its high moisture-binding capacity, pumpkin flour led to an increase in the moisture content of products (Bhat *et al.,* 2013). The water-absorbing capacity of flour products also increased, which may be due to the presence of hydroxyl groups, which ensured a stronger interaction with water. Pumpkin flour affected the rheological indicators of wheat flour products. The required time for the dough for flour confectionery increased due to a decrease in dough strength due to an increase in fiber content (Jesmin *et al.,* 2016). However, the tensile strength of the dough increased, while the extensibility decreased, which was associated with a partial disruption of the gluten framework due to the interaction between the structural units of pumpkin flour fibers and wheat proteins (Khan *et al.,* 2019).

Pumpkin processing products also contribute to reducing the risk of inflammatory processes in the gastrointestinal tract (Gad *et al.,* 2019). However, there was insufficient data on the effect of pumpkin processing products, in particular pumpkin seed meal flour, on rheological indicators in the process of making bakery products from wheat flour. In addition, the use of pumpkin processing products was recommended in diet therapy in combination with a lipid component, in particular phospholipids, the significant content of which is in lecithin (Dar *et al.,* 2017).

In various food products lecithin is used as an emulsifier. Thus, in the technology of extruded noodles from wheat flour, the addition of lecithin reduced the viscosity of the dough. Also, this additive weakened the structure of the dough and led to a decrease in the strength of the extruded noodles (Shiau, 2004).

The addition of lecithin to the recipe of gluten-free rice bread in the amount of 1.0% to the mass of flour contributed to the improvement of gas formation in the rice dough and had a positive effect on the porosity and specific volume of the finished bread. In addition, due to the high content of phospholipids, lecithin had an important physiological value, as it was involved in the formation of intestinal mucin (Medvid *et al.,* 2018).

The quality of bakery products was affected by the granulometric composition of raw materials, which depended on many factors, including the type of raw materials, feed speed and air pressure in the grinding device (in the case of jet grinding). When these parameters increasd, the content of damaged starch decreased (Protonotariou *et al.,* 2021).

Finer fractions of wheat flour had a lower ash content and a greater amount of dry gluten than coarser fractions. Flour of smaller fractions contributed to the production of bread with better sensory and textural properties. Photomicrographs of finer flour fractions showed a higher number of loosened individual starch granules than aggregates of starch and protein matrix compared to coarser fractions (Sakhare *et al.,* 2014).

It was found that the higher the dispersion of flour, the higher resistance to stretching and the actual extensibility of the cracker dough. The results of baking crackers showed a decrease in the number of bran on the surface with a decrease in their particle size (Wang *et al.,* 2016).

The results of farinograph dough studies showed a clear effect of small particles on increasing water absorption, but dough stability decreased (Ahmed *et al.,* 2021).

It was established that wheat flour particles of different sizes (from 52.36 μm to 108.89 μm) affected the content of damaged starch, as well as the rheological indicators of the dough. As the particle size decreased, the number of damaged granules decreased. The maximum tensile strength increased, but the tensile strength reached a maximum in samples with an average particle diameter (78 and 66 μm). In addition, the ratio of dynamic moduli (G″/G′) decreased with decreasing particle size. Bread making results showed that bread made from wheat flour with a smaller particle size had a significantly lower specific volume than bread made from flour with a larger particle size. Analysis of the texture profile showed that as the size of the wheat flour particles decreased, the hardness and chewability of the bread increased, and the elasticity decreased. In general, the quality of flour with an average particle size (78 μm) was better (Pang *et al.*, 2021).

In addition to bread volume measurement and texture profile analysis, to assess the quality of bread and products of other industries (Kambulova *et al.*, 2020), methods which provide an insight into the quality through the assessment of viscoelasticity using the dynamic oscillation method are used. Viscoelastic effects occur at each stage of the technological process due to changes in gluten and starch in the dough. For example, the storage modulus decreased when protein was damaged during kneading, fermentation, and baking. On the other hand, the loss tangent, which characterizes the ability of dough to behave as a solid or liquid substance, decreased at high temperatures in the oven due to gelatinization of starch and evaporation of water, forming a porous structure characteristic of bread (Gerardo-Rodríguez *et al.*, 2020).

This information confirms the interest of specialists in food industry in the use of non-traditional raw materials for inclusion in the recipe of traditional bakery products from wheat flour in order to expand the range of products, provide them with a health-improving effect and increase the nutritional value. At the same time, there is a need to establish the influence of additives on the course of the technological process of manufacturing bakery products, structural and mechanical properties of dough systems. So, the use of such raw materials as pumpkin seed meal flour and sunflower lecithin is appropriate from the point of view of their positive effect on the human body, in particular, in case of diseases of the gastrointestinal tract.

The purpose of the research was to determine the effect of pumpkin seed meal flour mixed with phospholipids on the structural and mechanical properties of wheat flour dough.

The structural and mechanical properties were studied from the point of view of rheological indicators, which in turn depend in particular on the particle size composition of the components of the formulation and their functional and technological characteristics and properties.

Materials and methods

Materials

For research, there were used wheat flour of premium grade ("KyivMlyn" LLC, Ukraine), salt ("Artemsil" SC, Ukraine), pressed baker's yeast ("Enzym" PJSC, Ukraine), sunflower lecithin with a content of 95.3% phosphatidylcholine (TM Fruity Yummy, Ukraine), pumpkin seed meal flour ("Organic-Eco-Produkt" LLC, Ukraine).

Dough making process

Dough samples were prepared from wheat flour, pumpkin seed meal flour to replace 5%, 10%, 15%, 20% of wheat flour, 3% of sunflower lecithin to the mass of flour, 3% of pressed baker's yeast and 1.5% of salt. The control was a sample from wheat flour pressed baker's yeast and salt. The dough was made using straight dough method.

Size distribution of flour particles

Bettersizer 2600 laser particle size analyzer (Bettersize Instrument Ltd., Dandong, China) was used to determine the particle size distribution in wet dispersion mode using ethanol and ultrasonication. The method was based on the principle of static light scattering, the measurement was carried out in accordance with ISO 13320. The particle size distribution and equivalent diameters at cumulative volumes of 10% (D10), 50% (D50) and 90% (D90) and the specific surface area were determined. A refractive index of 1.53 and an absorption parameter of 0.7 at an air supply pressure of 0.1 MPa were applied. The result was expressed as the mean value of three measurements (Drakos *et al.*, 2017; Lai *et al.*, 2022)

Flour microstructure

The results of the morphological properties of flour were analyzed using a Tescan MIRA 3 LMU scanning electron microscope (BrnoKohoutovice, Czech Republic). Thoroughly mixed flour samples were deposited on conductive carbon tape and coated with a thin layer of 50/50 gold/palladium (30 nm) using a PECS 682 sputtering system. Images were taken at different magnifications for each sample (Red'ko *et al.*, 2021).

Rheological characteristics of the dough

Rheological indicators were determined using Kinexus Pro+ rotary rheometer (Malvern Instruments Ltd., United Kingdom). The PU40 SR5040:PL61 ST geometry was used, which was a flat disk with a diameter of 40 mm, fixed on a vertical shaft. After kneading, a piece of dough weighing 50 g was loaded onto the lower platform of the rheometer, the upper disk fixed on the vertical shaft was lowered, and the dough was compressed to a gap of 18 mm. Then the system was left at rest for 15 min to ensure relaxation of the material. The determination was made at frequencies from 0.01 Hz to 10 Hz with 10 points per decade, the deformation was 1%. Measurements were made at 25ºC, immediately after kneading the dough and after 3.5 hours of fermentation (the total time of fermentation and proofing of dough for making bread). Using the rSpace software, the dependence curves were obtained using a frequency sweep oscillation test (Cristiano *et al.*, 2019). The results are presented in a logarithmic dependence.

Statistical analysis

The statistical processing of the result values was performed by sequential regression analysis using Origin Pro8 software.

Results and discussion

Characterization of the particle size distribution and microstructure of wheat flour and organic pumpkin seed meal flour

The course of processes in dough and its rheological indicators, which affect the quality and structure of finished bakery products, primarily depend on the chemical composition and properties of the raw materials from which such products are made. The most important characteristics of loose raw materials, in particular flour, are its granulometric composition, particle shape and functional and technological properties.

The size distribution of wheat flour and pumpkin seed meal flour particles is shown in Figure 1.

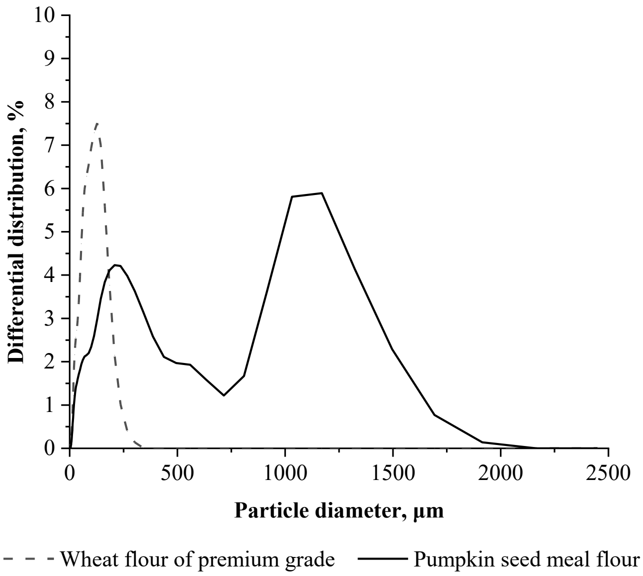

Figure 1. Particle distribution profile of wheat flour of premium grade and pumpkin seed meal flour.

The distribution curve of pumpkin seed meal flour was shifted to the right relative to the curve of wheat flour, which indicated a larger particle size. The wheat flour curve had a unimodal distribution with a peak in the range of 119.7-135.4 µm. The curve of pumpkin seed meal flour had a bimodal character, which indicated the unevenness of the available granules and the coexistence of fine and coarse particles. The main peak was observed in the size range of 971.1-1242.0 µm, the second – 196.0-221.6 µm. There was also an existing shoulder between them, extended from 410.2 to 858.6 µm. The percentage distribution of particles is given in Table 1.

Almost all wheat flour particles had diameter of up to 400 µm, while most pumpkin seed meal flour particles had much larger diameter. From the cumulative distribution of particles by size, D10, D50 and D90 were determined, which corresponded to the percentage content of 10%, 50% and 90% of particles below the declared size. 90% of all wheat flour particles had a size of less than 200 microns, while for pumpkin seed meal flour this limit was much higher.

Table 1. Distribution of particles of wheat flour of premium grade and pumpkin seed meal flour in percentage ratio (n = 3, p ≤ 0.05).

Particle diameter, µm	**Number of particles, %**	
	Wheat flour of premium grade	**Pumpkin seed meal flour**
0-400	98.66±0.05	66.31±0.05
400-500	0.04±0.001	3.84±0.001
500-600	0.3±0.001	2.88±0.001
600-700	0.52±0.001	1.84±0.001
700-800	0.3±0.001	1.49±0.001
800-900	0.12±0.001	2.29±0.001
900-1000	0.06±0.001	3.6±0.001
1000-1500	0.0±0.0	15.76±0.001
1500-2000	0.0±0.0	1.97±0.001
2000-2500	0.0±0.0	0.02±0.001
%	**Particle diameter, µm**	
D10	22.53±0.05	34.43±0.05
D50	80.27±0.05	226.1±0.10
D90	163.9±0.05	1176.0±0.50

Granulometric data were confirmed using scanning microscopy for each flour sample (Figure 2).

Wheat flour particles were characterized by an irregular, fairly sharp shape with a wider surface. There were two types of distribution of starch granules in their structure: large granules of approximately 20 µm and small granules of approximately 2-5 µm.

Compared to the wheat flour sample, the pumpkin seed meal flour particles were larger in size, had a smooth surface and many protein structures. The reason for this was the significantly higher protein content of this flour (Litvynchuk *et al.*, 2022).

Effect of pumpkin seed meal flour and lecithin addition on the wheat dough rheology

The influence of recipe components and their particle size distribution will greatly affect the structural and mechanical properties of dough and bread. The rheological indicators of the dough during the fermentation process were measured using the dynamic oscillation test. The measurement was performed in the linear viscoelastic mode at shear stress values that did not destroy the structure of the test system. The small-amplitude vibrational dynamic test was an effective tool for studying the viscoelastic properties of dough.

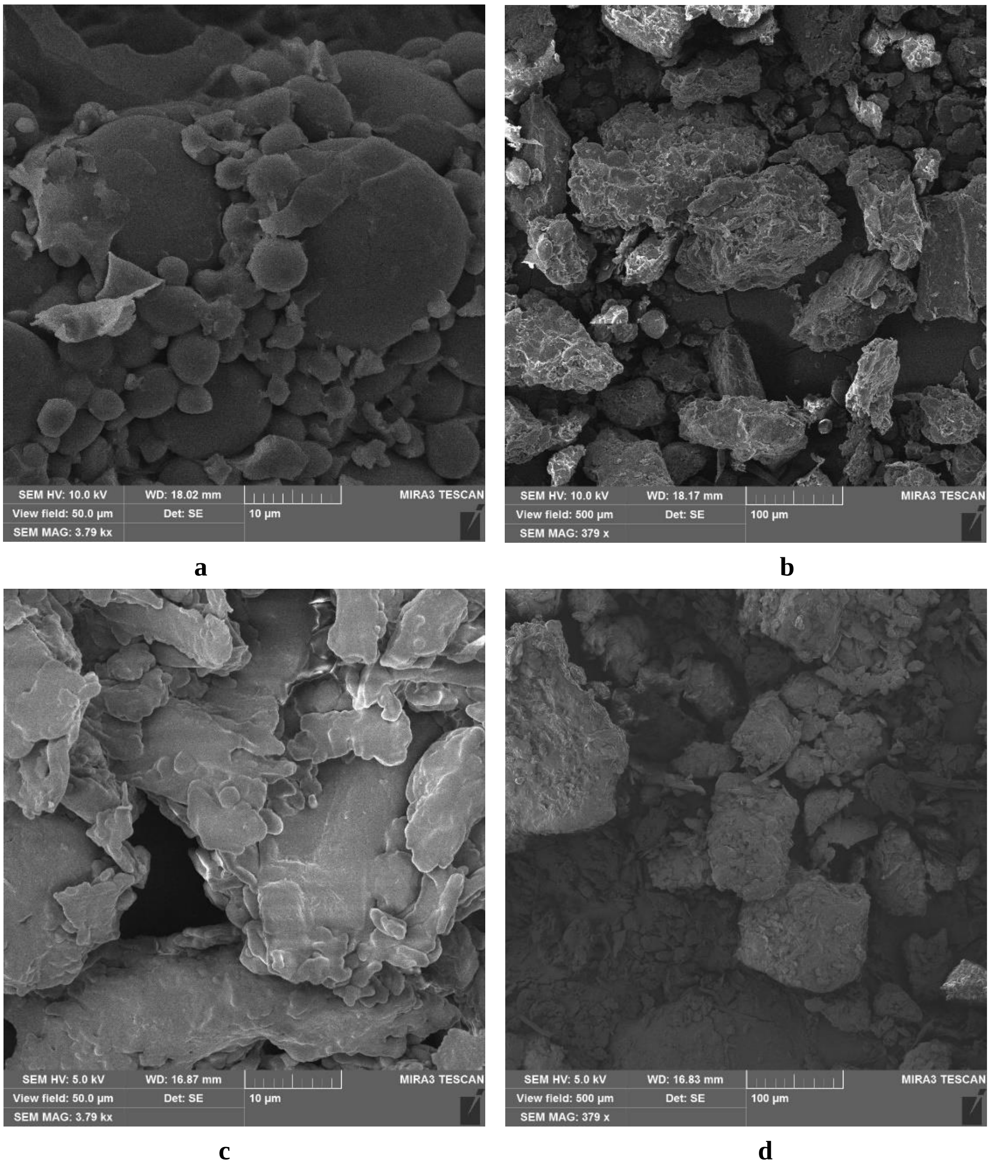

Figure 2. Photomicrographs (of different resolutions) of surface morphology: a, b –wheat flour of premium grade; c, d - pumpkin seed meal flour.

The storage modulus (G′) was used to determine the elastic characteristics and reflected the degree of deformation of the sample (Figure 3a, 3b). The loss modulus (G″) characterized the viscous properties of the dough and reflected the resistance of the sample to flow (Figure 3c, 3d). The loss tangent value tan(δ) was also determined, which was a measure of the relative size of the viscous and elastic parts of the dough system and characterized the ability of the dough to behave as a solid or liquid substance (Figure 3e, 3f).

For all dough samples, the same trend was observed – increasing G′ and G″ values with increasing frequency. This was characteristic of springy-elastic and at the same time visco-plastic systems (Selaković *et al.*, 2021), which were all the tested dough samples.

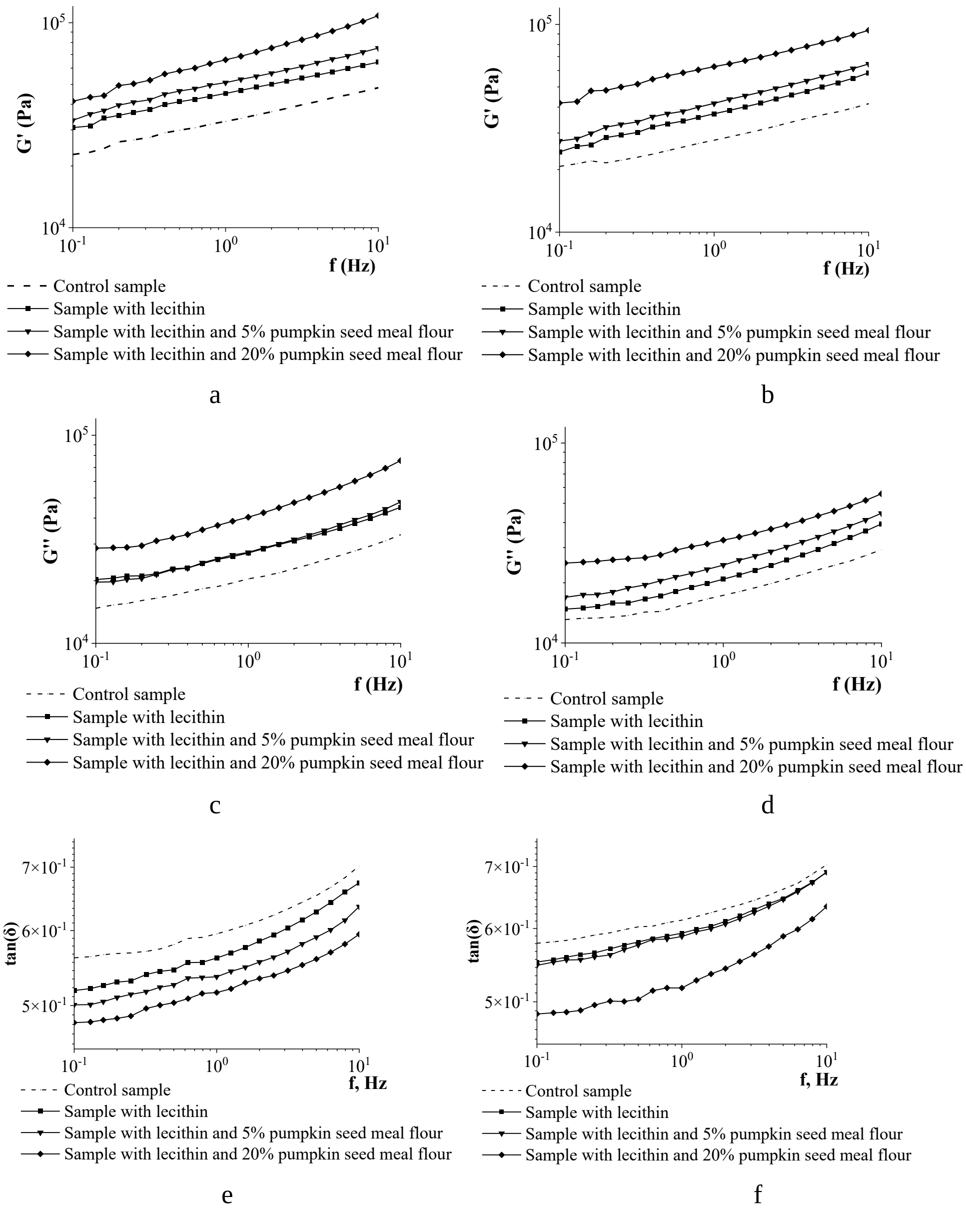

Figure 3. Storage modulus (a, b), loss modulus (c, d) and loss tangent (e, f) of dough samples with lecithin and replacement of 5% and 20% of wheat flour with pumpkin seed meal flour: a, c, e – after 20 minutes after mixing; b, d, f – after 3.5 hours of fermentation.

The value of the storage modulus G′ and the loss modulus G″ for samples with lecithin and for samples with the replacement of wheat flour with organic pumpkin meal flour was the higher, the higher the amount of additives.

The increase in the experimental parameters of wheat dough under the influence of lecithin can be explained first of all by the ability of lecithin to form liquid crystalline phase in water, which is associated with gliadin (Ahmed *et al.*, 2020). These structures helped to increase the elasticity of the dough, allowing the gas bubble to expand during the fermentation process, which led to an increase in the volume of the finished products. It is also known about the ability of lecithin to strengthen wheat dough due to the creation of a lecithin-gluten complex (Coelho *et al.*, 2015).

For samples with the introduction of pumpkin seed meal flour, this pattern is associated with the different granulometric composition of the tested types of flour. As established above, pumpkin seed meal flour particles had a lower dispersion compared to wheat flour, which caused differences in the interaction of protein substances and starch granules with water (Cristiano *et al.*, 2019). In turn, the water absorption and moisture retention capacity of the flour mixture changed and the storage and loss moduli increased. After 3.5 hours of fermentation, the structure of wheat dough weakened due to colloidal and enzymatic processes, and the values of storage and loss moduli were somewhat lower compared to those for freshly kneaded dough. However, the patterns were preserved and the moduli were higher in dough samples with lecithin and in samples with the replacement of wheat flour with organic pumpkin seed meal flour.

The values of storage modulus G′ for all samples were higher than the modulus of viscosity G″, indicating that elastic properties of the dough were manifested to a greater extent than the visco-plastic ones. For the control dough after kneading, the storage modulus at a minimum 0.1 Hz frequency and a maximum 10 Hz, 1.5 times exceeded the loss modulus. That is, the formed strong gluten framework allowed the dough structure to be maintained under the influence of vibrations at all measuring frequencies. For the dough with lecithin after kneading, the storage modulus at the minimum experimental frequency 1.8 times exceeded the loss modulus, and at the maximum frequency – 1.6 times. The structure of such dough at the minimum frequency values was more elastic compared to the control sample, and in the process of significant mechanical impact, intramolecular changes occured and the structure weakened. For the sample with lecithin and replacement of 5% wheat flour by pumpkin seed meal flour, the storage modulus at the minimum experimental frequency 1.7 times exceeded the loss modulus, which also proved the development of an springy-elastic structure due to changes in the flour composition. Such a structure was more resistant to mechanical stress and at the maximum frequency the ratio of the storage modulus to the loss modulus was 1.6, which, in turn, was greater than that of the control sample. In the sample with 20% of wheat flour replaced by pumpkin seed meal flour, for which the highest values of experimental indicators were noted, the storage modulus at the minimum and maximum frequencies exceeded the loss modulus 1.4 times, i.e. the difference between the springy-elastic and visco-plastic characteristics was smaller than in the control sample, which indicates a decrease in the springy-elastic characteristics.

Determination of tan (δ), which characterizes the ability of the dough to behave as a solid or liquid substance, showed that the values for samples with additives were lover compared to the control sample of wheat dough immediately after kneading. This indicates the superiority of hardness in the structure and is consistent with the previously presented data on the springy-elastic characteristics of the structure of these samples. At the minimum frequency tan (δ) of samples with lecithin was lower than the control sample by 7.6%, for sample with the addition of 5% pumpkin seed meal flour - by 10.8%, for sample with the addition of 20% pumpkin seed meal flour - by 14.6%. At the maximum frequency the values left lower than the control by 4%, 9.4% and 15.3%, respectively.

During further fermentation of dough samples, the structure changed due to microbiological, enzymatic and colloidal processes. Therefore, the curves of the dependence of the tangent of losses on the frequency of oscillations change their character. It is shewn in the figure 3f that the curves of the experimental samples with lecithin and pumpkin seed meal flour have significantly approached the curve of the control sample. Indeed, the difference in their indicators has decreased and at the minimum frequency of 0.1 Hz it was 4.6% (for the sample with lecithin), 5.4% (for the sample with lecithin and the replacement of 5% of wheat flour with pumpkin seed meal flour). The sample with the introduction of 20% of pumpkin seed meal flour at a frequency of 0.1 Hz was 16% less than the control, which indicates the preservation of the hardness of its structure under the influence of the frequency of mechanical impact.

Similar trends were observed for samples at the maximum frequency of 10 Hz. The difference between the control sample and the sample with lecithin was 1.8%, for the sample with lecithin and a 5% replacement of wheat flour with pumpkin seed meal flour – 1.8%, and for the sample with lecithin and a 20% replacement - 9.9%. Therefore, fermentation did not significantly affect the change in the internal structure of only the dough with lecithin and 20% pumpkin seed meal flour, since the higher concentration of dietary fiber in such flour and the higher amount of protein increased the intermolecular interaction (Milićević *et al.*, 2020). However, at the maximum experimental values, the load still collapsed and the system began to acquire the characteristics of a liquid body.

For the experimental samples, the dependence of the shear viscosity, the complex shear stress, and the phase angle on the frequency range was also determined.

The dependences of the shear viscosity on the frequency range (Figure 4) showed a decrease in the shear viscosity values in all samples with an increase in frequency, which is naturally associated with the destruction of the dough structure in the process of increasing mechanical impact. Along with this, it was noted that the shear viscosity values of the control sample are inferior to the viscosity values of samples with the introduction of lecithin or samples with pumpkin seed meal flour. Thus, at a minimum frequency of 0.1 Hz, the shear viscosity for the sample with lecithin was 37% higher than the control sample, for the sample with lecithin and the replacement of 5% of wheat flour with pumpkin seed meal flour the difference was 44%, and the sample with lecithin and the introduction of 20% of pumpkin seed meal flour was 84% higher. This confirms the development of a stronger dough structure in samples with experimental additives and is consistent with the patterns obtained when determining other rheological characteristics: storage modulus G′, loss modulus G″ and loss tangent. Indeed, changes occurred in the structure of the dough with the replacement of wheat flour, which characterize the strengthening of its structure: an increase in the content of dietary fibers and their participation in the formation of the gluten matrix, a change in the ratio of the fractional composition of proteins, namely an increase in the share of the globulin fraction and a decrease in glutelin, prolamin, an increase in water-holding and water-binding capacity (Litvynchuk *et al.,* 2022). The most pronounced differences were inherent in dough samples with lecithin and the replacement of 20% of wheat flour with pumpkin seed meal flour.

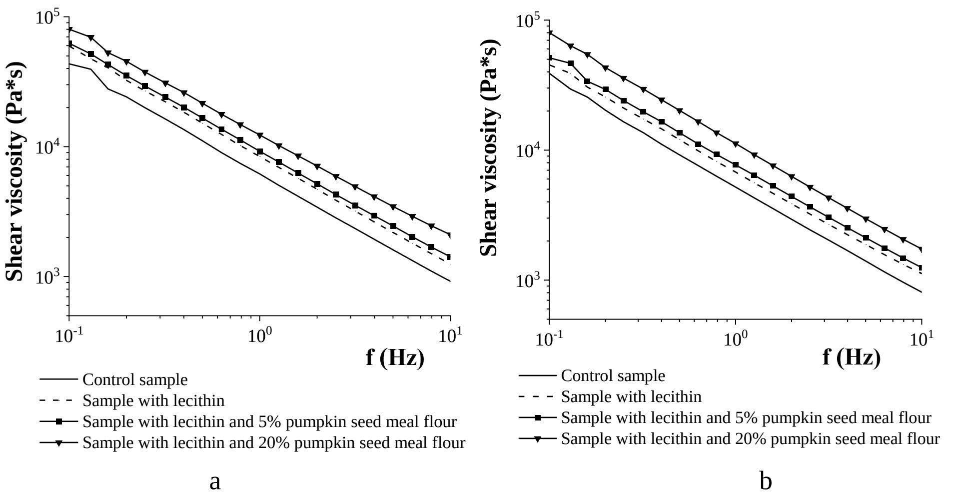

Figure 4. Shear viscosity of dough samples with lecithin and replacement of 5% and 20% of wheat flour with pumpkin seed meal flour:
a – after 20 minutes after mixing; b – after 3.5 hours of fermentation.

At a frequency of 10 Hz of mechanical impact on the dough, when the maximum intense action was exerted on the experimental system in the selected frequency range, a similar dependence was observed: the difference between the control sample and the sample with lecithin was 35%, for the sample with lecithin and a 5% replacement of wheat flour with pumpkin seed meal flour – 54%, and for the sample with lecithin and a 20% replacement - 128%.

For the dough that has been fermented, the shear viscosity values were lower compared to the values determined for the freshly kneaded dough. This is due to the occurrence of various biochemical processes, especially the hydrolysis of proteins, polysaccharides, alcoholic and lactic acid fermentation, an increase in the volume of carbon dioxide in the dough. However, the patterns in the relationship of the experimental samples compared to the control sample remain unchanged.

With an increase in the oscillation frequency from 0.1 to 10 Hz, the complex shear stress of each sample increased (Figure 5). Thus, in the control dough sample after kneading, the indicator increased 2.43 times, in the dough sample with lecithin - 2.38 times, in the samples with the introduction of pumpkin meal flour 5 and 20% - 2.58 and 2.89 times, respectively. The difference between the control sample and the sample with lecithin at the minimum frequency of 0.1 Hz was 38.7%, for the sample with lecithin ans the replacement of 5% of wheat flour with pumpkin seed meal flour - 45%, and for the sample with lecithin and the replacement of 20% - 91%. Similar dependences of the complex shear stress between the samples were also noted at the maximum frequency, which indicates an increase in the total force applied to deform the samples.

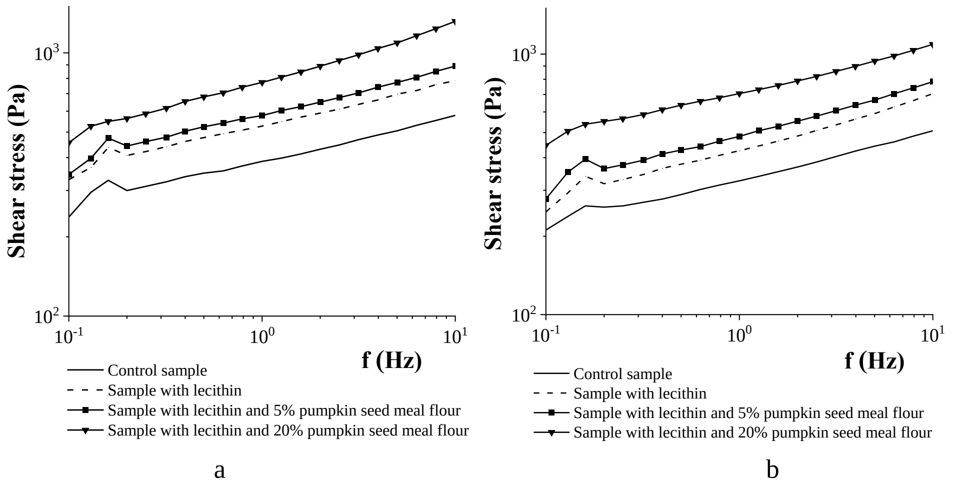

Figure 5. Shear stress of dough samples with lecithin and replacement of 5% and 20% of wheat flour with pumpkin seed meal flour:

a – after 20 minutes after mixing; b – after 3.5 hours of fermentation

Since the fermentation process affects the change in the internal structure of the dough, the complex shear stress index for all samples after fermentation decreased.

Analysis of the change in the phase angle index from the frequency when lecithin and pumpkin seed meal flour are jointly added to the dough showed (Figure 6) that at the minimum frequency the difference in the values of the phase angle of the samples after mixing and after fermentation was: when replacing 5% and 20% of flour – 2.95° and 4.15°, after fermentation – 0.8° and 4.1°, respectively. In the process of increasing the frequency, the trend was maintained. The curves of the control dough sample both after mixing and after fermentation were characterized by a greater slope than the samples with additional raw materials, which is explained by the lower viscosity of the dough and correlates with the previously obtained viscosity data. With an increase in the percentage of replacing wheat flour with pumpkin seed meal flour, the phase angle of the dough samples decreased and tended to zero, which indicates the resistive nature of such dough compared to the control. Moreover, samples after kneading were more resistant to the influence of vibration frequencies. However, with increasing frequency, the phase angle of all samples naturally increased, which indicates a decrease in the resistance of the dough to the destruction of its internal structure.

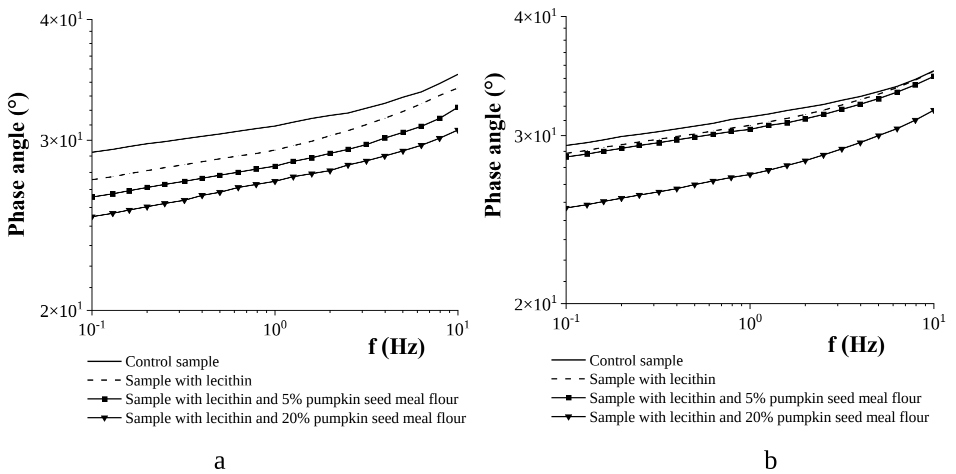

Figure 6. Phase angle index of dough samples with lecithin and replacement of 5% and 20% of wheat flour with pumpkin seed meal flour:
a – after 20 minutes after mixing; b – after 3.5 hours of fermentation.

The decrease in the phase angle is also associated with the content and quality of protein in the dough (in particular, the ratio of gliadin-glutenin fractions and the number of low- and high-molecular glutenin subunits). Since the introduction of pumpkin seed meal flour reduces the gluten content and changes its qualitative composition (Drobot *et al.*, 2021), and the introduction of lecithin affects the structure formation of the gluten framework, it is natural that the phase angle of the dough samples changes.

Thus, replacing a part of wheat flour with pumpkin seed meal flour in combination with lecithin changed the structural and mechanical properties of the dough system, such as elasticity and viscosity, resistance to deformation, which will have an impact on the quality indicators of finished bakery products with this raw material in the recipe.

Conclusions

To evaluate the influence of pumpkin seed meal flour in combination with phospholipids on the structural and mechanical properties of the dough for bakery products, its rheological characteristics were studied – storage modulus (elastic modulus), loss modulus (viscosity modulus), loss tangent, shear viscosity, complex shear stress and phase angle. Other parameters, such as particle size composition and surface morphology of wheat flour and pumpkin seed meal flour, were interrelated and also had an influence on the studied indicators. It was established that the particle size of wheat flour was mainly 119.7-135.4 microns, while pumpkin seed meal flour was 971.1-1242.0 microns and 196.0-221.6 microns.

Wheat flour particles were characterized by an irregular, rather sharp shape with a wider surface. There were two types of distribution of starch granules in their structure: large granules of approximately 20 µm and small granules of approximately 2-5 µm. Pumpkin seed meal flour particles were larger in size, had a smooth surface and many protein structures.

The addition of lecithin to samples of bread dough from wheat flour increased the storage modulus and loss modulus of the dough, shear viscosity and shear stress, reduced the loss tangent and phase angle, which indicates the strengthening of its internal structure. This effect of lecithin can be explained by the ability of lecithin to form liquid crystalline phases in water associated with gliadin, and due to hydrophobic interaction to promote the aggregation of gluten proteins in the lecithin-gluten complex. As a result, an improvement in the elasticity of the dough during fermentation was observed.

Replacing 5 and 20% of wheat flour with pumpkin seed meal flour had a greater effect. Pumpkin flour particles had a lower dispersion compared to wheat flour, which caused differences in the interaction of protein substances and starch granules with water, changes in the water absorption and moisture retention capacity of the flour mixture. This was reflected in the increase in storage and loss moduli, an increase in shear viscosity and complex shear stress, a decrease in the values of the loss tangent and phase angle. Therefore, changes occurred in the structure of the dough, which characterize the strengthening and elasticity of its structure. The explanation for this conclusion may be an increase in the content of dietary fibers in the flour mixture when pumpkin seed meal flour was added and their participation in the formation of the gluten matrix, a change in the ratio of the fractional composition of proteins, namely an increase in the share of the globulin fraction and a decrease in the glutelin, prolamin, increase in water-holding and water-binding capacity. The most pronounced differences were inherent in dough samples with the replacement of 20% of wheat flour with pumpkin seed meal flour.

During dough fermentation, its structure was weakened due to biochemical and colloidal processes, the values of all indicators were lower than those of the dough immediately after kneading, but the patterns of the influence of the experimental additives and the degree of their influence were preserved.

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