Mixing of flour mixture components in the production of pasta from nontraditional raw materials

Abdymanap Ospanov, Nurzhan Muslimov, Aigul Timurbekova, Dinash Nurdan, Dulat Zhalelov

ABSTRACT

Along with a balanced amino acid composition and high protein digestibility, food products should contain complex carbohydrates and ballast substances (dietary fibers) that ensure the normal functioning of the digestive organs. In this regard, fresh raw foods for dietary pasta are of interest for modern pasta production. It is to such raw materials for the manufacture of dough that flour and starch from some cereals, triticale flour, and stale deformed bread are referred. When forming pasta dough from nontraditional flour raw materials, an important technological value for giving the best rheological properties of the dough is the uniform distribution of the binder component in the mixture – dry wheat gluten (DWG). As an object of experimental research to study the mixing process, a loose flour mixture of cereals (barley, oats, corn, buckwheat, millet, peas, and soybeans) was used, compiled based on calculating the recipe using computer programs. The prepared mixtures are a valuable source of nutrients and minerals. At the same time, to improve the technological properties of the dough as a biologically active additive, 25% DWG is introduced to improve the rheological properties of the dough.

Keywords: dry wheat gluten, flour mixture, mixing, pasta, pasta dough recipe

INTRODUCTION

In the healthy nutrition policy, much attention is paid to nutrition physiology. Pasta made from nontraditional raw materials, in comparison with other types of flour products, will have several advantages: high digestibility of basic nutrients, high consumer properties (each category of persons can satisfy their taste needs), long shelf life, low cost and accessibility for all segments of the population [1], [2], [3], [4]. However, such products are not produced in our country, and manufacturers must use baking flour from soft wheat, the protein of which has a deficiency of the most important essential amino acids [5], [6], [7]. At the same time, the further development of pasta production will be directed towards expanding the range for the use of new types of raw materials, such as nontraditional poly-cereal raw materials, as well as improving the technological processes of mixing, pressing, forming the dough, drying, and cooking pasta [8].

Therefore, pasta production based on nontraditional poly-cereal raw materials is one of the promising directions for creating functional products.

Scientific Hypothesis

The main scientific hypothesis is to increase the nutritional value and consumer properties of traditional pasta by using nontraditional poly-cereal raw materials; develop a mathematical model of the process of mixing poly-cereal flour components; study the main technological parameters of the process of making pasta of increased nutritional and biological value based on nontraditional poly-cereal raw materials, depending on the proposed formulations.

MATERIAL AND METHODOLOGY

Samples

As an object of experimental research to study the mixing process, a loose flour mixture of cereals (barley, oats, corn, buckwheat, millet, peas, and soybeans) was used, compiled based on calculating the recipe using computer programs.

Chemicals

The chemical composition (mass fraction of protein, starch and fiber content, ash content) was determined using the Infrascan-105 "KAN" analyzer.

Animals and Biological Material

The animal and biological materials weren't used in this research.

Instruments

The Chopin Alveograph (France), Farinograph-AT company Brabender (Germany), Case drying SESh-3M (Russian Federation), and The Infrascan-105 "KAN" analyzer (Russian Federation) were used in this research.

Laboratory Methods

Experimental studies on the processes of mixing flour mixture components, pressing pasta dough, and drying finished pasta were carried out under the conditions of the International Research Center "Technology of Food and Processing Industries" of the Kazakh National Agrarian Research University; LLP "Kazakh Research Institute of Processing and Food Industry" and the Astana branch of LLP "Kazakh Research Institute of Processing and Food Industry".

The methodology and materials for assessing the quality and technological properties of poly-cereal raw materials in pasta production are described below.

Evaluation of quality, technological properties, and determination of Kazakhstan's food safety indicators of grain raw materials was carried out following the requirements of existing GOST standards.

Poly-cereal mixtures for the production of a promising range of pasta based on nontraditional raw materials were made following the results of automated calculation using our software [7], [20], [22]. This software is designed to compound composite mixtures from whole grains of cereals and legumes based on flour.

Study of the rheological properties of the test. The main technological properties that determine the efficiency of the technological process of pressing pasta dough are elastic-plastic properties: viscosity, elasticity, and extensibility of the dough. In this regard, we studied the rheological properties of pasta dough made in accordance with the developed recipe based on poly-slag raw materials. The prepared mixture will differ in terms of the properties studied. In this regard, to give the test the best elastic-plastic properties, dry wheat gluten was introduced into the formulation to improve the binding of all components introduced into the mixture formulation.

Determination of the rheological properties of flour using Chopin's Alveograph (France). The essence of the method consists of kneading the dough at constant humidity and a solution of sodium chloride, after which the dough is installed in a special compartment of the Alveograph, where the extensibility of the dough is determined during the inflating of dough balls, and automatic plotting with curves showing the rheology of flour.

Determination of water absorption and rheology of flour. The study was carried out on a Brabender Pharynograph (Germany). The principle of operation is to mix the dough in a dough mixer with the addition of the necessary amount of water to obtain the desired consistency. The results of the study were recorded in the observation log.

On the Faringraph device, water absorption, the dough's formation time, the dough's stability, the degree of dilution of the dough, and the degree of quality according to the Faringraph were also studied.

The production of pasta was carried out on a laboratory screw pasta press.

The study of pasta and the kinetics of drying was carried out following the technological process of pasta production after pressing the pasta dough.

The method of experimental research was as follows. The selected pasta sample was sent for drying in the drying cabinet SESh-3M at the temperatures of the drying agent at 40, 50, and 60 °C and at intervals of every 5 minutes, the humidity values of the experimental suspension of pasta were determined. In the course of experimental studies, the time (duration) of the convective effect of the drying agent on pasta, and the mass fraction of moisture of the experimented product was recorded. Then, on the data obtained, diagrams and drying kinetic curves were constructed, which characterize the drying process of pasta.

The assessment of the quality of consumer properties of pasta was carried out following GOST R 51865-2002, according to which the assessment is descriptive. It also provides a score analysis of the quality of pasta, which facilitates a comparative assessment of products, more objectively reflecting their consumer advantages and quality changes during their long-term storage.

The evaluation of the developed batch of pasta was carried out according to the following indicators: appearance, colour, smell, taste, consistency, and state of the cooking water. Each indicator is characterized by five to six descriptive categories with the assignment of these points. The total maximum score is 100 points.

Description of the Experiment

Sample preparation: To conduct further experimental studies to substantiate the technology of pasta production based on nontraditional grain raw materials, raw materials of plant origin have been identified as the object of research, which can be conditionally divided into three groups:
• flour mixtures (3 recipes), compiled according to a scientifically based recipe and compiled based on the calculation of the recipe using computer programs;
• pasta dough (3 types), obtained based on nontraditional poly-cereal raw materials;
• pasta (3 types) from dough made based on the developed recipe.
To form a uniform and homogeneous flour mixture, the kinetics of mixing was studied on a laboratory kneading machine.

Number of samples analyzed: We analyzed 36 samples.

Number of repeated analyses: Repeated analyses 9.

Number of experiment replication: Triple.

Statistical Analysis

Experimental studies were conducted to study the effect of the duration of kneading pasta dough on the rheological properties of the dough according to the following indicators: the dependence of the elasticity of the dough (P, mm×H_2O); the extensibility of the dough (L, mm); specific work (W, e.a.); the coefficient of elasticity (Ie, %) on the rotational speed of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of pasta dough from nontraditional raw materials, compiled according to recipes No.1, No.2, No.3 and a control sample of pasta dough from wheat flour of the 1st grade. Conventional and special methods of mathematical statistics, methodical approach, and methods of comparative analysis were used to conduct experimental studies.

RESULTS AND DISCUSSION

When forming pasta dough from nontraditional flour raw materials, an important technological value for giving the best rheological properties of the dough is the uniform distribution of the binder component in the mixture – dry wheat gluten (DWG) [7], [9], [10]. In general, the efficiency of the mixing process depends on the design, technological and kinematic parameters: [11], [12], [13]:

$$E_c = \Psi\left(K_3 \frac{W_1...W_{n-1}}{W_n} \cdot t \cdot n \right) \qquad (1)$$

Where:
K_3 is the filling factor; $W_1...W_{n-1}$, W_n is the ratio of components in the mixture; n – is the rotation frequency of the working body; t – is the mixing time.

Applying probability theory to the kinetics of mixing and emulsification, the magnitude of the interface at a certain time will be equal to [11], [12], [13]:

$$S = S_p\left(1 - e^{-tc}\right) \qquad (2)$$

Where:
S is the size of the interface; t – is the mixing time; S_p – is the maximum possible surface; $(1 - e^{-tc})$ – maximum possible partition surface; $c = \ln\dfrac{1}{(1-\varepsilon)}$.

Equations (1 and 2) are valid for all mixing systems since when all devices work, the goal is to increase the interface of the phases. It is possible to move the components of the interface to the individual components of the loading volume [11], [12], [13].

The part of the total number of elementary volumes, which consists of equal volumes containing at least one of the elements of the surface, the section obtained by mixing over time is determined by the formula [11], [13].

$$P_\tau = 1 - e^{-RS_p\left(1-e^{-\tau c}\right)}$$

(3)

Where:

R is the proportionality coefficient.

The value of the fraction of the total number of volumes V, which consists of volumes V_o containing one of the components of the mixture, is determined by the formula [11], [12], [13]:

$$(P_t)_E = 1 - \left[e^{-RS_p\left(1-e^{-\tau c}\right)}\right]^{\frac{V}{V_0}}$$

(3)

Where:

V is the total volume of the mixture; V_o is the volume of samples taken from the mixture.

Thus, in the case when $(P_t)_E$ is taken as the final value for a satisfactory mixing result, the desired time can be obtained by solving equation (3) relatively [10], [17].

In practice, the mixing efficiency is estimated by the coefficient of variation of the distribution of the key component in the micro-volumes of the mixture [11], [12], [13]:

$$V_c = \frac{100}{x}\sqrt{\frac{\sum_{i=1}^{i=n}(x_i - x)^2}{n-1}}$$

(4)

Where:

x is the arithmetic mean of the quantity values, that is, the average content of the key component in the samples; x_i is the value of a random variable in the i-th experiment; n is the number of samples.

At the same time, statistical methods are used to predict the quality of mixing [14], [15].

The process of mixing a multicomponent bulk mixture is a probabilistic process, the study of which involves statistical methods and probability theory. Fischer F. K. gives the diffusion mixing equation for a horizontal cylindrical mixer [16], [17], [18], [19]:

$$\frac{dW}{dt} = D_o\frac{d^2W}{dz} + D_2\left(\frac{d^2}{dr} + \frac{1}{r} + \frac{dW}{dr}\right)$$

(5)

Where: W is the probability distribution density, meaning the particle concentration; D_0 and D_z are the coefficients of axial and radial diffusion; r and z are the distance in the radial and axial directions; t is the mixing time.

The longitudinal mixing of particles obeys the following law [16], [17], [18], [19]:

$$\frac{dc}{dt} = -\omega\frac{dc}{dx} + D_l\frac{d^2c}{dx^2}$$

(6)

Where:

D_l is the coefficient of longitudinal mixing.

The model is called two-component if mixing occurs simultaneously in the longitudinal and transverse directions [16], [17], [18], [19]:

$$\frac{dc}{dt} = -\omega \frac{dc}{dx} + D_l \frac{d^2c}{dx^2} + \frac{Dr}{r} \cdot \frac{dc}{dr}\left(r\frac{dc}{dr}\right) \tag{7}$$

Where:
r is the radius of the apparatus; D_r is the coefficient of transverse mixing.

   Due to various physical and mechanical properties, the mixing of bulk components is simultaneously accompanied by the opposite process to the above – segregation of the finished mixture. Segregation is the concentration of particles having a similar characteristic (mass, size, shape, etc.) under the influence of gravitational and inertial forces. The end of the mixing process must be established at the moment when the phenomenon of segregation has not begun to manifest itself [12], [20].
   To better represent the physical picture of mixing, a graph of the dependence of the coefficient of variation (V_c) on the mixing time (t) is plotted. The curve characterizing the mixing process is called the "mixing curve". The analysis of the mixing kinetics (Figure 1) shows the presence of three zones [7], [22]:
- I zone – zone of intensive mixing as a result of shear and convective processes;
- II zone – zone of delayed diffusion mixing;
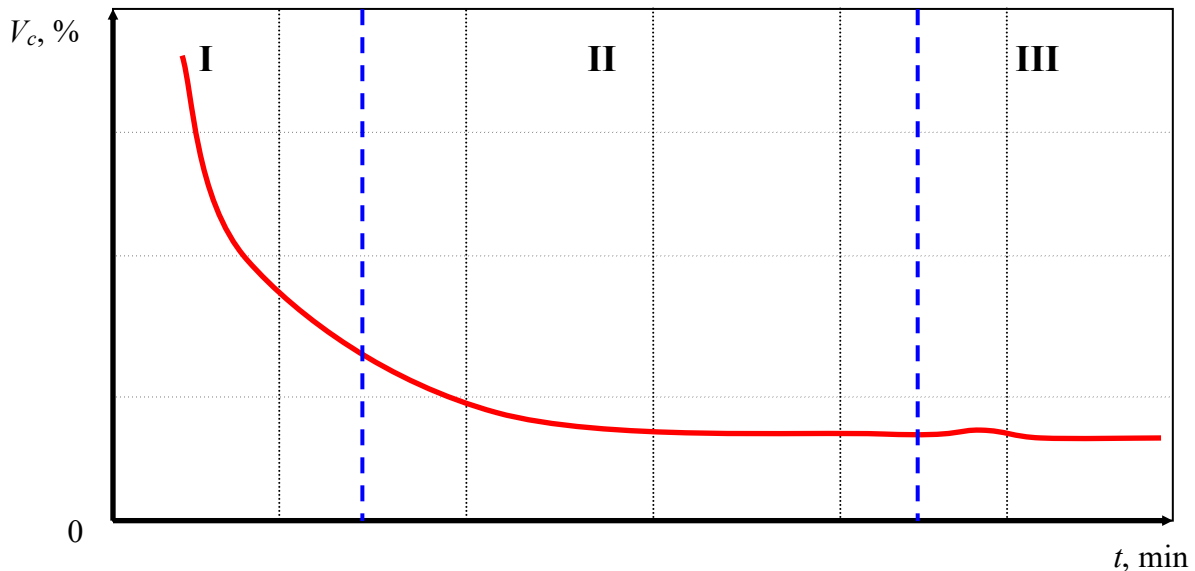- III zone – is a manifestation of the segregation process, increasing the coefficient of variation.

**Figure 1** Kinetics curve of mixing of bulk components in a mixture.

   Moreover, unlike diffusion mixing, the first two processes (shear and convective) do not depend on the characteristics of the mixed components. During the mixing of the components, the one at which $V_c \rightarrow$ min should be taken [7], [22]. Given this physical picture of mixing, it is necessary to distinguish between two main parameters – the quality of the process and the duration of the operation until the specified quality is achieved.
The above theoretical prerequisites for mixing the components were laid down as the basis for several experimental works. To conduct experimental studies on the study of the dough kneading process, a recipe for pasta made from nontraditional raw materials was developed – No. 1, No. 2, and No. 3. The calculated indicators of the selected recipes are indicated in Table 1. [20], [21], [22].
   Experimental studies were conducted aimed at studying the effect of the duration of kneading pasta dough on the rheological properties of the dough according to the indicators: dough elasticity (P, mm×H$_2$O), dough extensibility (L, mm), specific work (W, e.a.), elasticity coefficient (Ie, %), at fixed values of the rotational speed of the working organ (n, min^{-1}) and the time spent on the process of kneading pasta dough (t, sec). Based on experimental data, a graph was constructed of the dependence of the change in the values of the rheological properties of the pasta dough on the rotation frequency of the working organ and the time spent on kneading the pasta dough [7], [22].

Table 1 Recipe of the flour mixture for the production of pasta dough +25% DWG.

Name of raw materials	Values, %	Estimated nutritional value of the mixture
	Recipe No1	
corn	33.3333333333333	protein – 18.028%;
oats	33.3333333333333	starch – 60.256%;
millet	16.6666666666667	fiber – 8.076%;
soy	16.6666666666667	fats – 8.61%;
		ash – 3.664%;
		energy value – 405.847 kcal
	Recipe No2	
corn	50.0	protein – 17.824%;
oats	16.6666666666667	starch – 63.076%;
buckwheat	16.6666666666667	fiber – 6.684%;
soy	16.666666666666	fats – 8.348%;
		ash – 2.946%;
		energy value – 408.028 kcal
	Recipe No3	
barley	16.0	protein – 18.5%;
corn	25.0	starch – 56.7%;
oats	15.0	fiber – 13.23%;
buckwheat	27.3	fats – 7.76%;
peas	16.7	ash – 5.34%;
		energy value – 406.07 kcal

Figure 2 shows the three-dimensional dependence of the change in the elasticity values of the dough (P, mm×H_2O) on the rotation speed of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of the pasta dough from unconventional raw materials compiled according to experimental recipes No. 1 – No. 3 and a control sample of pasta dough.
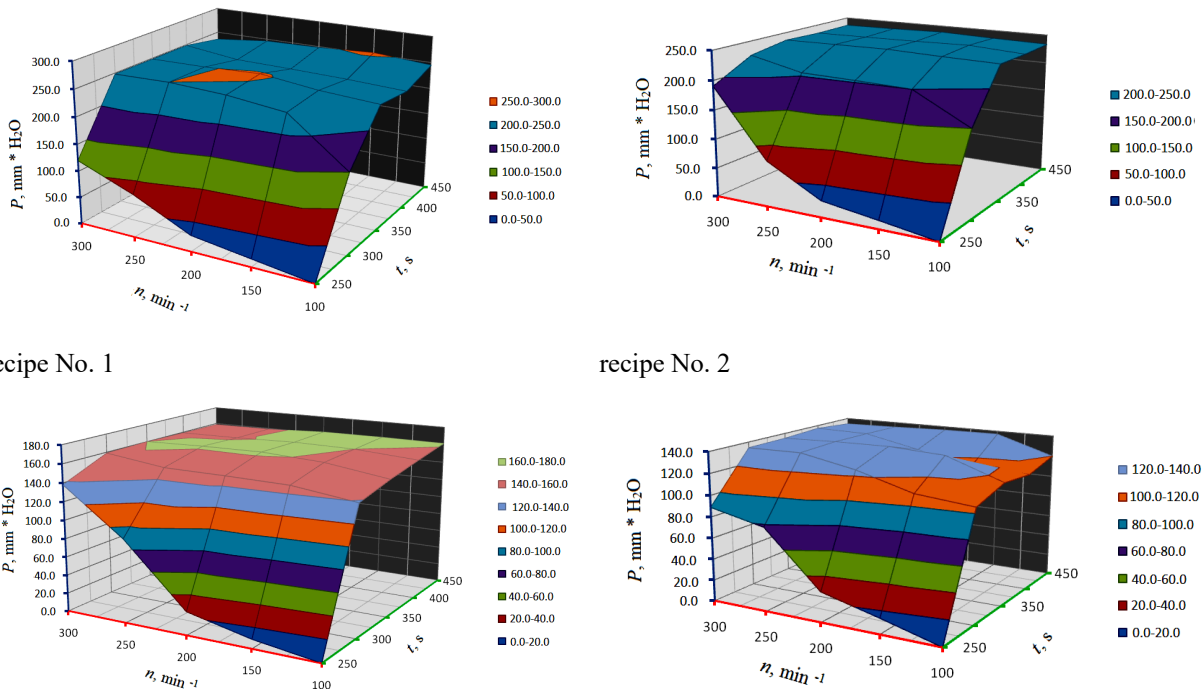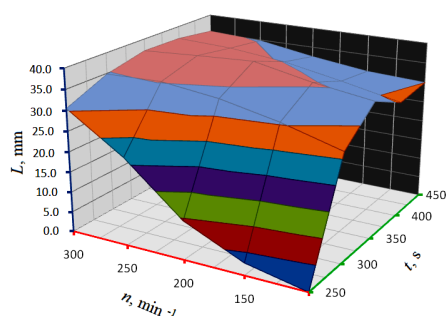

recipe No. 1

recipe No. 2

recipe No. 3

control sample of pasta dough from wheat flour of the 1st grade

Figure 2 Three-dimensional dependence of the change in the elasticity values of the dough (P, mm×H_2O) on the rotation speed of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of pasta dough from nontraditional raw materials.
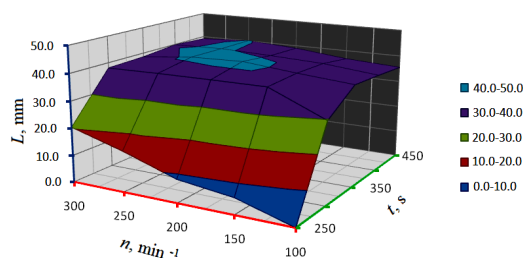
The analysis of the three-dimensional dependencies of the kneading of the pasta dough showed that with an increase in the rotation speed of the working body of the kneading unit and the processing time of the pasta dough of the loose flour mixture, the values of the elasticity of the dough increase to specific values. Similar dynamics were observed in all formulations No. 1 – No. 3 and a control sample of pasta dough made based on wheat flour of the 1st grade. At the same time, prolonged processing of the pasta dough leads to a decrease in the experimental values of the elasticity of the dough (P, mm×H_2O), since prolonged processing of the object of study leads to the destruction of the structure of the pasta dough, thereby reducing the experimental values. The maximum values of the dough elasticity were reached at $n = 200$ min^{-1} and the duration of kneading $t = 350$ sec. The minimum values of the elasticity of the dough were observed at $n = 100$ min^{-1} and the time of kneading the dough $t < 200$ sec.

As a result of experimental studies conducted to study the rheological properties of pasta dough from nontraditional flour raw materials in terms of the elasticity of the dough (P, mm×H_2O), it was found that the best characteristics were pasta dough made according to recipe No1 [7], [22]. For example, the maximum elasticity values of pasta dough were 253.0 mm×H_2O with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}. At the same time, the value of the elasticity index of the control sample of pasta dough based on wheat flour of the 1st grade was 137.0 mm×H_2O with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}. The maximum elasticity values of pasta dough No. 2 and No. 3 of the sample were 238.0 mm ×H_2O and 162.0 mm×H_2O, respectively, with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}.
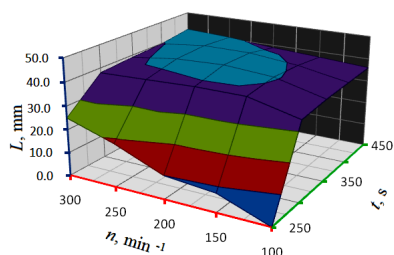
Next, three-dimensional surfaces were constructed to change the values of dough extensibility (L, mm) from the rotation speed of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of pasta dough from nontraditional raw materials, compiled according to recipes No. 1 – No. 3 and a control sample of pasta dough from wheat flour of the 1st grade (Figure 3).
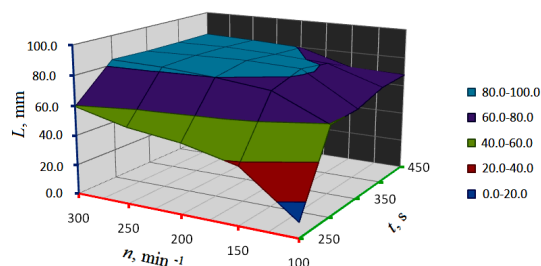

recipe No. 1

recipe No. 2

recipe No. 3

control sample of pasta dough from wheat flour of the 1st grade

Figure 3 Three-dimensional dependence of the change in extensibility values (L, mm) on the rotation speed of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of pasta dough from nontraditional raw materials.

The analysis of the three-dimensional dependencies of the kneading of the pasta dough showed that with an increase in the rotation speed of the working organ of the dough mixing plant and the processing time of the

pasta dough, the values of the extensibility of the dough increase to the maximum values. Similar dynamics were observed in all formulations No. 1 – No. 3 and a control sample of pasta dough made based on wheat flour of the 1st grade. At the same time, prolonged processing of the pasta dough leads to a decrease in the experimental values of extensibility (L, mm), since prolonged processing of the object of study leads to the destruction of the gluten structure in the pasta dough, thereby reducing the experimental values. The maximum values of the elasticity of the dough were reached at $n = 200$ min^{-1} and the duration of kneading $t = 350$ sec. The minimum values of the test extensibility were observed at $n = 100$ min^{-1} and the time of kneading the dough $t < 200$ sec.

As a result of the experimental studies conducted to study the rheological properties of pasta dough from nontraditional flour raw materials in terms of the extensibility of the dough (L, mm), it was found that the control sample of pasta dough made based on wheat flour of the 1st grade had the best characteristics [7], [22]. The maximum values of the extensibility of the control sample of the pasta dough were 84.0 mm with a kneading duration of 350 seconds and a rotation speed of the working body of the kneading unit $n = 200$ min^{-1}. At the same time, the minimum values of the extensibility index of 38.5 mm corresponded to the pasta dough compiled according to recipe No1 at the average values of the rotation speed of the working body of the kneading unit $n = 200$ min^{-1} and the duration of kneading $t = 350$ sec. The maximum values of the extensibility index of the pasta dough in test samples No. 2 and No. 3 were 41.0 and 42.2 mm, respectively.

Next, three-dimensional surfaces were constructed to change the values of specific work (W, e.a.) from the rotation frequency of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of pasta dough from unconventional raw materials compiled according to recipes No. 1 – No. 3 and a control sample of pasta dough from wheat flour of the 1st grade (Figure 4).
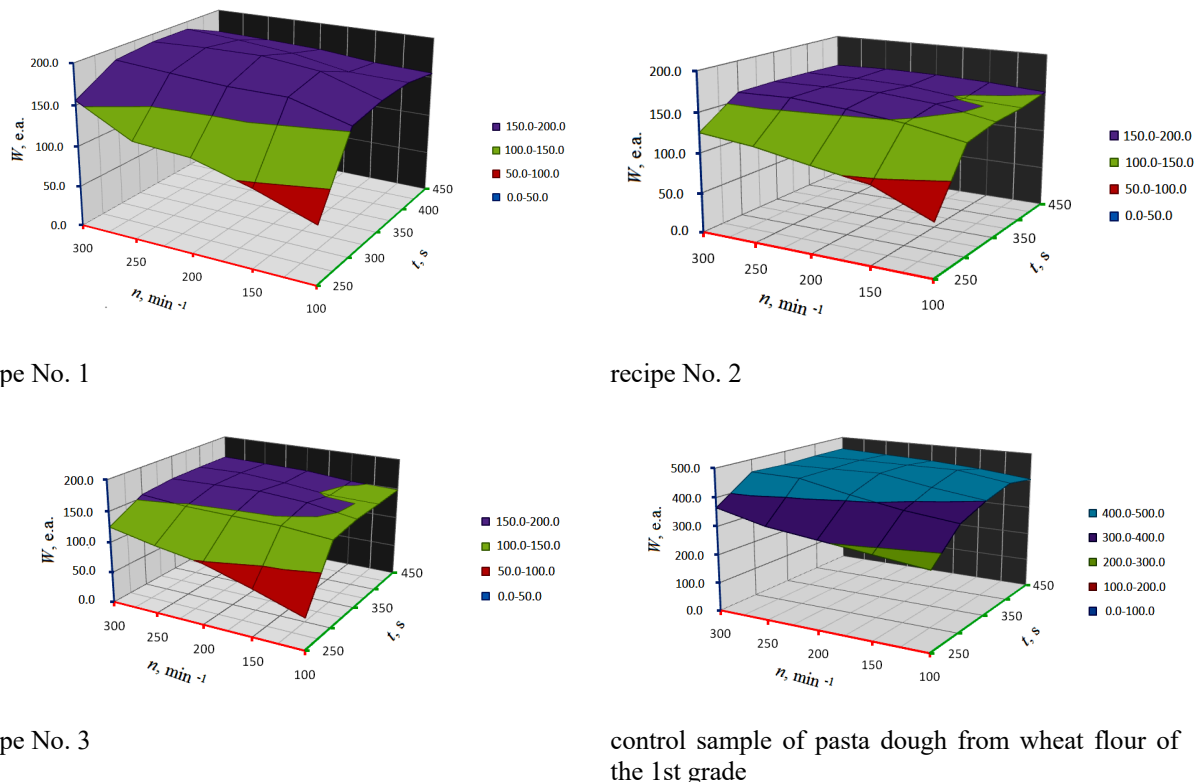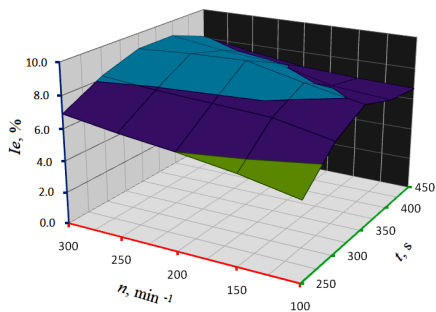

recipe No. 1

recipe No. 2

recipe No. 3

control sample of pasta dough from wheat flour of the 1st grade

Figure 4 Three-dimensional dependence of the change in the values of specific work (W, e.a.) on the rotation speed of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of the control sample of the pasta dough.

The analysis of the three-dimensional dependencies of the kneading of the pasta dough showed that with an increase in the rotation speed of the working body of the dough mixing plant and the processing time of the pasta dough, the values of the specific work of the dough increase to certain values. The physical pattern of changes in the values of W (e.a.) is identical in all formulations No. 1 – No. 3 and the control sample of pasta dough from wheat flour of the 1st grade. At the same time, prolonged processing of the pasta dough leads to a

decrease in the experimental values of the specific work (W, e.a.), since prolonged processing of the object of study leads to the rupture of gluten, and hence the structure of the pasta dough, thereby slightly reducing the experimental values of the rheological properties of the pasta dough. The maximum values of the specific work of the test were reached at $n = 200$ min^{-1} and the duration of kneading $t = 350$ sec. The minimum values of the elasticity of the dough were observed at $n = 100$ min^{-1} and the time of kneading the dough $t < 200$ sec.

As a result of the experimental studies conducted to study the rheological properties of pasta dough from nontraditional flour raw materials in terms of the specific work of the dough (W, e.a.), it was found that the control sample of pasta dough made based on wheat flour of the 1st grade had the best characteristics [7], [22]. For example, the maximum value of the specific work of the pasta dough was 455.0 units (e.a.) with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}. At the same time, the test's specific work index values for experimental samples No. 1, No. 2, and No. 3 were 193.0, 162.0, and 164.0 e.a. respectively, with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}.
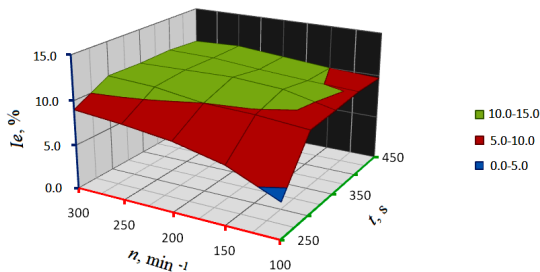
Next, three-dimensional surfaces were constructed to change the values of the elasticity coefficient (Ie, %) from the rotation speed of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of pasta dough from nontraditional raw materials compiled according to recipes No. 1 – No. 3 and a control sample of pasta dough from wheat flour of the 1st grade (Figure 5).
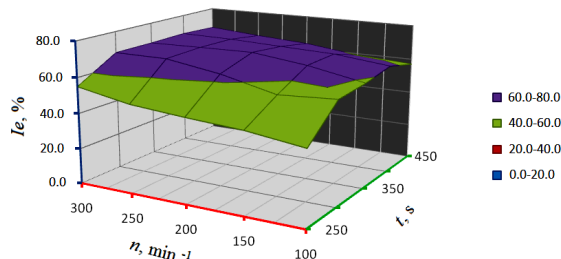

according to recipe No.1
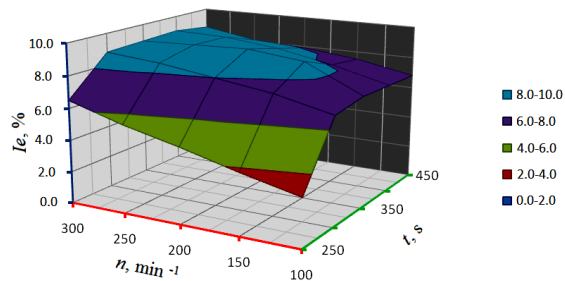
according to recipe No. 22

according to recipe No. 33

according to the control sample of pasta dough from wheat flour of the 1st grade

Figure 5 Three-dimensional dependence of the change in the values of the elasticity coefficient (Ie, %) on the rotation speed of the working body (n, min^{-1}) of the kneading machine and the time spent on the kneading process (t, sec) of pasta dough from nontraditional raw materials.

The analysis of the three-dimensional dependencies of the pasta dough kneading showed that with an increase in the rotation speed of the working body of the dough mixing plant and the processing time of the pasta dough, the values of the elasticity coefficient increase to maximum values. Similar dynamics were observed in all formulations No. 1 – No. 3 and a control sample of pasta dough made based on wheat flour of the 1st grade. At the same time, prolonged processing of the pasta dough leads to a slight decrease in the experimental values of the elasticity coefficient (Ie, %), since prolonged processing of the object of study leads to the destruction of the structure of the pasta dough, thereby reducing the experimental values of rheological properties. The maximum value of the elasticity coefficient (Ie, %) was achieved at $n = 200$ min^{-1} and the duration of kneading $t = 350$ sec. The minimum values of the elasticity coefficient of the dough were observed at $n = 100$ min^{-1} and the duration of kneading the dough $t < 200$ sec.

As a result of experimental studies conducted to study the rheological properties of pasta dough from nontraditional flour raw materials in terms of the coefficient of elasticity (*Ie*, %), it was found that the best characteristics were pasta dough made according to recipe No. 1 **[7]**, **[22]**. For example, the maximum value of the coefficient of elasticity of a control sample of pasta dough based on wheat flour of the 1st grade was 68.9%, with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}. At the same time, the values of the coefficient of elasticity of the pasta dough of experimental samples No. 1, No. 2, and No. 3 were within the same limits. They amounted to 9.3%, 9.1%, and 11.2%, respectively, with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}. The minimum values were 4.8%, 3%, and 4% for experimental samples No. 1, No. 2, and No. 3 with a kneading duration of 250 seconds and a rotation speed of $n = 100$ min^{-1}.

Thus, according to the results of the experimental studies, it was established (Figure 2) that the maximum value of elasticity (*P*, mm×H$_2$O) of pasta dough is 253.0 mm×H$_2$O with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}. The value of the elasticity index for the control sample of pasta dough based on wheat flour of the 1st grade was 137.0 mm×H$_2$O with the same kneading duration and rotation frequency. The maximum elasticity values of pasta dough No. 2 and No. 3 of the sample were 238.0 mm×H$_2$O and 162.0 mm×H$_2$O, respectively, with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}.

The results of the study of the rheological properties of the pasta dough from nontraditional flour raw materials in terms of the extensibility of the dough (*L*, mm) showed (Figure 3) that the control sample of the pasta dough had the best characteristics. The maximum extensibility values of the control sample of the pasta dough were 84.0 mm with a kneading duration of 350 seconds and a rotation speed of the working body of the kneading unit $n = 200$ min^{-1}. At the same time, the minimum values of the extensibility index of 38.5 mm corresponded to the pasta dough compiled according to recipe No. 1 with the above average values of the rotation speed of the working body of the kneading unit and the duration of kneading. The maximum values of the indicator (*L*, mm) in test samples No. 2 and No. 3 were 41.0 and 42.2 mm, respectively.

The results of the study of the rheological properties of pasta dough from non-traditional flour raw materials in terms of the specific work of the dough (*W*, e.a.) showed (Figure 4) that the control sample of the pasta dough also had the best characteristics. The maximum value (*W*, e.a.) was 455.0 units with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}. For experimental samples No. 1, No. 2 and No. 3, the maximum value (*W*, e.a.) was 193.0, 162.0 and 164.0 e.a., respectively, at the above values of the kneading duration and rotation frequency.

The results of the study of the rheological properties of pasta dough from non-traditional flour raw materials in terms of the coefficient of elasticity (*Ie*, %) showed (Figure 5) that the pasta dough made according to recipe No. 1 had the best characteristics. The maximum value of the elasticity coefficient for the control sample of the pasta dough was 68.9% with a kneading duration of 350 seconds and a rotation speed of $n = 200$ min^{-1}. The maximum values of the pasta dough indicator (Ie, %) for experimental samples No. 1, No. 2, and No. 3 were 9.3%, 9.1% and 11.2%, respectively. At the same time, the kneading duration was 350 seconds at a rotational speed of $n = 200$ min^{-1}. For these samples, the minimum values of the elasticity coefficient were 4.8%, 3% and 4%, respectively, with a kneading duration of 250 seconds and a rotation speed of $n = 100$ min^{-1}.

CONCLUSION

The analysis of the theoretical foundations of the mixing process showed that during the mixing of the components, one should take the one at which the coefficient of variation $V_c \rightarrow min$. Given this physical picture of mixing, it is necessary to distinguish between two main parameters – the process's quality and the operation's duration until the specified quality is achieved.

In existing mixers, the mixing process is carried out on the principle of a random process with the expectation of the probability of a favorable outcome, which is a significant disadvantage of mixer designs.

Analyzing the presented three-dimensional surfaces, we can confidently judge the kinetics of the process of kneading pasta dough from nontraditional flour raw materials in pasta production according to the recipes we developed. In the first stage, we observe a prolonged pasta dough formation until a thick mass is formed. Further, a uniform redistribution of all particles in the total mass was observed, while the process of water absorption by starch grains of the flour mixture is actively underway.

It should be noted that further intensification of the processing of pasta dough from nontraditional flour raw materials leads to the destruction of the protein structure, resulting in mechanical denaturation of gluten.

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Contact Address:

Abdymanap Ospanov, Kazakh National Agrarian Research University, Faculty of Technology and Bioresources, Department of food technology and safety, Almaty, Avenue of Abay, 8, 050010, Republic of Kazakhstan,
Tel.: +7 707 223 2959,
E-mail: ospanov_abdymanap@mail.ru
ORCID: https://orcid.org/0000-0002-3813-603X

Nurzhan Muslimov, Astana branch of the Kazakh Research Institute of Processing and Food Industry, Nur-Sultan, Republic of Kazakhstan,
Tel.: +7 747 486 8866,
E-mail: n.muslimov@inbox.ru
ORCID: https://orcid.org/0000-0002-0302-2817

Aigul Timurbekova, Kazakh National Agrarian Research University, Faculty of Technology and Bioresources, Department of food technology and safety, Almaty, Avenue of Abay, 8, 050010, Republic of Kazakhstan,
Tel.: +7 707 403 2757,
E-mail: timurbekova_aigul@mail.ru
ORCID: https://orcid.org/0000-0001-5955-9253

*Dinash Nurdan, Kazakh National Agrarian Research University, Faculty of Technology and Bioresources, Department of food technology and safety, Almaty, Avenue of Abay, 8, 050010, Republic of Kazakhstan,
Tel.: +7 702 355 0886,
E-mail: nurdanova92@mail.ru
ORCID: https://orcid.org/0000-0002-8569-6750

Dulat Zhalelov, Kazakh National Agrarian Research University, Faculty of Technology and Bioresources, Department of food technology and safety, Almaty, Avenue of Abay, 8, 050010, Republic of Kazakhstan,
Tel.: +7 777 188 3689,
E-mail: dula_219@mail.ru
ORCID: https://orcid.org/0000-0002-9688-2639

Corresponding author: *