Development of technological schemes for the processes of preparation and milling of two-component grain mixtures

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Abstract. A study of the preparation and milling of a grain mixture containing 7% of flax seeds has been carried out in order to obtain a composite wheat-flax flour, in which the entire biopotential of flax seeds was preserved. During the wheat grain preparation the cold conditioning was carried out, the modes of which were the following: humidity - 15.5%, dwell time in the water - 24 hours. The optimal conditions for milling the wheat-flax mixture have been determined, which are the following: yield (%) / ash content (%) in 3 break systems (in terms of the 1st break system - grain) for the first break system - 53.5 / 1.00; for the second break system - 22.2 / 1.11; totally for the first and the second break systems - 75.7 / 1.035; totally for the first, the second and the third break systems - 81.0 / 1.1. The technological schemes have been developed and the new varieties of wheat-flax flour with predetermined technological properties and increased nutritional value have been formed. The approximate indices of yield and quality of the new wheat-flax flour varieties are the following: Flour A - yield 45-50%, lipids 3.6-4.0%, protein 13-13.5%, ash 0.55-0.70%, whiteness - 50 conventional units; Flour B - yield 20-25%, lipids 5.5-6.0%, protein 14-14.5%, ash 0.9-1.25%, whiteness - 22 conventional units; Flour C - yield 70-75%, lipids 4.5-5.0%, protein 13.6-14.0%, ash 0.75-0.90%, whiteness - 36 conventional units.

1. Introduction

The enrichment of the products of wheat grain processing with proteins, minerals, and dietary fiber is achieved by introducing the milling products of some cereal crops into wheat flour. This solution has found a wide application in the bakery production in the form of so-called composite flour mixtures. However, in recent years the demand of grain products enrichment with essential fatty acids, especially with linolenic acid (the \( \omega-3 \) family of fatty acids), the deficiency of which negatively affects human health, has emerged [1,2,3].

Analysis of the lipid composition of various oilseeds shows that linseed oil, as a source of unsaturated fatty acids of the \( \omega-3 \) family, has an absolute advantage. The main fatty acid of the oil from flax seeds is linolenic acid, the relative content of which varies according to different sources from 47.5% to 68.1% [4].

The problem of flour enrichment with essential fatty acids is currently solved by using crushed linseed cake (flax meal). The use of linseed cake has several disadvantages. First of all, according to various authors’ studies the content of such flax meal in the composite mixture should be 15-25% to
provide essential fatty acids in the required amount, but such content significantly degrades the consumer properties of bread [4,5]. The direct use of flax seeds will allow one to significantly (3-4 times) reduce the content of products of flax seeds processing in the composite mixture at maintaining the amount of unsaturated fatty acids, primarily of essential linolenic acid, necessary in terms of composition balance [5,6].

The introduction of flax seeds in the mixture sets the task of developing technology for processing mixtures. First of all, it is necessary to determine the milling conditions of such mixtures (parameters and milling modes), each component of which has its own specific features.

2. Object of study
The object of the study was wheat grain and seeds of white and brown seed flax. Tables 1 and 2 show the technological properties and chemical composition of the initial components of the grain mixture.

| Agricultural crop | Moisture, % | Mass of 1000 seeds, g | Test weight, g/l | Vitreousness, % | Medium geometric grain sizes, mm |
|-------------------|-------------|-----------------------|------------------|----------------|--------------------------------|
|                   |             |                       |                  |                | a-width, b-thickness, l-length |
| wheat             | 12/2        | 44.66                 | 769              | 52             | a = 3.6                       |
|                   |             |                       |                  |                | b = 2.9                       |
|                   |             |                       |                  |                | l = 6.5                       |
| flax seeds:       |             |                       |                  |                |                               |
| white             | 5.2         | 8.40                  | 668              | –              | a = 2.5                       |
|                   |             |                       |                  |                | b = 1.2                       |
|                   |             |                       |                  |                | l = 5.2                       |
| brown             | 5.1         | 8.37                  | 667              | –              | a = 2.5                       |
|                   |             |                       |                  |                | b = 1.2                       |
|                   |             |                       |                  |                | l = 5.1                       |

| Agricultural crop | Protein, % | Fat, % | Starch, % | Cellulose, % | Gluten, % |
|-------------------|------------|--------|-----------|--------------|-----------|
| wheat             | 13.43      | 1.83   | 66.8      | 2.2          | 24.7      |
| flax seeds:       |            |        |           |              |           |
| white             | 24.68      | 39.80  | 5.2       | 15.0         | –         |
| brown             | 24.42      | 37.33  | 5.1       | 15.1         | –         |

The components of the grain mixture are characterized by an average level of values both in chemical composition and technological properties and can be considered as quite representative. The content of flax seeds in the mixture was determined based on the recommended levels of consumption of food and biologically active substances [6] and averaged about 7%.

3. Research methods
To study the milling and production of wheat and wheat-flax flour, the RSA-5 reduction and sorting unit with corrugated rollers for break systems (P·10⁻¹ cm) and microrough surface rollers for reduction systems, the laboratory plansifter and the laboratory bran finisher were used. The whiteness of flour (WF) was determined by measuring the reflectivity of a densely smoothed flour surface using a photovoltaic device (GOST 26361-2013), ash content (Z) – by burning flour and bran, followed by determination of the fireproof residue mass (GOST 27494-2016). The total protein content was
determined by the Kjeldahl method \((N \times 6.25)\) (GOST 10846-91); lipids content – according to Soxhlet (GOST 29033-91); fiber content – according to Kuschner and Hanek; starch content – according to Evers (GOST 31675-2012) [7].

4. Discussion of the results

Processing of grain mixtures, the components of which have significant differences in physical and chemical properties, is a rather complicated task [8,9,10,11].

The study of the processes of preparation and milling of a grain mixture containing flax seeds was carried out using 93% wheat grain and 7% flax seeds content. The conditions for the joint processing of wheat grain and flax seeds are the separate preparation and thorough mixing of the components immediately before milling. The content of flax seeds in the mixture was determined in accordance with the "Recommended levels of consumption of food and biologically active substances", it averaged about 7%. During the wheat grain preparation the cold conditioning was carried out, the modes of which corresponded to “The rules of organization and process control at flour mills” [12], humidity - 15.5%, dwell time in the water - 24 hours.

Analysis of the geometric sizes of flax seeds and wheat grain shows the impossibility of their joint cleaning. The preparation scheme should consist of independent preparation flows.

The scheme of the two-factor experiment for determining the optimal conditioning parameters is presented in table 3.

### Table 3. Estimated and actual moisture content of the original wheat grain

| Milling number | Estimated moisture, % | Actual moisture, % | Dwell time in the water, hour |
|----------------|-----------------------|--------------------|-------------------------------|
| 1 (control)    | 16,0                  | 14,7               | 24                            |
| 2              | 16,5                  | 15,2               | 24                            |
| 3              | 16,5                  | 14,9               | 12                            |
| 4              | 15,0                  | 14,4               | 18                            |
| 5              | 14,5                  | 13,6               | 12                            |
| 6              | 14,5                  | 13,7               | 24                            |

The results of grain mixtures milling are presented in tables 4, 5.

### Table 4. Yield (Y) flour and bran, %

| Technological system | Milling № 2 | Milling № 3 | Milling № 4 | Milling № 5 | Milling № 6 |
|----------------------|-------------|-------------|-------------|-------------|-------------|
| break I              | 8,4         | 11,9        | 8,3         | 8,3         | 9,5         |
| break II             | 10,8        | 11,9        | 7,7         | 7,7         | 8,8         |
| break III            | 3,6         | 3,3         | 4,3         | 4,0         | 3,8         |
| reduction system 1   | 35,6        | 35,4        | 31,4        | 30,7        | 32,1        |
| reduction system 2   | 5,2         | 2,5         | 11,0        | 11,7        | 8,4         |
| reduction system 3   | 2,4         | 2,9         | 5           | 6,0         | 3,8         |
| \(\Sigma\) flour     | 66,0        | 67,9        | 67,7        | 68,4        | 66,4        |
| Bran from break systems | 23,2   | 18,5        | 19,0        | 16,3        | 19,5        |
| Bran from reduction systems | 10,8 | 13,6        | 13,3        | 15,3        | 14,1        |
| Bran from break systems / bran from reduction systems | 2,15 | 1,36 | 1,43 | 1,07 | 1,38 |
| \(\Sigma\) bran     | 34,0        | 32,1        | 32,3        | 31,6        | 33,6        |
Table 5. The results of laboratory grinding on the whiteness of flour, units

| Technological system | Milling № 2 | Milling № 3 | Milling № 4 | Milling № 5 | Milling № 6 |
|----------------------|-------------|-------------|-------------|-------------|-------------|
| break I              | 73          | 69          | 69          | 67          | 66          |
| break II             | 56          | 52          | 53          | 51          | 51          |
| break III            | 37          | 31          | 31          | 30          | 29          |
| reduction system 1   | 55          | 51          | 50          | 50          | 50          |
| reduction system 2   | 36          | 29          | 36          | 35          | 33          |
| reduction system 3   | 28          | 23          | 24          | 21          | 23          |

Statistical analysis of laboratory milling results using the MINITAB14 program revealed statistically significant linear regression equations. The result of statistical processing of the dependence of flour whiteness on conditioning parameters (table 3) is presented below.

Regression Analysis: WF2 versus Y2
The regression equation is
\[ WF2 = 72.45 - 0.2759 \times Y2 \]
\[ S = 2.39544 \quad R-Sq = 91.0\% \quad R-Sq(adj) = 88.8\% \]

Regression Analysis: WF3 versus Y3
The regression equation is
\[ WF3 = 69.93 - 0.2675 \times Y3 \]
\[ S = 1.95253 \quad R-Sq = 93.2\% \quad R-Sq(adj) = 91.5\% \]

Regression Analysis: WF4 versus Y4
The regression equation is
\[ WF4 = 69.30 - 0.3255 \times Y4 \]
\[ S = 1.84777 \quad R-Sq = 96.1\% \quad R-Sq(adj) = 95.1\% \]

Regression Analysis: WF5 versus Y5
The regression equation is
\[ BM5 = 67.16 - 0.3066 \times Y5 \]
\[ S = 1.92102 \quad R-Sq = 95.3\% \quad R-Sq(adj) = 94.2\% \]

Regression Analysis: WF6 versus Y6
The regression equation is
\[ WF6 = 67.16 - 0.3051 \times Y6 \]
\[ S = 2.26688 \quad R-Sq = 93.1\% \quad R-Sq(adj) = 91.3\% \]

Regression Analysis: WF1 versus Y1
The regression equation is
\[ WF1 = 75.00 - 0.09554 \times Y1 \]
\[ S = 0.369080 \quad R-Sq = 98.8\% \quad R-Sq(adj) = 98.3\% \]

Based on the obtained equations, the yield indices of top-grade flour were calculated.

The optimal values of the conditioning parameters were determined using the method of contour-graphical analysis, where the following optimization criteria were used: the estimated yield of top-grade flour; maximum value of whiteness of flour; the ratio of the bran yield of break systems to the bran yield of reduction systems, as a characteristic of the grit formation efficiency; they amounted to moisture content of at least 15% and dwell time in the water of at least 18 hours, which corresponds to the recommendations [12]. Thus, the introduction of flax seeds into the mixture does not affect the choice of conditioning parameters.

Mixing wheat grain with flax seeds during the processing of a grain mixture is a difficult task and is possible only immediately before milling, as they have significant differences in physical and chemical properties. In addition, this is based on the separate preparation of the components and self-sorting of the mixture during movement [10, 11].

To determine the necessary conditions for the formation of a binary grain mixture, the main mixing methods were modeled:

- active - with a high relative speed of components movement, which are based on a convective movement mechanism (paddle mixers);
- passive - based on the movement of layers sliding relative to each other (drum mixers).

Evaluation of the quality of the mixture by the heterogeneity coefficient (coefficient of variation) was carried out according to the formula:
\[
V = \frac{100}{\bar{c}} \sqrt{\sum_{i=1}^{n} \frac{(c_i - \bar{c})^2}{n - 1}}, \% \quad \text{where}
\]

\(\bar{c}\) - the arithmetic mean value of the key component concentration; 
\(c_i\) - current concentration value; 
n - the number of measurements.

The number of samples and the mass of the sample were determined in accordance with the recommendations [11] and amounted to - the number of samples - 8, the mass of the sample according to calculation - 5 g, in fact - 50 g.

Comparison of the mixing methods showed that the passive method is significantly inferior to the active one. So with equal mixing cycles, the coefficient \(V\) is 37.4\% for the drum mixer and 15.9\% for the screw mixer. Subsequently, the active mixing method was used, which ensured satisfactory quality. The basic scheme for the grain mixture preparing for milling includes: separate cleaning of wheat grain flow and flax seeds flow from impurities, cleaning of the surface (shelling) of wheat grain, wheat grain conditioning, wheat grain and flax seeds mixing, forming of a grain mixture flow.

The program of experimental studies of milling modes in the first, the second and the third break systems provided for a wide range of yield indices, which was achieved by a corresponding variation of the roll space: for the first break system from 0.75 mm to 0.20 mm, providing yield index from 25 to 70\%, for the second break system from 0.20 mm to 0.05 mm, which corresponded to yield indices from 48 to 66\%; for the third break system from 0.05 mm to 0.00, and the yield indices range was from 22 to 45\%.

Analysis of the grain-size composition shows that the better part of the intermediate products lies in the size range of 600-150 microns. (Figure 1).

The fractional composition of grains is shown in Figure 2.
The bulk of the grains is characterized by a size of 250 - 560 microns, according to the classification [10] – this is a mixture of small and medium grains.

The optimal zone of the milling mode is determined, first of all, by the maximum endosperm content (minimum ash content) in the grains of break systems (Figure 3).

**Figure 3.** The dependence of the ash content of grains on the total yield (break I system)
The optimal milling conditions were characterized by the following values (yield / ash content): in terms of the first break system - 53.5 / 1.00; the second break system - 22.2 / 1.1; totally the first and the second break systems - 75.7 / 1.03 and the third break system - 5.3 / 2.07. Totally for the first, second and third break systems - 81.0 / 1.10.

Based on the analysis of the grains qualitative characteristics the principle scheme of a two-component grain mixture milling was formed, it included three break systems, one scratch, one sizing systems and five reduction systems. The yield of flour varied from 70 to 75%. The peculiarity of the technological scheme was that the break process was reduced, in fact, the selection of grains was carried out in the first and the second break systems, in the third break system only the dunst was selected. The flow of medium grains was directed to the sizing system, small grains were directed to the 1st reduction system and the dunst from the first, the second and the third break systems – to the 2nd reduction system.

Analysis of quantitative and qualitative characteristics of flour (yield, whiteness, ash) showed that the color of flax seeds has an important role in the market condition of flour and bread (Figure 4).

![Figure 4. Cumulative curves of whiteness of flour: red color – wheat grain milling, black color – wheat + flax brown, green color – wheat + flax white](image)

In addition, considering the non-uniform lipids distribution between individual flows, namely that the lipids content increases with the turn from the first to the last milling systems, and also taking into account the principle of the formation of flour varieties, which is based on the fact that the individual flows belong to different anatomical parts of the grain, flour varieties A, B and C were formed.

Variety A included flour flows from the central part of the endosperm – the first break system, the second break system, the sizing system, the first reduction system, the second reduction system, the third reduction system, - are characterized by low ash content and high whiteness value.

Variety B was obtained by mixing the flour flows: the third break system, the scratch system, the fourth reduction system, the fifth reduction system. It represents the crushed peripheral parts of the grain.

Variety of flour C was obtained as a result of combining all flows of flour.

The approximate indices of yield and quality of the new wheat-flax flour varieties are the following:

- **Flour A** – yield 45-50%, lipids 3.6-4.0%, protein 13-13.5%, ash 0.55-0.70%, whiteness – 50 conventional units;
- **Flour B** – yield 20-25%, lipids 5.5-6.0%, protein 14-14.5%, ash 0.9-1.25%, whiteness – 22 conventional units;
Flour C – yield 70-75%, lipids 4.5-5.0%, protein 13.6-14.0%, ash 0.75-0.90%, whiteness – 36 conventional units.

5. Conclusion
Technological schemes for the preparation and milling of two-component grain mixtures based on wheat grain and flax seeds are developed. The patterns of preparation and milling of binary grain mixtures to obtain composite types of flour with specified technological properties and increased nutritional value on account of the enrichment of the traditional types of grain by adding flax seeds with valuable nutritional components such as PUFA, essential amino acids, and other irreplaceable nutritional factors are revealed.

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