The effect of bean flour on the rheological properties of a tritikale flour based composite mixture based tritikale flour

M S Maradudin and I V Simakova
Saratov State Agrarian University named after N.I. Vavilov, Saratov, Russia
E-mail: maradudinms@yandex.ru

Abstract. In this research work, we have studied and compared the main parameters of the rheological state of dough made from triticale flour (a variety of the promising line by the FSBIS Agricultural Research Institute of the South-East), dough made from flour of white and red bean seeds, as well as parameters of dough from flour of composite mixtures based on them. It has been found that the water absorption capacity of flour highly correlates with moments of force during the liquefaction phase and with moments of force characterizing the minimum and maximum consistency of the dough during the phase of starch retrogradation. The type of beans significantly influenced the correlation of the water absorption capacity of flour with the dough stability, the moment of force characterizing the stability of the dough during the gelatinization phase, as well as with the total energy consumption for kneading the dough. Taking into account the research results of the rheological state of the dough, bread with various mass fractions of components was baked experimentally. The results obtained confirmed the improving effect of bean flour, which is in the fact that even with a high mass fraction (60-100%) of bean flour in the composite mixture, it was possible to obtain a complete rheological profile of the studied system, and, consequently, preservation of the optimal dough structure.

1. Introduction
The problem of creating functional products with an improved chemical composition can be solved through the widespread introduction of multicomponent flour mixtures enriched with complete proteins, vitamins, minerals, and dietary fiber. The basis of such mixtures, as a rule, is cereal flour (mainly wheat and rye), which is supplemented with whole-ground or fermented flour, wheat germ, wheat bran, various types of cereal flakes, flax seeds, sunflower seeds, sesame seeds, and legume flour (mainly soybeans), etc [1-2].

There is quite a large number of theoretical and experimental works studying the effect of the composite mixture ingredients on the carbohydrate-amylase and protein-proteinase complexes of such mixtures, on the basis of which new technologies for the production of bread with increased nutritional value have been developed. However, it is noted that, possessing certain advantages, both wheat and rye have their own disadvantages, which include both the defective amino acid composition of wheat and the low gluten capacity of rye. In this regard, triticale is a more promising crop as the basis of the composite mixture, which combines the best properties of its progenitors - wheat and rye, specifically, a high protein content with its best amino acid composition. It is also noted that due to the increased content of the most complete protein substances, sugars, vitamins, macro- and microelements, triticale grain has a high biological value [3-4].
As an additional raw material in the production of functional bakery and flour confectionery products, it is proposed to use legumes, which, due to their unique biochemical composition, occupy a special place among food raw materials of plant origin. Due to the high content of protein, micro- and macroelements, as well as other equally important nutrients, they can be widely used as one of the main raw materials in the production of multicomponent flour mixtures (MFMs) with a high content of vegetable protein, thereby compensating for the lack of animal proteins [12].

Among all the variety of legumes, one of the most attractive crops, as an additional component for composite mixtures, is beans. The flour obtained from beans has a high protein content and a balanced amino acid composition. The protein content ranges from 23.2 to 33.4%, essential amino acids vary from 8384 to 12147 mg, the predominant amino acids were leucine and lysine. In addition, it has a significant content of vitamins (thiamine, riboflavin, niacin, vitamin E). The total amount of ash is 2.6–3.7%, while the flour contains potassium, calcium, magnesium, sulfur, phosphorus, iron, copper, manganese [5-6].

Thus, a composite mixture of triticale flour and beans is undoubtedly promising for creating functional bakery products.

2. Problem setting
The aim of the research work was to study the effect of bean flour, as an improver, on the rheological properties of dough from a composite mixture, to confirm the possibility of its use in various types of bakery and confectionery products. The degree of influence was determined by establishing a correlation between the qualitative characteristics of composite flour from triticale with beans and the rheological properties of dough based on it.

3. Research object
The objects of research were triticale flour of the promising selection line of the FSBIS Agricultural Research Institute of the South-East and whole-ground flour from white and red beans (GOST 7758-75), obtained by successive grinding of beans in the grinding mechanism of a multifunction kitchen machine (MKM) and a laboratory mill Junior Quadrumat (Brabender), as well as composite mixtures based on them in percentage ratio: 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80 and 10:90.

4. Materials and methods.
The rheological properties of the dough were determined using a Mixolab device (Mixolab, Chopin, France) according to the GOST ISO 17718-2015 method [7]. This device, based on the Chopin + protocol, in real time, measures the rotation moment in N • m (Nwm) that occurs between two kneading blades when mixing dough out of flour and water for several successive kneading phases due to different temperatures. This provides complete information that provides a comprehensive assessment of the technological properties of flour and objectively determines its intended use [8-10].

The main parameters of the rheological state of the dough were analyzed, including water absorption capacity (WAC,%), stability time (T₂, min), moment of force during the liquefaction phase (C₂, N * m), moment of force during the gelatinization phase, (C₃, N * m), moments of force characterizing the minimum (C₄, N * m) and maximum (C₅, N * m) consistency of the dough during the phase of starch retrogradation, as well as the energy absorbed during the dough formation (P, W * h / kg), which were compared with the indicators of the water absorption capacity for the flour of the initial components and composite mixtures.

Test baking of bread with different mass fractions of components was carried out in the laboratory of the FSBIS Agricultural Research Institute of the South-East according to the method of state crop variety testing of agricultural crops. During the research, we used composite mixtures based on triticale flour (TrF) and white bean flour (WBF) and red bean flour (RBF) in a ratio of 90:10; 80:20; 70:30; 60:40. Experimental dough samples were prepared in accordance with the recipe for the unpaired method of laboratory baking with intensive dough kneading [11].
The correlation between the studied parameters was determined using Microsoft Excel programs. Critical values of the correlation coefficient (r) at 5% significance were identified by the method of V.M. Dospekho [12].

5. Discussion
The research results of the rheological properties of the dough and the correlation coefficients between them and the water absorption capacity are presented in table 1.

Table 1. Parameters of mixolabograms of dough made from triticale flour (a variety of the promising line of the FSBIS Agricultural Research Institute of the South-East) and composite mixtures with white food bean flour (WBF) and red (RBF).

| No | Composite mixture, % | WAC % | T₂, min | C₂ N * m | C₃ N * m | C₄ N * m | C₅ N * m | PA, W*h kg |
|----|----------------------|-------|----------|-----------|-----------|-----------|-----------|------------|
| 1  | Triticale flour 100% | 53.5  | 2.82     | 0.25      | 1.22      | 1.18      | 1.98      | 78.56      |
| 2  | TrF 90%+10% WBF     | 53.6  | 2.35     | 0.26      | 1.29      | 1.21      | 2.18      | 82.63      |
| 3  | TrF 80%+20% WBF     | 52.6  | 3.37     | 0.27      | 0.50      | 1.37      | 2.51      | 91.80      |
| 4  | TrF 70%+30% WBF     | 54.3  | 3.60     | 0.30      | 0.43      | 1.49      | 2.89      | 98.20      |
| 5  | TrF 60%+40% WBF     | 54.5  | 3.23     | 0.31      | 0.44      | 1.58      | 3.24      | 108.15     |
| 6  | TrF 50%+50% WBF     | 57.0  | 2.52     | 0.30      | 0.36      | 1.46      | 3.15      | 100.31     |
| 7  | TrF 40%+60% WBF     | 58.0  | 2.32     | 0.33      | 0.38      | 1.43      | 3.18      | 103.51     |
| 8  | TrF 30%+70% WBF     | 59.1  | 2.13     | 0.35      | 0.39      | 1.28      | 3.09      | 99.49      |
| 9  | TrF 20%+80% WBF     | 60.0  | 2.72     | 0.40      | 0.45      | 1.14      | 2.88      | 98.47      |
| 10 | TrF 10%+90% WBF     | 61.0  | 3.13     | 0.43      | 0.44      | 0.79      | 1.97      | 76.27      |
| 11 | WBF 100%            | 63.9  | 4.50     | 0.45      | 0.47      | 0.68      | 1.94      | 75.42      |
| 12 | WAC correlation coefficient (r) | 1.0 | 0.07 | 0.91 | 0.22 | 0.51 | 0.02 | 0.06 |

Based on White bean flour (WBF)

| No | Composite mixture, % | WAC % | T₂, min | C₂ N * m | C₃ N * m | C₄ N * m | C₅ N * m | PA, W*h kg |
|----|----------------------|-------|----------|-----------|-----------|-----------|-----------|------------|
| 1  | Triticale flour 100% | 53.5  | 2.82     | 0.25      | 1.22      | 1.18      | 1.98      | 78.56      |
| 2  | TrF 90%+10% RBF     | 53.9  | 2.60     | 0.23      | 1.21      | 1.15      | 2.18      | 80.95      |
| 3  | TrF 80%+20% RBF     | 53.9  | 3.18     | 0.25      | 0.41      | 1.37      | 2.62      | 92.35      |
| 4  | TrF 70%+30% RBF     | 53.9  | 3.28     | 0.26      | 0.35      | 1.46      | 2.58      | 94.03      |
| 5  | TrF 60%+40% RBF     | 53.5  | 4.12     | 0.27      | 0.35      | 1.59      | 2.80      | 98.00      |
| 6  | TrF 50%+50% RBF     | 53.1  | 3.48     | 0.26      | 2.24      | 2.10      | 2.39      | 90.45      |
| 7  | TrF 40%+60% RBF     | 55.3  | 2.48     | 0.33      | 2.04      | 2.00      | 2.27      | 75.72      |
| 8  | TrF 30%+70% RBF     | 55.7  | 1.35     | 0.34      | 2.27      | 2.18      | 2.15      | 86.52      |
| 9  | TrF 20%+80% RBF     | 56.7  | 1.85     | 0.39      | 1.85      | 1.75      | 1.43      | 79.15      |
| 10 | TrF 10%+90% RBF     | 58.8  | 2.05     | 0.40      | 1.42      | 0.76      | 0.01      | 59.01      |
| 11 | RBF 100%            | 61.2  | 2.95     | 0.42      | 1.18      | 0          | 0          | 55.25      |
| 12 | WAC correlation coefficient (r) | 1.0 | 0.17 | 0.85 | 0.03 | 0.44 | 0.86 | 0.77 |

Based on Red bean flour (RBF)

It was found that with the increase in the amount of bean flour in the composite mixture from 10 to 90%, the water absorption capacity increases by 13.8% (from 53.6% to 61.0%) when using white bean flour, and by 5.2% (from 55.9% to 58.8%) when using red bean flour. This confirmed the previously obtained data on the effect of morphological features of beans on the water absorption capacity [13-14].

The change in the content of bean flour in the composite mixture affected the stability time; however, since this parameter changed abruptly, the correlation dependence between the WAC parameters and the stabilization time was not significant. Moreover, up to a certain ratio (60:40) of the components, the stabilization time increased (for both white and red beans), and then this indicator decreased. It is known that increasing the stability time has a positive effect on the dough, providing a
good rise in the bread during proofing. Therefore, it can be expected that increasing the content of bean flour in the composite mixture by 30-40% will not significantly reduce the rise of baked goods.

The correlation between water absorption capacity and moment of force during the phase of liquefaction ($C_2$) ($r = 0.91$ and $r = 0.85$) was more significant. This parameter characterizes the process of activating proteolytic enzymes, leading to a decrease in the consistency of the dough due to the rupture of hydrogen bonds in the protein molecules that hold the protein molecular chains together. Degradation of gluten proteins and liquefaction of the dough occurs. Moreover, the lower the moment $C_2$ is, the higher the volumetric bread yield becomes. Since in our case the opposite process was observed, we can expect a decrease in the volumetric yield of baked products as the content of bean flour in the composite mixture increases.

The increase in the amount of bean flour in the composite mixture affected the change in the moment of force ($C_3$), which characterizes the properties of starch and amylolytic activity in the analyzed sample [5-6]. High values of $C_3$ characterize a weak enzymatic activity, and low values, on the contrary, characterize high enzymatic activity [7].

However, since the change in this parameter was of an abrupt nature, and the correlation between the water absorption capacity and the moment $C_3$ is insignificant ($r = 0.22$ and $r = 0.03$), then, taking into account the available data, it can be assumed that varietal features of beans have a more significant effect on the gelatinization process.

It was also noted that the increase in the content of bean flour in the composite mixture affects the change in the moments of force characterizing the minimum ($C_4$) and maximum ($C_5$) dough consistency during the starch retrogradation phase. However, the effect of the content of bean flour on these parameters is ambiguous due to the varietal features of beans.

The moments of force at the extremum points $C_3$, $C_4$, $C_5$ characterize the carbohydrate-amylase complex of the studied system and the processes occurring in it. Low values of these parameters, characterizing high autolytic activity, ensure the formation of a finely dispersed crumb structure during baking. Bakery and confectionery products obtained from composite mixtures with low values of the $C_5$ moment are distinguished by greater resistance to staleness, and, therefore, increased shelf life.

However, for composite mixtures based on triticale, with an increase in the content of bean flour in the mixture from 10% to 40%, an increase in the moments of force is observed from the minimum to the maximum value. With a subsequent increase in the content of bean flour in the mixture, the $C_5$ moment decreases in a smoother mode when a bean flour content is 80%; there is a sharper decrease for the further increase to 90%. This indicates a more complex interaction of the protein-carbohydrate complex of two plant cultures - triticale and beans, and the need for a deeper study of these systems.

The research results of test baked bread with different mass fraction of components (figure 1) are shown in table 2.

![Figure 1](image.png)

**Figure 1.** Samples of test baking of bread from composite mixtures with different mass fractions of components (a - using white bean flour (WBF), b- using red bean flour (RBF)).
Table 2. Assessment of the quality of bread from a composite mixture based on triticale flour (a variety of the promising line of the FSBIS Agricultural Research Institute of the South-East) and white (WBF) and red bean (RBF) flour in the ratio of 90:10, 80:20, 70:30 and 60:40.

| No | Composite mixture sample | Bread volume yield, cm³ | Texture, point | Acidity, % |
|----|--------------------------|-------------------------|---------------|-----------|
| 1  | Triticale flour 100%      | 460                     | 4.5           | 2.47      |
| 2  | TrF 90% + 10% WBF        | 390                     | 4.6           | 2.64      |
| 3  | TrF 80% + 20% WBF        | 300                     | 4.4           | 3.49      |
| 4  | TrF 70% + 30% WBF        | 290                     | 4.4           | 4.17      |
| 5  | TrF 60% + 40% WBF        | 260                     | 4.0           | 4.42      |
| 6  | TrF 90% + 10% RBF        | 400                     | 4.5           | 3.01      |
| 7  | TrF 80% + 20% RBF        | 330                     | 4.3           | 3.18      |
| 8  | TrF 70% + 30% RBF        | 270                     | 4.2           | 3.01      |
| 9  | TrF 60% + 40% RBF        | 240                     | 4.0           | 4.13      |

As can be seen from table 2, with the increase in the amount of bean flour in the composite mixture from 10 to 40%, a decrease in the volumetric yield of bread by 1.8-1.9 times and an increase in the acidity of the crumb by 1.8-1.7 times are observed. At the same time, an increase in the content of bean flour in the composite mixture by only 10% reduces the volumetric bread yield by only 15.0% when using white bean flour, and by 13.0% when using red bean flour.

6. Conclusion

The improving effect of bean flour lies in the fact that even with a high mass fraction (60-100%) of bean flour in the composite mixture, it was possible to obtain a full rheological profile of this system, which indicates the preservation of the optimal dough structure. In addition, dosed use of bean flour as a component in a flour composite mixture or a complete replacement of triticale flour with bean flour, increasing the protein content in bakery, pasta and confectionery products, allows one to influence the shape stability of the final product:

- When the content of bean flour in the mixture is up to 10%, the stability time changes insignificantly, therefore, the shape and volume of bakery products (tin bread) will not change significantly;
- When the content of bean flour is up to 40%, the stability time increases 1.4 - 1.5 times, which indicates a more significant effect on the shape stability of the final product, and, therefore, such mixtures can be recommended for functional food products, for which he content of the final product is more important than its shape;
- When the content of bean flour is more than 70%, the stability time is reduced 3 - 4 times, and, therefore, such mixtures can be used for low-gluten food products of functional purpose with an unfixed shape.

At the same time, a significant difference in the tendencies of changes in the rheological properties of the dough made from composite mixtures with triticale, in comparison with the rheological properties of the dough based on wheat, indicates a more complex interaction of the components that require a more careful study.

References

[1] Matveeva T V and Koryachkin S Ya 2012 Physiologically functional food ingredients for bakery and confectionery products (Oryol: FGBOU VPO State University UNPK) 947
[2] Baturina N A Litvinova E V and Muzalevskaya R S 2010 The use of flour from seeds of legumes to improve the nutritional value of wheat bread. Commodity research and technological aspects of the development of food products for functional and specialized
purposes (Voronezh: Scientific book) 174-99

[3] Matveeva T V and Koryachkina S Ya 2016 *Flour confectionery products for functional purposes* (Scientific bases, technologies, recipes St. Petersburg, GIORD) 360

[4] Koryachkina S Ya, Kuznetsova E A and Cherepnin L V 2012 *Technology of whole grain bread triticale: monograph* (Oryol: FGBOU VPO State University - UNPK) 177

[5] Gorbatovskaya N A, Muslimov N Zh and Dzhumabekova G B 2015 Effect of bean flour additives on the physical properties of wheat dough. *Young scientist* 6 141-3

[6] Korshenko L O and Chizhikova O G 2015 *The use of beans for food purposes, New in technology and technology of functional food based on medical and biological views* (Voronezh: VGUIT) 23-5

[7] *Grain and flour from soft wheat. Determination of the rheological properties of the dough depending on the kneading conditions and temperature rise* 2015 (Moscow. Standartinform) 31

[8] Dubat A and Risev K 2008 A modern method of quality control of grain and flour by the rheological properties of the dough, determined with a mixolab profiler. Management of the rheological properties of food products. *Materials of the First Scientific-practical conference and exhibition with international participation. Moscow* 86-95

[9] Kazantseva I L, Kulevatova T B and Zlobina L N 2018 On the use of flour from chickpea grain in the technology of flour confectionery products. *Grain legumes and cereals* 1(25) 76-81

[10] Kulevatova T B 2017 *Methodical approaches to assessing the quality of winter wheat grain by rheological properties of the test* (Saratov: FBGNU Research Institute of Agriculture of South-East) 21

[11] *Methodology of state variety testing of agricultural crops. Technological assessment of cereals, cereals and leguminous crops* 1988 (Moscow) 73

[12] Dospekhov B A 1985 *Field experiment technique* (Moscow: Agropromizdat) 49

[13] Maradudin M and Simakova I 2019 *Study of the structural and mechanical properties of flour from a composite mixture based on beans and premium wheat* *Proceedings of the First International Symposium Innovations in Life Sciences (ISILS 2019)* 194-6

[14] Simakova I, Maradudin M, Veber A and Strizhevskaya V 2019 *Functional and Technological Properties of Composite Mixtures Based on Bean Protein-Carbohydrate Matrix (BPCM). Proceedings of the International Scientific Conference, The Fifth Technological Order: Prospects for the Development and Modernization of the Russian Agro-Industrial Sector (TFTS) Series, Advances in Social Science, Education and Humanities Research* 32221