The bean flour effect on the rheological properties of the dough from a wheat flour based composite mixture

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Abstract. Department of Food Technology, at Saratov State Vavilov Agrarian University, studied and compared the main parameters of the rheological state of the dough from whole grain wheat flour and straight white wheat flour, dough from white beans and red beans. Dough parameters from flour composite mixtures based on beans were also studied and compared with each other. It was found that the water absorption ability of flour highly correlates with dough stability time, with a force moment characterizing the minimum consistency of the dough during the starch retrograde phase and with a force moment characterizing the maximum consistency of the dough during the end of the starch retrograde phase, as well as with the total energy consumed during dough mixing. To a lesser extent, the water absorption ability of flour correlates with the time of dough development, the force moment during the liquefaction phase, and the force moment characterizing the stability of the dough during the gelatinization phase. When comparing the main rheological parameters of the dough from the studied types of flour, it was found that both the degree of grinding and the morphological characteristics of the beans used as a donor or basis for composite mixtures influence the correlation between rheological parameters. The water absorption ability correlates to a greater extent with the main rheological indices of the dough of composite mixtures based on straight white wheat flour rather than composite mixtures based on whole grain flour.

1. Introduction
Currently, there is quite a large number of studies by Russian and foreign scientists on the creation of vegetable based functional foods, aimed at increasing the content of essential nutrients and improving the balance of the main irreplaceable nutrients.

One way to solve this issue is the use of flour multicomponent mixtures (MCM) for flour products, flour confectionery and pasta with a high content of vegetable protein and a low glycemic index [1,2,3,4,5]. In the present work, it is proposed to use haricot beans as a crop with high nutritional value and a high content of vegetable protein as one of the main types of protein-containing raw materials with a specific carbohydrate profile in the production of such food products [6,7].

2. Problem statement / Aim
The aim of this paper was to study the effect of bean flour, as an improver of the rheological and baking properties of the dough from the composite mixture, to confirm the possibility of its use in...
various types of dough by establishing a correlation between the qualitative characteristics of the dough based on whole grain wheat flour (WGF) and straight white wheat flour (SWF).

3. Object of studies
The objects of research for this paper were whole grain wheat flour (TU (general specification) 10.61.20-001-38744625 “Flour in assortment”), straight white wheat flour (GOST (state standard) R 52189-2003), whole grain wheat flour from white and red beans (GOST 7758-75) obtained by sequential grinding of bean seeds in the grinding mechanism of a universal kitchen machine (UKM) and the laboratory mill Quadrumat Junior (Brabender company), as well as composite mixtures based on them in a percentage ratio: 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80 and 10:90.

Table 1. Mixolabogram parameters of dough from whole grain wheat flour (WGF), straight white wheat flour (SWF) and flour from composite mixtures based on white bean flour (WBF).

| №  | Composite mixtures, % | WAA, % | T1, min | T2, min | C2, N*m | C3, N*m | C4, N*m | C5, N*m | PA, W*h kg |
|----|-----------------------|--------|---------|---------|--------|--------|--------|--------|-----------|
| 1  | WGF 100%              | 58.5   | 8.77    | 10.42   | 0.49   | 2.27   | 2.73   | 2.73   | 190.2     |
| 2  | WGF 90%+10% WBF      | 61.1   | 8.80    | 10.73   | 0.48   | 1.94   | 2.44   | 4.90   | 180.0     |
| 3  | WGF 80%+20% WBF      | 61.4   | 6.28    | 9.43    | 0.38   | 3.94   | 3.96   | 3.96   | 146.2     |
| 4  | WGF 70%+30% WBF      | 61.5   | 5.33    | 5.98    | 0.38   | 3.37   | 3.32   | 3.50   | 137.7     |
| 5  | WGF 60%+40% WBF      | 62.0   | 5.18    | 8.52    | 0.36   | 0.73   | 2.00   | 3.53   | 128.9     |
| 6  | WGF 50%+50% WBF      | 61.0   | 4.72    | 8.70    | 0.37   | 0.61   | 1.94   | 3.81   | 132.1     |
| 7  | WGF 40%+60% WBF      | 60.6   | 0.87    | 7.08    | 0.36   | 0.51   | 1.82   | 3.77   | 130.9     |
| 8  | WGF 30%+70% WBF      | 61.9   | 1.02    | 6.48    | 0.37   | 0.46   | 1.51   | 3.58   | 114.9     |
| 9  | WGF 20%+80% WBF      | 62.3   | 1.02    | 3.42    | 0.38   | 0.44   | 1.18   | 2.96   | 98.0      |
| 10 | WGF 10%+90% WBF      | 63.4   | 1.18    | 3.15    | 0.42   | 0.45   | 0.90   | 2.60   | 86.8      |
| 11 | WGF 100%             | 60.8   | 1.27    | 2.77    | 0.46   | 0.47   | 0.69   | 2.47   | 80.4      |

Coefficient (r) by WAA 1.0 0.28 0.31 0.23 0.08 0.12 0.58 0.45

| №  | Composite mixtures, % | WAA, % | T1, min | T2, min | C2, N*m | C3, N*m | C4, N*m | C5, N*m | PA, W*h kg |
|----|-----------------------|--------|---------|---------|--------|--------|--------|--------|-----------|
| 1  | SWF 100%              | 54.5   | 2.07    | 10.78   | 0.64   | 1.70   | 2.16   | 6.54   | 168.72    |
| 2  | SWF 90%+10% WBF      | 55.8   | 5.63    | 9.48    | 0.45   | 1.38   | 2.51   | 5.93   | 182.70    |
| 3  | SWF 80%+20% WBF      | 57.3   | 5.90    | 8.28    | 0.36   | 0.89   | 2.33   | 5.22   | 164.30    |
| 4  | SWF 70%+30% WBF      | 57.8   | 5.20    | 6.43    | 0.34   | 3.82   | 3.76   | 4.32   | 148.88    |
| 5  | SWF 60%+40% WBF      | 59.1   | 5.57    | 8.48    | 0.35   | 0.53   | 2.22   | 4.52   | 147.69    |
| 6  | SWF 50%+50% WBF      | 60.1   | 6.42    | 9.98    | 0.31   | 0.43   | 2.11   | 4.40   | 143.12    |
| 7  | SWF 40%+60% WBF      | 61.1   | 7.85    | 10.42   | 0.30   | 0.36   | 1.80   | 4.29   | 133.26    |
| 8  | SWF 30%+70% WBF      | 62.2   | 0.93    | 3.03    | 0.30   | 0.34   | 1.38   | 3.50   | 108.89    |
| 9  | SWF 20%+80% WBF      | 62.4   | 1.20    | 3.32    | 0.35   | 0.37   | 1.01   | 2.71   | 92.85     |
| 10 | SWF 10%+90% WBF      | 66.7   | 0.98    | 2.02    | 0.37   | 0.40   | 0.79   | 2.17   | 76.35     |
| 11 | WBF 100%             | 63.8   | 1.07    | 3.20    | 0.43   | 0.44   | 0.61   | 1.98   | 73.11     |

Coefficient (r) by WAA 1.0 0.22 0.57 0.17 0.28 0.59 0.89 0.89
4. Materials and methods

The rheological properties of the dough were determined on a Mixolab instrument (Mixolab, Chopin, France) according to the method of GOST ISO 17718-2015 [8]. This instrument, based on the Chopin + protocol, measures in real time the torque in N·m that occurs between two dough mixing blades when mixing dough from flour and water for several consecutive kneading phases due to different temperatures. This provides the complete information that allows one to objectively evaluate the technological properties of flour and determine its intended use [9, 10, 11]. The main parameters of the rheological state of the dough were analyzed. The parameters included the water absorbing ability (WAA, %), the time of dough development (T1, min), stability time (T2, min), the force moment during the dilution phase (C2, N·m), the force moment during the gelatinization phase, (C3, N·m), the force moments characterizing the minimum (C4, N·m) and maximum (C5, N·m) consistency of the dough during the "starch retrogradation" phase, as well as energy absorbed in the process of dough development (P, Wh/kg), which were compared with the indicators of water absorption ability of the flour of the initial components and composite mixtures.

The correlation between the studied parameters was determined using Microsoft Excel programs. The critical values of the correlation coefficient (r) at the 5% and 1% significance levels were identified by the method of V.M. Dospekhov [12].

Table 2. Parameters of mixolabograms of dough from whole grain wheat flour (WGF), straight white wheat flour (SWF) and flour from composite mixtures based on red bean flour (RBF)

| №   | Composite mixtures, % | WAA, % | T1, min | T2, min | C2, N·m | C3, N·m | C4, N·m | C5, N·m | PA, Wh/kg |
|-----|-----------------------|--------|---------|---------|---------|---------|---------|---------|-----------|
| 1   | WGF 100%              | 58.5   | 8.77    | 10.42   | 0.49    | 2.27    | 2.73    | 2.73    | 190.2     |
| 2   | WGF 90%+10% RBF       | 59.4   | 7.42    | 11.95   | 0.52    | 2.10    | 2.66    | 5.59    | 184.6     |
| 3   | WGF 80%+20% RBF       | 59.9   | 6.30    | 9.07    | 0.45    | 5.27    | 5.23    | 5.29    | 180.8     |
| 4   | WGF 70%+30% RBF       | 60.2   | 7.00    | 7.03    | 0.40    | 4.51    | 4.46    | 4.65    | 164.1     |
| 5   | WGF 60%+40% RBF       | 61.3   | 6.63    | 5.68    | 0.34    | 3.71    | 3.66    | 3.96    | 143.2     |
| 6   | WGF 50%+50% RBF       | 59.5   | 6.05    | 5.73    | 0.33    | 0.66    | 2.15    | 3.98    | 139.6     |
| 7   | WGF 40%+60% RBF       | 59.2   | 6.20    | 6.78    | 0.30    | 0.46    | 1.93    | 3.86    | 147.7     |
| 8   | WGF 30%+70% RBF       | 59.4   | 4.97    | 7.92    | 0.31    | 1.91    | 1.87    | 3.37    | 109.1     |
| 9   | WGF 20%+80% RBF       | 59.5   | 0.93    | 6.22    | 0.34    | 1.91    | 1.82    | 0.23    | 66.3      |
| 10  | WGF 10%+90% RBF       | 60.4   | 0.97    | 2.05    | 0.40    | 1.60    | 1.09    | 0.02    | 61.5      |
| 11  | RBF 100%              | 57.3   | 1.08    | 1.80    | 0.43    | 1.35    | 0.00    | 0.61    | 61.6      |
| 12  | Coefficient (r) by WAA| 1.0    | 0.04    | 0.04    | 0.08    | 0.22    | 0.32    | 0.03    | 0.03      |

| №   | Composite mixtures, % | WAA, % | T1, min | T2, min | C2, N·m | C3, N·m | C4, N·m | C5, N·m | PA, Wh/kg |
|-----|-----------------------|--------|---------|---------|---------|---------|---------|---------|-----------|
| 1   | SWF 100%              | 54.5   | 2.07    | 10.78   | 0.64    | 1.70    | 2.16    | 6.54    | 168.72     |
| 2   | SWF 90%+10% RBF       | 55.3   | 1.82    | 10.00   | 0.49    | 1.45    | 2.56    | 5.85    | 183.37     |
| 3   | SWF 80%+20% RBF       | 58.1   | 5.77    | 10.52   | 0.40    | 1.08    | 2.50    | 5.07    | 169.25     |
| 4   | SWF 70%+30% RBF       | 60.9   | 6.82    | 7.28    | 0.30    | 4.68    | 2.29    | 4.66    | 155.34     |
| 5   | SWF 60%+40% RBF       | 61.7   | 7.15    | 5.80    | 0.28    | 0.58    | 2.07    | 4.25    | 138.75     |
| 6   | SWF 50%+50% RBF       | 61.1   | 7.95    | 9.90    | 0.29    | 3.92    | 1.99    | 3.91    | 133.34     |
| 7   | SWF 40%+60% RBF       | 61.1   | 7.72    | 10.72   | 0.29    | 0.39    | 1.75    | 3.69    | 124.35     |
| 8   | SWF 30%+70% RBF       | 60.6   | 1.08    | 9.17    | 0.31    | 2.70    | 2.65    | 2.74    | 101.24     |
| 9   | SWF 20%+80% RBF       | 61.9   | 0.78    | 1.93    | 0.36    | 1.80    | 1.26    | 0.00    | 65.43      |
| 10  | SWF 10%+90% RBF       | 64.0   | 0.88    | 1.70    | 0.39    | 1.36    | 0.80    | 0.00    | 57.75      |
| 11  | RBF 100%              | 63.1   | 1.12    | 2.88    | 0.45    | 1.47    | 0.00    | 0.00    | 57.31      |
| 12  | Coefficient (r) by WAA| 1.0    | 0.01    | 0.45    | 0.33    | 0.01    | 0.41    | 0.64    | 0.66       |
5. Results

The research results of the rheological properties of the dough and the correlation coefficients between them and water absorption ability are presented in tables 1, 2.

In order to confirm the stability of the effect of water absorption on the rheological parameters of composite mixtures, we determined the correlation between similar parameters for composite mixtures based on WGF and SWF (Table 3).

Table 3. Correlation coefficients between rheological indicators of composite mixtures based on WGF and SWF

| Correlation coefficient (r) | WAA % | T1, min | T2, min | C2 N*m | C3 N*m | C4 N*m | C5 N*m | PA, W*h/kg |
|----------------------------|-------|---------|---------|---------|---------|---------|---------|------------|
| WAA with WBF              | 0.60  | 0.08    | 0.68    | 0.89    | 0.50    | 0.72    | 0.79    | 0.89       |
| WAA with RBF              | 0.03  | 0.27    | 0.55    | 0.80    | 0.01    | 0.55    | 0.99    | 0.98       |

The analysis of the obtained data confirmed a high correlation between the water absorption ability and the main rheological properties of the dough from composite mixtures based on whole grain flour and straight white wheat flour. It was found that with an increase in the amount of bean flour from 10 to 90% in a composite mixture based on straight white wheat flour, there is an increase in water absorption ability from 55.8% to 66.7% when using white bean flour and from 55.3% to 64.0% when using red bean flour. At the same time, for a composite mixture based on whole grain flour, the change in water absorption ability is not so significant: from 61% to 63.4 for white bean flour and from 59.4 to 60.4 for red bean flour. Consequently, not only the morphological characteristics of beans, but also the type of flour, on the basis of which the composite mixture is formed, affects the water absorption ability.

Since the increase in water absorption ability due to the hydrophilicity of high molecular mass compounds of bean proteins leads to better gelatinization and less thickening of starch, and this, in turn, contributes to a greater dough rise when baking, it can be considered that the use of bean flour in a composite mixture has a beneficial effect on the baking properties of composite mixtures.

A change in the content of bean flour in the composite mixture from 10 to 90% affects the dough development time and stabilization time, however, the correlation dependence in this range between the WAA indices and these parameters was also influenced by the type of bean and flour.

An increase in the content of bean flour in composite mixtures leads to an increase in WAA and to a decrease in T1 and T2 of dough with WGF and SWF. At the same time, the correlation between WAA and these parameters is insignificant and is, respectively, for composite mixtures of WGF and SWF:
- for T1: -0.28 and 0.22 with WBF; -0.04 and 0.01 with RBF;
- for T2: -0.31 and 0.57 with WBF; -0.04 and 0.45 with RBF.

The correlation between WAA of composite mixtures with WGF and SWF (Table 3) turned out to be quite high when using white bean flour (r = 0.6) and insignificant when using red bean flour (r = 0.03). Also, the correlation between the stabilization time for composite mixtures with WGF and SWF turned out to be quite high (r = 0.68 for MPE and r = 0.55 for MPC), which indicates the stability of the effect of beans on these parameters.

It is known that low stability negatively affects the baking process as the dough does not rise during proofing, but spreads. This is explained by the fact that the process of gas formation is associated with stability. The increase in stability time has a positive effect on the dough, providing a good rise of bread during proofing. For the studied composite mixtures with a bean flour content of more than 20%, the stability time is reduced in almost all cases by 2-3 minutes. Therefore, if an increase in the content of bean flour outnumbers this value, it will lead to a decrease in the volumetric parameters of bakery products. A sharp decrease in stability time is observed when the bean flour content in the composite mixture is more than 70%. Therefore, this ratio of components will be
unacceptable for bakery products, but quite acceptable for flour confectionery products such as shortcakes or gingerbread.

The force moment during the liquefaction phase characterizes the process of proteolytic enzymes activation, which leads to a decrease in the consistency of the dough due to the breakdown of hydrogen bonds in protein molecules that fix protein molecular chains. Gluten protein degrades and liquefies dough. Moreover, the lower the moment C2 is, the higher the volumetric yield of bread is. The correlation between water absorption ability and C2 moment also has a significant character (r = 0.69-0.58). The decrease in C2 moment is explained by a decrease in the amount of gluten-free gliadin and glutenin proteins of wheat with an increase in bean globulin proteins.

The force moments at the extremum points C3, C4, C5 characterize the carbohydrate-amylose complex of the studied system and the processes occurring in it. High autolytic activity, characterized by low values of C3, C4, C5, ensures the formation of highly dispersed structure of the soft bread part during baking. High values of C3 mean weak enzymatic activity [11]. An increase in the amount of bean flour in the composite mixture influenced the change in the C3 force moment, which characterizes starch properties and amylolytic activity in the analyzed sample [10]. However, since the change in this parameter is spasmodic, and the dependence of the water absorption ability on the C3 moment is insignificant (r = 0.20-0.01), taking into account the available data, it can be considered that the varietal characteristics of beans have a more significant effect on the gelatinization process. It was also noted that an increase in the content of bean flour in the composite mixture provides a stable decrease in the force moments characterizing the minimum and maximum consistency of the dough during the phase of “starch retrogradation”. This gives reason to believe that bakery and confectionery products obtained from composite mixtures will be more resistant to staling, and, consequently, have an extended sell-by date. An important fact is that an increase of bean flour in the composite mixture will reduce the cost of total energy consumed per dough mixing (Tables 1 and 2).

Thus, the results of studies of composite mixtures based on whole grain flour and straight white flour confirmed the positive effect of bean flour on the rheological properties of the dough, taking into account the morphological characteristics of beans and type of flour [13,14,15]. There is a high degree of correlation between the main indicators of the rheological properties of the dough of composite mixtures based on WGF and SWF, including the water absorption ability of flour, dough stabilization time, force moments characterizing the minimum and maximum consistency of the dough during the “starch retrogradation” phase, as well as the energy absorbed during the dough development. To a lesser extent, for composite mixtures, the development time and the force moment during the gelatinization phase are correlated.

6. Conclusion
The improving effect of bean flour is that even with a high mass fraction of bean flour in the composite mixture (60-100%), it was possible to obtain a complete rheological profile of this system, which indicates the preservation of the dough optimum structure. In addition, the dosed use of bean flour as a component in a flour composite mixture or the complete replacement of wheat flour with bean flour, increasing the protein content in bakery, pasta and confectionery products, allows one to:

a) influence the shape stability of the final product:
- when the content of bean flour in the mixture is up to 20%, the stability time does not change significantly, therefore, the shape and volume of bakery products (such as shaped bread) will not change significantly;
- when the content of bean flour is up to 60% - 70%, the stability time is reduced 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 foods for which the 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.
b) create conditions for preserving the freshness of bakery and flour confectionery products, and, consequently, extending the see-by date of the final product, which is caused by a stable decrease in the force moment characterizing the minimum C4 and maximum C5 consistency of the dough during the phase of "starch retrogradation";

c) reduce energy consumption during the dough mixing, and, therefore, reduce the cost of the final product, since there is a direct correlation of the total energy consumption per dough mixing and the content of bean flour in the composite mixture.

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