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Effects of a Plant-Based Additive on the Properties of Flour and Dough during Fermentation

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Abstract.
To ensure a balanced diet, bakers use plant-based raw materials with a high nutritional value which affect the properties of flour and dough. We aimed to study the effects of a complex additive based on plant components on wheat flour's amylolytic activity and gas-forming ability, as well as on the dough's rise and gas-retaining ability during fermentation.

Our study objects included premium wheat flour, a water-flour suspension, and wheat dough with a complex additive (at concentrations of 10, 16, and 22% by weight of flour mixtures). The additive contained whole wheat flour, crushed sprouted spelt, powdered pumpkin seeds, oyster mushrooms, and gooseberries at a ratio of 56.3:25.0:17.2:0.9:0.6, respectively. An amylograph-E was used to study the viscosity of the water-flour suspension during heating, an ICHP-1-2 apparatus measured the falling number, and an F4 rheofermentometer assessed the flour's gas-forming ability and the dough's rise and gas-retaining ability.

The complex additive improved the enzymatic activity of the flour, increased the dough rise by an average of 8.4 mm, and reduced the fermentation time needed to reach the maximum height by an average of 17.8%, compared to the control. The total volume of carbon dioxide, as well as the volumes of lost and retained carbon dioxide, increased by an average of 35.8, 99.7, and 26.9%, respectively, compared to the control. The optimal concentration of the complex additive introduced into premium wheat flour was 16%, at which the dough rose to its maximum height and had the longest porosity time. To obtain high-quality products with this concentration of the additive, the total time of dough fermentation and proofing should be reduced by 17.8% compared to the unfortified dough.

The results can be used in the production of bakery products from premium wheat flour fortified with the complex additive based on plant components. During the process, it is important to determine the duration of dough maturation and reduce the total time of dough fermentation and proofing depending on the concentration of the additive. Further research is needed to study the effect of the complex additive on the structural and mechanical properties of dough during its development.

Keywords. Bakery products, dough, plant raw materials, fortification, quality, gas formation, gas-retaining ability, amylolytic activity, amylogram

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Влияние комплексной добавки на хлебопекарные свойства муки и теста при брожении

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Аннотация.
В хлебопекарной промышленности для обеспечения сбалансированности состава готовых изделий используется растительное сырье повышенной пищевой ценности, которое влияет на свойства муки и тестовых полуфабрикатов. Цель исследования заключалась в изучении влияния пищевой комплексной добавки на основе композиции растительных компонентов на амилолитическую активность и газообразующую способность муки пшеничной, динамику поднятия и газоудерживающую способность теста в процессе брожения.
Объектами исследования являлись мука пшеничная высшего сорта, водно-мучная суспензия и пшеничное тесто с пищевой комплексной добавкой (в концентрациях 10, 16 и 22 % к массе готовых мучных смесей). Пищевая комплексная добавка представляет собой смесь муки пшеничной обойной и измельченной пророщенной спельты, а также порошков семян тыквы, плодовых тел грибов вешенки и ягод крыжовника при соотношении 56,3:25,0:17,2:0,9:0,6 соответственно. Вязкость водно-мучной суспензии исследовали при нагревании с применением амилографа-Е, число падения определяли на приборе ИЧП-1-2, газообразующую способность муки, динамику поднятия и газоудерживающую способность теста – на реоферментометре F4.
Установлено, что при внесении пищевой комплексной добавки повышается ферментативная активность муки, увеличивается высота подъема теста в среднем на 8,4 мм и сокращается продолжительность брожения до достижения максимальной высоты подъема в среднем на 17,8 % по сравнению с контролем. Выявили увеличение общего объема и объемов потерянного и удержанного углекислого газа в среднем на 35,8, 99,7 и 26,9 % соответственно по сравнению с контролем. Оптимальная концентрация пищевой комплексной добавки совместно с пшеничной мукой высшего сорта составляет 16 %. В этом случае отметили максимальные высоту подъема теста и время начала потери тестом углекислого газа. Для получения готовых изделий высокого качества при данной дозировке пищевой добавки общее время брожения теста и расстойки тестовых заготовок следует сократить на 17,8 % по сравнению с тестовыми полуфабрикатами без добавки.
Полученные результаты могут быть использованы в производстве обогащенных хлебобулочных изделий из пшеничной муки высшего сорта с внесением пищевой комплексной добавки на основе растительных компонентов. Необходимо определять продолжительность созревания теста и сокращать общее время брожения и расстойки тестовых заготовок в зависимости от дозировки добавки. Целесообразно продолжить исследования в направлении изучения влияния пищевой комплексной добавки на структурно-механические свойства тестовых полуфабрикатов в процессе созревания.

Ключевые слова. Хлебобулочные изделия, тесто, растительное сырье, обогащение, качество, газообразование, газоудерживающая способность, амилолитическая активность, амилограмма

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Introduction

Public health maintenance is a major strategic task that involves creating conditions for a balanced diet. The growth in non-infectious diet-related diseases is a cause of disability and lower life expectancy [1, 2]. Monitoring surveys among Russian children and adults show that their diets do not comply with the principles of healthy nutrition. In particular, they have high calorie and fat intakes and are low in proteins, vitamins, macro- and microelements, and fiber [3, 4].

This adds weight to the studies aiming to enhance the nutritional value of food products by enriching them with highly nutritional ingredients [5–9]. A balanced diet should contain enriched staple foods, such as bakery products, which are affordable for various population groups [10].

Bakers use various raw materials of plant origin to increase the nutritional value of products and enhance their functional properties [11–15]. Sprouted spelt, pumpkin seeds, oyster mushrooms, and gooseberries are some of the most promising raw materials in terms of their chemical composition and technological properties. In previous studies, we established an optimal ratio of these ingredients in a complex food additive and determined its effect on the rheological properties of wheat dough during kneading [16, 17].

Fermentation and proofing of dough pieces are important stages in the production of bakery products. During these stages, the dough loosens and accumulates those compounds which are responsible for the bread's taste and aroma during baking. The dough's loosening during fermentation depends on its rheological properties, namely its ability to expand and retain carbon dioxide produced under the action of yeast. Changes in the dough's rheological properties during fermentation affect its workability when cutting, shaping, and rounding. This way, they affect the quality of the finished product [18]. Of great importance is also the gas-forming ability of flour. It is determined by the content of sugars, the amylolytic activity of enzymes, and the degree of damage to starch granules [19, 20].

Enriching additives change the baking properties of flour and the intensity of dough fermentation. Therefore, these properties need to be evaluated when using non-traditional ingredients [12]. The amylolytic activity of flour can be determined by the falling number. This indicator indirectly assesses the viscosity of a gelatinized flour suspension by the speed of the lowering stirrer rod [21]. Alternatively, amylographs and viscometers are used to directly determine changes in viscosity over time during starch gelatinization by the magnitude of the torque [22].

Several methods are applied to assess the rheological properties of dough during fermentation. One of them determines the dynamic density of dough [23]. A maturograph (Brabender) is used to measure the volume of dough during proofing [24]. A rheofermentometer (Chopin Technologies) can assess the height of dough and the volume of gas released and retained during dough fermentation [25, 26]. In baking, it is mainly used to study the enzymatic activity of flour and yeast action, as well as the effect of technological additives, enzymes, or non-traditional ingredients on the process of dough fermentation [25]. In addition, a rheofermetometer can indirectly indicate the quality of complex gluten proteins [21].

We aimed to study the effect of a complex additive on the amylolytic activity and gas-forming ability of flour, as well as the dough's rising and gas-retaining ability during fermentation.

Study objects and methods

For this study, we used the following raw materials and ingredients:

1) premium wheat flour (Makfa, Russia), State Standard 26574-2017;

2) a complex additive consisting of whole wheat flour (Garnets, Russia), State Standard 26574-2017, crushed sprouted spelt, and powders of pumpkin seeds, oyster mushrooms, and gooseberries obtained in a vibrating dryer-mill in a ratio of 56.3:25.0:17.2:0.9:0.6, respectively [27]. The composition of the additive was based on the experiments reported in [16]. The additive was introduced into the flour at concentrations of 10, 16, and 22%;

3) pressed baking yeast (Saf-Neva, Russia), State Standard R 54731-2011; and

4) food-grade salt (Araltuz, Kazakhstan), State Standard R 51574-2018.

The amylolytic activity of the flour was determined by the viscosity of a water-flour suspension (80 g flour, 450 mL distilled water) during its gelatinization when heated according to State Standard ISO 7973-2013, using an amylograph-E (Brabender, Germany). Another indicator of the amylolytic activity was the falling number. It was determined by the Hagberg-Perten method on an IChP-1-2 apparatus (Dolgoprudnenskoe Research and Production Enterprise, Russia) according to State Standard ISO 3093-2016.

The flour's gas-forming ability and the dough's rising and gas-retaining ability were determined on an F4 rheofermentometer (Chopin Technologies, France). The dough samples were kneaded for 4 min in a U1-ETV-MT laboratory dough-maker for trial baking (Mototech, Russia) according to the formulations in Table 1. The moisture content in the finished wheat dough was 44%.

Rheofermentometer studies were conducted according to the AACC Standard 89-01 to measure yeast activity and gas production [28]. For this, 315 g dough samples were placed in the fermentation chamber, with a 2000 g load placed on top of them.

Table 1. Formulations for dough samples from premium wheat flour

Таблица 1. Рецептуры тестовых полуфабрикатов из пшеничной муки высшего сорта

Ingredients, g	Control	Concentrations of the additive to the weight of the flour mixture, %		
		10	16	22
Premium wheat flour grade	100	90	84	78
Complex additive	0	10	16	22
Pressed yeast	2,8	2,8	2,8	2,8
Food-grade salt	2	2	2	2
Water	as calculated	as calculated	as calculated	as calculated

The measurements were taken at 28.5°C for 180 min, namely:

1) the maximum dough height under load (H_m, mm);

2) the maximum dough height corresponding to the maximum volume (H'_m, mm);

3) the dough height at the end of the study (h, mm);

4) the dough falling coefficient (($H_m - h$) × 100/H_m, %);

5) the dough rise rate ($DS = H_m^{40\ min} - H_m^{10\ min}/30$);

6) the fermentation time needed to reach maximum height (T_1, min);

7) the fermentation time needed to reach maximum volume (T'_1, min);

8) the dough porosity time, or the time at which the dough begins to lose carbon dioxide (T_x, min);

9) the volume of carbon dioxide lost (V_1, mL);

10) the volume of carbon dioxide retained (V_2, mL);

11) the total volume of carbon dioxide produced (V_{1+2}, mL); and

12) the gas retention coefficient (V_1 × 100/V_{1+2}, %).

MS Excel was used for statistical analysis, equations of second degree polynomial regression, and reliable approximation R^2. Statistica 13 was used for correlation analysis.

Results and discussion

The baking properties of wheat flour largely depend on starch gelatinization and α-amylase activity. These indicators can be measured using an amylograph-E. This apparatus heats the water-flour suspension at 1.5°C/min, which is consistent with the heating rate of dough pieces in the oven [21]. Figure 1 shows the amylograms of a water-flour suspension made from premium wheat flour and containing a complex additive. Their analysis is presented in Figs. 2 and 3.

According to Fig. 1, the complex additive increased the gelatinization start temperature by an average of 0.8°C compared to the control, with a maximum reached by its concentration of 22%. However, higher concentrations of the additive decreased the gelatinization temperature and maximum viscosity. This is due to the amylolytic enzymes in sprouted spelt contained in the additive. The given changes corresponded to the second degree polynomial equations and were confirmed by the values of reliable approximation R^2 (Fig. 2).

Figure 3 shows the effect of the complex additive on the falling number of premium wheat flour and the time it took the water-flour suspension to reach maximum viscosity during heating.

We found that increased concentrations of the complex additive decreased the falling number and the time it took the water-flour suspension to reach maximum viscosity during heating. The correlation analysis showed a significant relationship between the falling number (Fig. 3) and the amylograph-E's measurements (Figs. 2 and 3) of gelatinization temperature (r = 0.99, p = 0.007), maximum viscosity (r = 0.99, p = 0.007), and the time of reaching maximum viscosity (r = 0.99, p = 0.007). The data indicated that the complex additive increased the enzymatic activity of wheat flour, which helps to reduce the time of dough fermentation and proofing.

The effects of the complex additive on the gas-forming ability of flour, as well as the rising and gas-retaining abilities of dough during fermentation are presented in Figs. 4–8.

The dough rise curves (Fig. 4) show a rapid increase in the dough height at the beginning of fermentation. This was due to the dough's ability to hold all the gas produced by the yeast. However, as fermentation continued, the dough rose more slowly until it reached its maximum height and stopped rising. During this process, only part of the gases was retained, while the rest was lost. Pores forming as a result of gas retention expanded and some of them were destroyed by increasing pressure, releasing some of the gases and preventing the dough rise [19].

The maximum dough height under load (H_m, mm) depends on the gluten framework and the dough's rheological properties, as well as correlates with the volume of the finished bread. This indicator characterizes the gas-forming ability of flour and the general structure of the matrix in the system. Higher H_m values mean that the combination of gas production and matrix structure is more conducive to dough volume maintenance compared to the system with lower H_m values. The more gas is retained in the dough, the higher the volume of the finished bread [20].

According to Figs. 4 and 5, introducing the complex additive into premium wheat flour increased the height

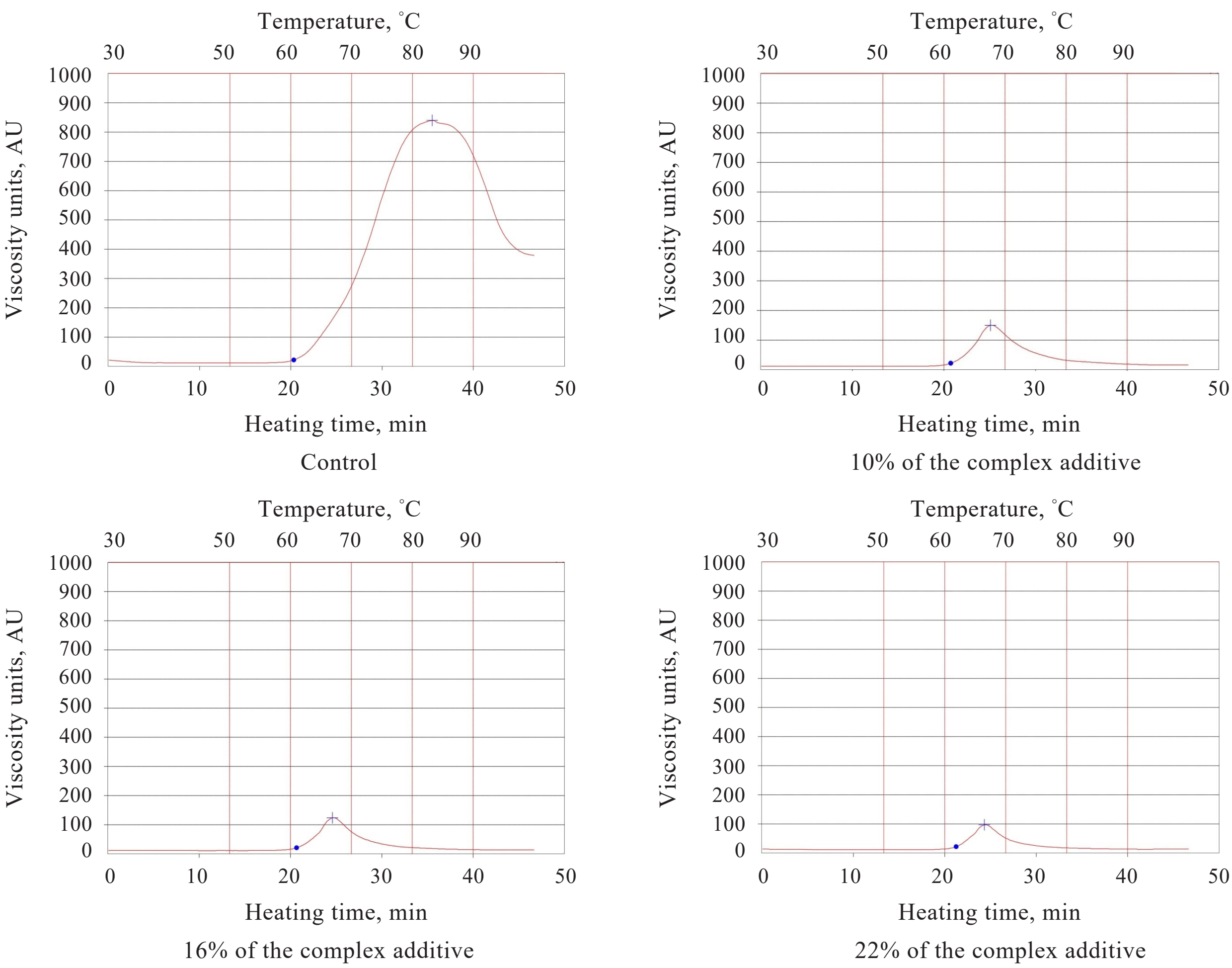

Figure 1. Amylograms of a water-flour suspension from premium wheat flour and the complex additive

Рисунок 1. Амилограммы водно-мучной суспензии из смеси муки пшеничной высшего сорта и пищевой комплексной добавки

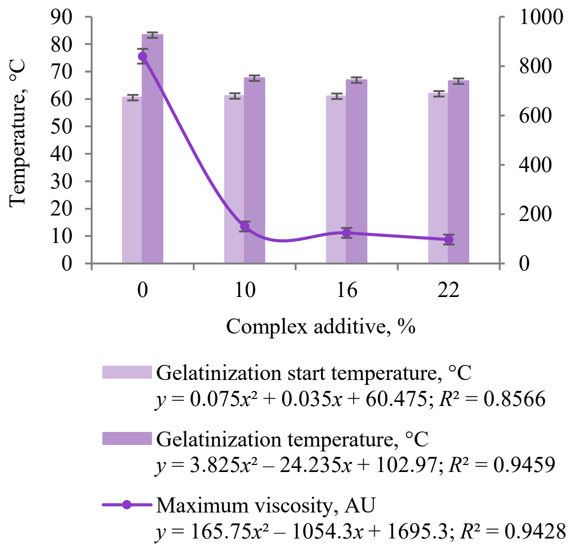

Figure 2. The effect of the complex additive on the gelatinization of a water-flour suspension

Рисунок 2. Влияние пищевой комплексной добавки на показатели клейстеризации водно-мучной суспензии

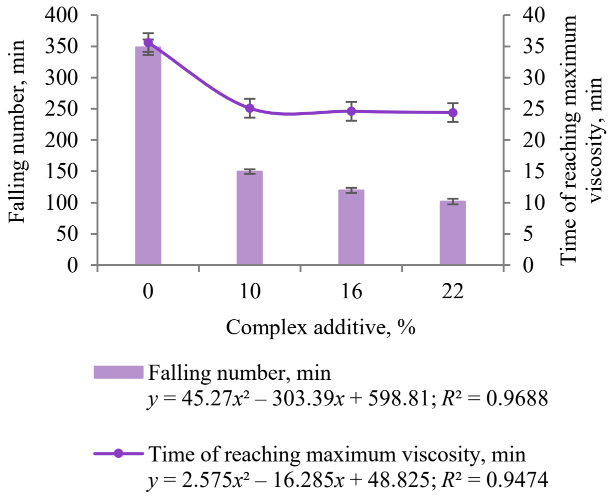

Figure 3. The effect of the complex additive on the falling number of premium wheat flour and the time of reaching maximum viscosity during heating

Рисунок 3. Влияние пищевой комплексной добавки на число падения и время до достижения максимальной вязкости водно-мучной суспензии при нагревании

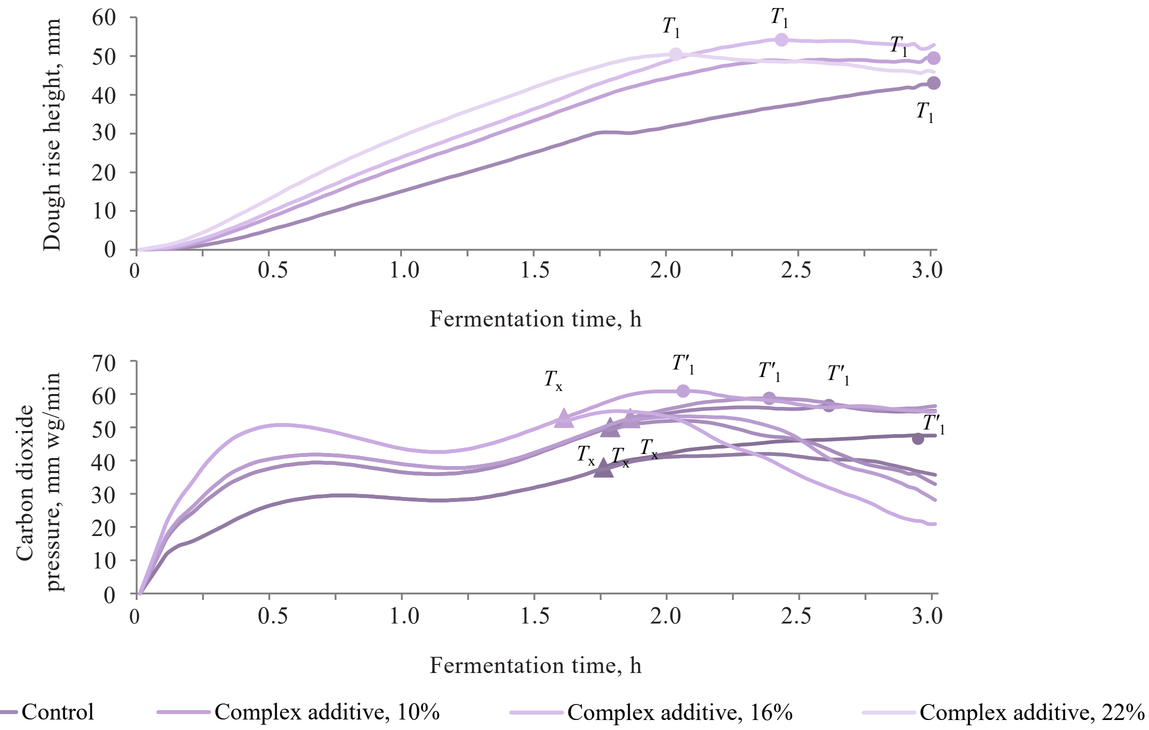

Figure 4. Effects of the complex additive on gas production, dough rise, and gas-retaining ability during fermentation

Рисунок 4. Влияние пищевой комплексной добавки на газообразующую способность пшеничной муки высшего сорта, динамику поднятия и газоудерживающую способность пшеничного теста

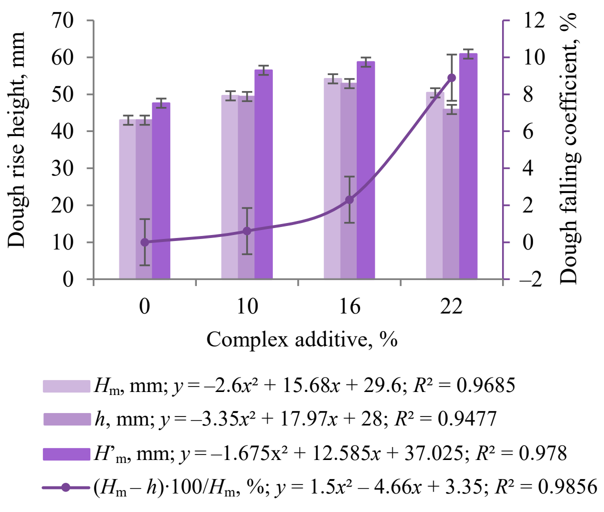

Figure 5. The effect of the complex additive on the wheat dough development

Рисунок 5. Влияние пищевой комплексной добавки на динамику поднятия пшеничного теста

of the dough samples by 6.6–11.2 mm compared to the control. The dough with 16% of the additive had the maximum height, which was 26.0% higher than the control. Noteworthily, the control sample reached its maximum height only at the end of the three-hour test, while the dough with 16% of the additive did it 36 min faster. The sample with 22% of the additive was fastest in reaching its maximum rise, namely 58.5 min –faster than the control.

As can be seen in Fig. 5, higher concentrations of the additive increased the maximum dough rise (consistent with the maximum volume) by an average of 23.3%, compared to the control. Further, the fermentation time required to reach the maximum volume was reduced by an average of 34.5 min, compared to the control dough without the additive.

The gas graphs (Fig. 4) show two peaks. The first peak indicates the gas produced by yeast during the fermentation of sugars in the flour mixture, while the second peak is characteristic of maltose fermentation. The test samples reached the first peak faster than the control. In particular, the sample with 22% of the additive reached the first peak faster than the other samples and 15 min faster than the control. Noteworthily, the amount of carbon dioxide released by the yeast at the first peak was higher compared to the control. In addition, the complex additive increased the dough rise rate during fermentation (Fig. 6).

We found that yeast cells were activated by the presence of the complex additive at the beginning of fermentation. As a result, they not only fermented flour sugars faster, but also released more carbon dioxide due to extra nutrients contained in the additive.

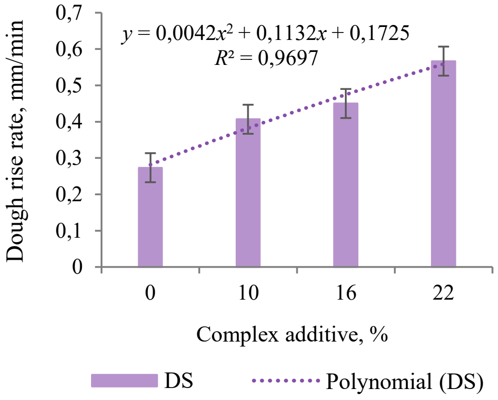

Figure 6. The effect of the complex additive on the dough rise rate

Рисунок 6. Влияние пищевой комплексной добавки на скорость подъема пшеничного теста

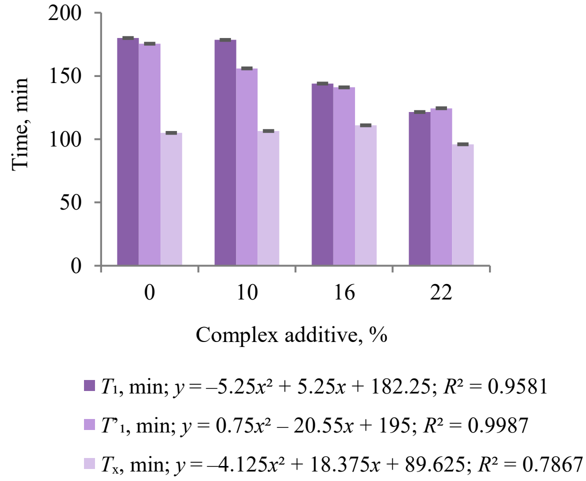

Figure 7. The effect of the complex additive on the wheat dough fermentation time

Рисунок 7. Влияние пищевой комплексной добавки на продолжительность брожения пшеничного теста

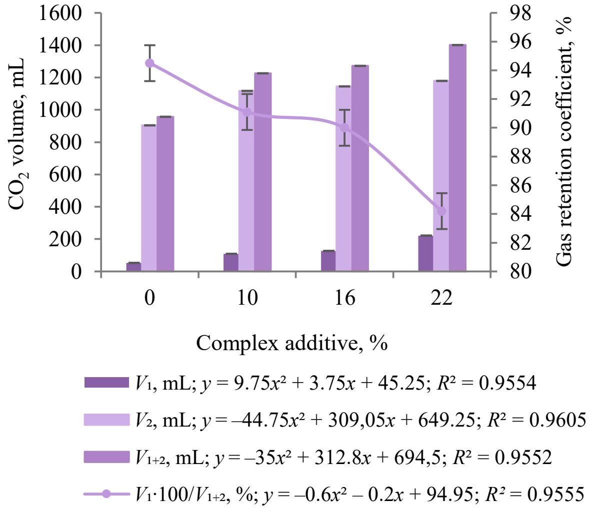

Figure 8. The effect of the complex additive on the dough's gas-retaining ability and the flour's gas-forming ability

Рисунок 8. Влияние пищевой комплексной добавки на газоудерживающую способность тестовых полуфабрикатов и газообразующую способность муки

The dough samples with 10 and 16% of the additive began to lose carbon dioxide (T_x) 1.5 and 6.0 min later than the control, respectively. However, the dough with 22% of the additive began to lose carbon dioxide 9.0 min earlier than the control (Fig. 7). This concentration probably had a stronger destructive effect on the protein-starch matrix of wheat dough compared to the other concentrations under study. These data were consistent with the results of our previous rheological studies on a farinograph. In particular, introducing 22% of the additive into the flour mixture significantly shortened the dough formation time compared to the control or the samples with other concentrations [16].

According to Fig. 8, higher concentrations of the complex additive increased the total volume of carbon dioxide by an average of 35.8% compared to the control. The volumes of lost and retained carbon dioxide were also higher by an average of 99.7 and 26.9%, respectively, compared to the control. Since more carbon dioxide was lost than retained, the gas retention coefficient decreased by 3.6–10.9% with higher concentrations of the additive. The high enzymatic activity of sprouted spelt contained in the additive might have negatively affected the gas-retaining ability. This is associated with higher dough permeability caused by the weakening of the protein–carbohydrate matrix during starch hydrolysis and peptide bonds in proteins [29]. Similar data were obtained for sprouted wheat [30].

The correlation analysis showed a significant statistical relationship ($p < 0.05$) between the concentration of the additive and the maximum dough height corresponding to the maximum volume ($r = 0.97$), the gas retention coefficient ($r = 0.98$), and the fermentation time until the maximum volume is reached ($r = 0.996$).

The readings of the rheofermetometer depended on the flour's enzymatic activity. In particular, we found reliable statistical negative correlations ($p < 0.05$) between the maximum dough height corresponding to the maximum volume and the gelatinization temperature ($r = –0.97$), maximum viscosity ($r = –0.97$), falling number ($r = –0.99$), and the time it takes to reach maximum viscosity ($r = –0.97$). The volume of carbon dioxide loss positively correlated ($p < 0.05$) with the gelatinization start temperature ($r = 0.99$), while the volume of retained gas negatively correlated with the gelatinization temperature ($r = –0.99$), maximum viscosity ($r = –0.99$), falling number ($r = –0.99$), and the time it takes to reach maximum viscosity ($r = –0.99$). Also, the gas retention coefficient negatively correlated with the gelatinization start temperature ($r = –0.99$).

Using the data from our previous study [17], we performed a correlation analysis to establish the effect of flour mixtures and the dough's rheological parameters during kneading on the dough during fermentation. We found significant correlations ($p < 0.05$) between the maximum dough height corresponding to the maximum volume and the quality of wet gluten, water absorption (500 FE), moisture of flour mixtures, dough stability, farinograph quality number, and moisture of wet gluten ($r = 0.98$, 0.98, –0.99, –0.95, –0.95, and 0.96, respectively). There were also strong correlations ($p < 0.05$) between the volume of CO_2 retained by the dough and the above indicators ($r = 0.99$, 0.97, –1.0, –0.98, –0.98, and 0.96, respectively), as well as the degree of softening according to the ICC standard ($r = 0.97$). The total gas volume negatively correlated ($p < 0.05$) with the dough development time ($r = –0.97$) and positively correlated with the quality of wet gluten ($r = 0.97$) and water absorption (500 FE) ($r = 0.95$). The fermentation time needed to reach the maximum volume positively correlated ($p < 0.05$) with the dough formation time ($r = 0.96$). This indicated that the properties of dough during fermentation are determined by the baking properties of wheat flour and the rheological properties of dough during kneading.

Thus, taking into account the changes in dough rise, as well as the dough's gas-retaining ability and the flour's gas-forming ability, we selected an optimal concentration of the complex additive (16%) for premium wheat flour. This concentration ensured the maximum dough rise and the longest dough porosity time (when the dough starts to lose CO_2).

Conclusion

We studied the effects of the complex additive on the viscosity of a water-flour suspension during its gelatinization when heated, the flour's gas-forming ability, dough development, and the dough's gas-retaining ability during fermentation.

According to the results, the complex additive increased the enzymatic activity of wheat flour. In particular, it raised the gelatinization start temperature and lowered the temperature of complete gelatinization, maximum viscosity, the time needed to reach maximum viscosity, and the falling number, compared to the control. The correlation analysis showed a significant positive relationship between the falling number and the readings of the amylograph-E, namely the gelatinization temperature, maximum viscosity, and time needed to reach maximum viscosity ($r = 0.99$, $p < 0.05$).

The dough samples made with the complex additive were 8.4 mm higher than the control. Their fermentation time until they reached the maximum height decreased by an average of 17.8% compared to the control. Their maximum height corresponding to the maximum volume increased by an average of 23.3% compared to the control. The fermentation time it took the doughs to reach the maximum volume decreased by an average of 19.9% compared to the control.

The complex additive increased the total volume of carbon dioxide by an average of 35.8% compared to the control. The volumes of lost and retained carbon dioxide increased by an average of 99.7 and 26.9%, respectively. Larger amounts of the additive decreased the retention coefficient by 3.6–10.9% compared to the control sample.

We found that 16% was an optimal concentration of the complex additive introduced into premium wheat flour. This amount contributed to the maximum dough rise and the longest dough porosity time when the dough begins to lose carbon dioxide.

In practical terms, our results can be used in the production of bakery products from premium wheat flour fortified with 16% of the complex additive. In order to obtain high-quality products, the total time of fermentation and proofing should be reduced by 17.8% compared to the dough without the additive.

Further research is needed to study the effect of the complex additive on the structural and mechanical properties of dough during its development.

Contribution

A.V. Maslov reviewed literature, conducted experimental studies and data analysis, and edited the manuscript. T.A. Yamashev conducted experimental studies and data analysis. O.V. Starovoitova and Z.Sh. Mingaleeva developed the study concept, administered the research, analyzed experimental data, and edited the manuscript.

Conflict of interest

The authors declare that there is no conflict of interest.

Критерии авторства

А. В. Маслов – аналитический обзор источников информации, проведение экспериментальных исследований, анализ экспериментальных данных и корректировка рукописи. Т. А. Ямашев – проведение экспериментальных исследований и анализ экспериментальных данных. О. В. Старовойтова и З. Ш. Мингалеева – администрирование и разработка концепции исследования, анализ экспериментальных данных и корректировка рукописи.

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

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