This work is aimed at developing a procedure for controlling the rheological properties of wheat dough during its kneading based on a parametric model. Dough kneading is the most important technological operation in the production of bakery products. When organoleptically assessing the consistency of the dough, it is difficult to accurately determine its rheological properties while maintaining the mass of water and its intensity at a constant level of the mass of the kneaded dough, considering the processed flour. However, our proposed procedure can solve these problems. According to the results obtained, it was experimentally found that the nature of changes in the specific intensity of dough kneading, which contributed to obtaining the best quality bread at a kneading body rotational speed of 150 rpm, is optimal. The dough kneading intensity leads to a reduction in the kneading time from 290 s at nm=60 rpm to 90 s at nm=240 rpm. The optimal duration of dough kneading was 124 s.

The results make it possible to determine the water absorption capacity of flour in the production of bakery products, considering its baking properties and dough recipe, and, accordingly, the optimal moisture content of the dough

Keywords: rheology, dough, organoleptic, procedure, elasticity, force, kneading machine, deformation, dispersion

UDC 664
DOI: 10.15587/1729-4061.2022.257323

DEVELOPING A PROCEDURE FOR CONTROLLING THE RHEOLOGICAL PROPERTIES OF DOUGH DURING ITS KNEADING BASED ON A PARAMETRIC MODEL

Elvira Mailybayeva
Doctoral Student, Research Associate
Department of Food Technology,
Processing Industries and Biotechnology
M. Kh. Dulaty Taraz Regional University
Tole bi str., 40, Taraz, Republic of Kazakhstan, 080000

Alimzhan Imanbayev
Corresponding author
PhD, Associate Professor
Department of Technology and Safety of Food Products*
E-mail: alimzhanimanbayev1@gmail.com

Gulmira Yessirkep
PhD, Associate Professor
Department of Technology and Standardization
Kazakh University of Technology and Business
Pushkina str., 166/8, Nursultan, Republic of Kazakhstan, 010000

Saltanat Mussayeva
Associate Professor
Department of Food Engineering*

Azret Shingissov
Doctor of Technical Sciences, Professor
Department of Technology and Food Safety*
*Mukhtar Auezov South Kazakhstan University
Tauke Khan str., 3, Shymkent, Republic of Kazakhstan, 160012

Received date 07.04.2022
Accepted date 28.05.2022
Published date 30.06.2022

***How to Cite**: Mailybayeva, E., Imanbayev, A., Yessirkep, G., Mussayeva, S., Shingissov, A. (2022). Developing a procedure for controlling the rheological properties of dough during its kneading based on a parametric model. Eastern-European Journal of Enterprise Technologies, 3 (11 (117)), 31–38. doi: https://doi.org/10.15587/1729-4061.2022.257323*

1. Introduction

In Kazakhstan, during the transition to market conditions, all food enterprises became mainly assortment enterprises, which entailed high requirements for the management of technological operations of food products.

In Europe, for example, for bakery to be transported normally, the range of bakery products produced reaches 300–400 items per day. In this regard, to fulfill an order from a distribution network for specific types of bakery products, kneading takes place only while holding the dough, which serves the strict requirements for the production process: dough kneading, maturation, shaping dough pieces, their final proofing and baking, providing finished products of the resulting quality. In addition, when supplying flour with bakery products, it is necessary to correct its technological properties by determining the dosages introduced by the optimal carriers [1–4].

For the technologist to be able to make quick decisions in perceiving production habits and adequately respond to changes in the properties of processed products and product formulations to obtain the best quality finished product, the specialist must be able to manage the rheological characteristics of semi-finished products [5, 6].

The formation of the rheological properties of dough occurs at the kneading stage. Dough kneading is the most important initial technological operation in the production of bakery products, which, firstly, produces a homogeneous mass as a single system from disparate ingredients and, secondly, forms this mass with certain physical and chemical properties that ensure the optimal flow of all stages of the bakery production process.

A direct indicator reflecting the rheological behavior of wheat dough during the kneading process is the value of the torque M_t on the drive of the kneading elements of the kneading machine or the value of the power consumption Nn of the electric drive of the kneading elements.

In this regard, it is a relevant task to control the rheological properties of wheat dough during kneading. Besides this issue, it is crucial firstly to indicate changes in the duration of dough kneading and changes in the dough consistency index in all its stages.

2. Literature review and problem statement

The work [7] described wheat flour dough as one of the most complex rheological systems, which has been studied by several cereal scientists, food technologists, and rheologists through many decades. The author also mentioned that the research on fundamental rheological properties of wheat flour dough appears to be increasing in importance recently because of the application of continuous and automatic food processing operations such as extrusion, MDD bread making, and sheeting in modern bakery industries.

Different groups of studies characterize the way of flour quality evaluation, and according to this work, the mills and bakery industries employ common rheological techniques such as alveographical, farinographical and mixographical measurements. Recording dough mixers, such as farinograph and mixograph, have been developed for specific use in the cereal industry [8]. Scientists also differentiate parameters of flours such as development time, stability and dough softening that can be recorded during mixing by measuring the resistance of dough to mixing, by these techniques; while in the alveograph, the dough is subjected to biaxial extension [9]. Other work [10] also agrees with the above-given facts and in their opinion, these techniques usually can differentiate flours of different characteristics and are useful in practical applications, but they have the disadvantage, however, of being mostly empirical in nature.

By the description of previous research works, rheological techniques are well suited for the characterization of viscoelastic materials such as wheat flour dough and wheat gluten. The information about the rheological behavior of the flour doughs obtained by the four methods was complementary and in good agreement, despite differences in applied strains, deformation rates and modes of deformation [10]. The empirical tests showed that the extensibility of the biscuit flour dough was less compared to that of the other doughs. This study suggests that to obtain a high loaf volume and a fine crumb structure, wheat flour dough must exhibit biaxial strain hardening and extensibility exceeding a minimum level; the resistance to deformation may vary within a certain range.

Different research was carried out [11] where the effect of mixing time on wheat protein composition and gluten formation was studied for three commercial flour mixtures (biscuit, standard and strong) and one durum flour. The obtained results presented that there is no effect of mixing on the storage modulus (G′) of gluten for any of the flours. The G′ value of gluten was around 3, 3, 4 and 8 for standard, biscuit, strong and durum flour, respectively. Therefore, the increased water content during prolonged mixing was not related to the effect on G′. The strong flour resulted in the lowest G′ for dough, a high G′ for gluten, and no increase in gluten water content with overmixing. The weaker standard flour resulted in the highest gluten water content, which increased considerably with mixing time. The durum flour did not show gluten development and breakdown like the other flours.

Dynamic rheological testing has become a powerful and preferred approach for examining the structure and fundamental properties of wheat flour doughs and proteins because of its characteristic and sensitive response to the structure variation of wheat flour doughs and proteins. The influences of various additives on the rheological properties of gluten proteins and flour doughs are illustrated and the component interactions are emphasized. Moreover, the authors' theoretical analyses concerning the relationship between rheological behavior and structure are summarized [12].

The relaxation properties of flour-water-salt doughs prepared from four different flour types (weak, medium, strong, and extra strong) at different water absorption levels from 58 to 66 % with protein contents of 10.0, 10.9, 13.2, and 11.8 %, respectively, were studied [13] by imposing varying strain amplitudes of 0.1–29 %. This work demonstrated the consistency in oscillatory and relaxation measurements for dough. It also showed that linear viscoelastic data, although important in the characterization of time scales in the dough, are largely irrelevant in differentiating between dough types.

A few study results presented [14] changes in dough rheology, specifically shear and extensional properties, occurring during different stages of the mixing process.

However, when organoleptically assessing the consistency of dough in a specialized way, the rheological properties of dough cannot be accurately determined while maintaining the mass of water and its intensity at a constant level of the mass of the kneaded dough, considering the processed flour.

3. The aim and objectives of the study

The main point of this study is to develop a procedure for controlling the rheological properties of wheat dough during its kneading based on the developed parametric model.

To achieve this aim, the following objectives were set:

– to define factors and indicators for developing a parametric model procedure;

– to knead the dough by the developed procedure and obtain its parameters by the Farinograph M567;

– to identify the parameters of the dough kneading process and bread quality during and after the process.

4. Materials and methods

For conducting this study, top-grade wheat flour was kindly delivered by the flour mill "Tsesna" (Akmola region, the Republic of Kazakhstan).

Dough kneading has been performed on a dough mixer brand OEM-ALI FA121 (Italy) with a bowl volume of 16 l (12 kg) with a fixed kneading body.

Wheat dough parameters were identified before and after kneading on a Farinograph M567 (Italy). The principle of farinograph operation is based on the resistance of dough to the kneader shaft. The resistance moment to the kneader shaft has increasing variation when mixing the components, hydrating flour particles, dough formation and development, up to a maximum value, close to the value of normal dough consistency.

Defining factors and parameters indicated by the parametric model procedure (Fig. 1).

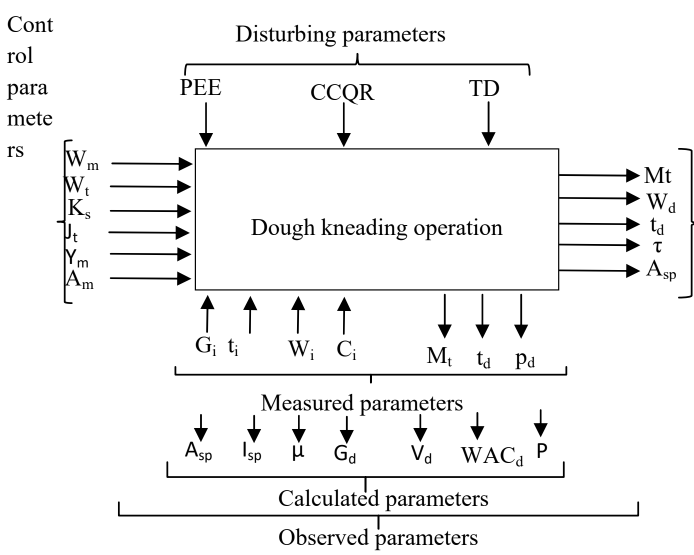

Fig. 1. Parametric model of wheat dough kneading

In accordance with the requirements of the system analysis, all factors and coverage indicators in the measurement parameters are checked for disturbing, controlling, adjustable and sensitive, in turn, covered by the measured and calculated ones.

Disturbing parameters:

– PEE – parameters of the external environment (atmospheric pressure, relative air humidity, air temperature, etc.).

– CCQR – chemical composition and quality of raw materials, including the granulometric composition of flour.

– TD – technological deviations (mass of kneaded dough, temperature of components, moisture content of raw materials, concentration of solutions, etc.).

Control parameters:

– W_m – mass of water introduced during dough kneading, kg;

— W_t – water temperature;

– K_s – rotational speed of kneading bodies;

– J_t – kneading chamber jacket temperature;

– Y_m – mass of baker's yeast, kg;

– A_m – mass of additives-improvers, kg.

Managed parameters:

– M_t – torque on the drive of kneading bodies (indicator of dough consistency), *N*m* (or power consumption by the drive of kneading bodies of the kneading machine, *W* and other classical and conditional rheological characteristics of dough);

– W_d – dough humidity, %;

– t_d – dough temperature;

– $t^{\#}_{knead}$ – duration of dough kneading until ready, s;

– A_{sp} – amount of specific mechanical energy spent on the formation of the dough structure.

Observed parameters:

1) measured parameters:

– *G* – weight of the i-th prescription components, kg;

– t_i – temperature of the i-th prescription components;

– W_i – humidity of the i-th prescription components, %;

– C_i – concentration of solutions of the i-th prescription components, %;

– M_t – torque on the drive of kneading bodies, N*m;

– t_d – dough temperature;

– ρ_d – electrical conductivity of the dough, cm;

2) calculated parameters:

– A_{sp} – amount of specific mechanical energy spent on the formation of the dough structure, kJ/kg;

– I_{sp} – specific intensity of dough kneading, kJ/kg;

– *M* – number of dough deformation cycles;

– G_d – dough mass, kg;

– V_d – dough output, kg;

– WAC_d – water absorption capacity of dough, %;

– *P* – power of flour.

To assess the dough kneading process and determine the moment of its readiness, it is more expedient to use the specific intensity (1), since it is a relative integral characteristic that reflects changes in the rheological properties of the kneaded dough and the nature of mechanical energy consumption during kneading:

$$I = 2^{*}1^{*}n_m. \tag{1}$$

Determining the dough kneading mode, in addition to determining the optimal kneading duration $t^{\#}_{knead}$, is also reduced to finding the optimal rotational speed of the kneading bodies nm. This search consists in determining the features in the change of controlled parameters from the rotational speed of the kneading bodies. The most preferred controlled integral parameter is the amount of mechanical energy A_{sp} spent on the formation of the dough structure:

$$A_{sp} = 2 * \pi * nM_t(\tau_d)d\tau_d / G_m. \tag{2}$$

To determine the optimal mode of dough kneading $t^{\#}_{knead}$ I nm, a dimensionless technological criterion μ can also be used, which combines two determined parameters:

$$\mu = n_m * \tau^{\#}_d. \tag{3}$$

Dough parameters determination process on the Farinograph M567. To determine the optimal values of the control parameters for wheat dough kneading, considering disturbing technological factors, the critical points of its rheological properties and temperature must be known, i.e., the main controllable parameters that provide the best quality finished bakery products.

Wheat dough kneading control provides for the establishment of the optimal kneading mode, which is characterized by two main parameters – kneading time to readiness $t^{\#}_{knead}$ and rotational speed of the kneading bodies n_m of the kneading machine.

The formation of wheat dough structure during kneading is associated with the cost of a certain combination of computational energy. Therefore, several authors control dough kneading, which is recommended to be carried out following the value of the specific work shown by glucose in adipose tissue. GosNIIKhP developed recommendations on the cost of mechanical energy when kneading dough from wheat flour, considering its "strength": for weak flour – 15–25 kJ/kg; for medium-strength flour – 25–40 kJ/kg and for individual flour – 40–50 kJ/kg. However, specific work values, especially the best quality of the baked bread, a high degree of sharpness from the selection of choice, for example, flour flavors, dough recipes, properties of recipe components, optimal features of dough mixers, speed of kneading organs, etc., which is due to the use of accuracy data in practice.

Therefore, the control of the dough batch should be based on technological criteria, taking into account the dynamics of the regulation of parameters and the kinetics of their change depending on the control parameters. Analysis of the dynamics of the development of the process of ensuring the need for supply during mixing $t^{\#}_{knead}$ and analysis of the kinetics of the development of the kneading bodies.

Identification of parameters of the dough kneading process and bread quality during and after the process. To identify the dough and bread quality during and after the kneading process, the dough kneading mode, and quality scoring methods were used. Besides these, the technological properties of wheat flour samples and the influence of dough humidity on the amount of mechanical energy spent on the formation of its structure during kneading were also investigated.

5. Results of studying the control of rheological properties of wheat dough during kneading

5. 1. Main factors and indicators of parametric models of dough kneading

In production conditions, besides the above-mentioned processes, depending on the technological properties of flour, for example, water absorption capacity, to obtain dough with the expectation of rheological dosages of water, the basis of the organoleptic assessment of the dough consistency by the specialist who maintains the kneading machine changes. Therefore, the following processes firstly must be progressed: at the initial stage of kneading, various components are mixed: flour, water, yeast, salt, and other ingredients. Water is supplied not from above but along the walls of the kneading chamber and interacts with flour to form a monophasic dispersed system, thanks to the hydrophilic groups of colloids, then the destruction of flour particles occurs due to decompaction of the surface layer by the diffusion of water molecules, washing out of water-soluble substances and wedging of particles owing to pressure of osmotically bound water. The first stage of dough kneading ends – the stage of flour hydration, the formation of a polydisperse system of water-soluble proteins, gluten proteins, starch, pentosans, fiber, etc.

When flour is hydrated, adsorption moisture fills the smallest spaces between protein chains and amorphous and crystalline lamellas of starch grains, which leads to an increase in the volume of these structural components and the release of a large amount of heat. The first stage of the mixing of the components corresponds to the linear section "OA" on the torque change curve (Fig. 2). Fig. 2 shows a characteristic curve of changes in the torque value on the drive of the kneading bodies depending on the duration of dough kneading.

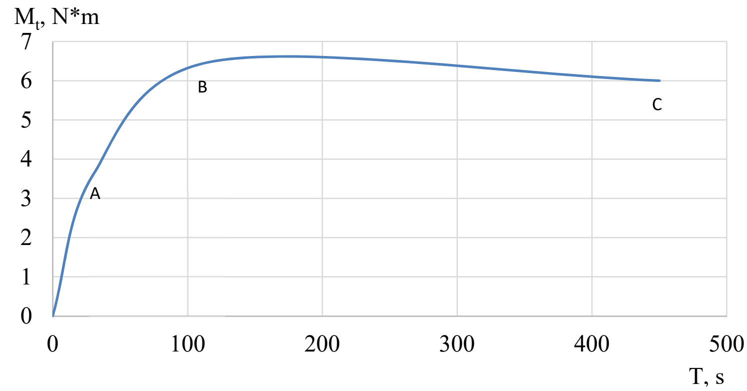

Fig. 2. Influence of dough kneading duration on changes in the dough consistency index, the torque value on the drive of the kneading body

After the first stage of mixing, the formation of a coagulation structure occurs due to the adhesion of elements of the polydisperse system, and then a crystallization structure due to the formation of bifilar helices (secondary superstructure) due to hydrogen bonds, the formation of spatial (over the entire volume) micellar structures due to hydrophobic interaction (formation of a gluten skeleton), "cross-linking" of biopolymer molecules into aggregates due to covalent (disulfide) bonds and metal ions.

When kneading is limited to a homogeneous viscous medium, which is a gluten network, which includes interspersed starch fibers, yeast cells, bran particles, droplets of free water, etc. air and plasticization of the structure due to the alternation of manifestations of various manifestations in its zones: manifestations, twisting, shear, due to the rotation of the kneading bodies. The curve section "AB" corresponds to the formation of the coagulation-crystallization structure of the dough.

The mechanical stresses arising during the kneading process reduce the strength of the gluten framework and, as a result, lead to its destruction. The increase in torque or the development of the dough structure stops in the perception of "B" at the moment of the beginning of relaxation, which occurs with the destruction of the structure. Point "B" is the moment when the dough is ready during kneading.

With the continuation of the kneading action, the change in the composition of the rheological properties is associated with the course of enzymatic processes, changes in the temperature regime and the number of free nutrients. The number of inclusions that can pass into the liquid phase of the dough also increases. The step of the stage corresponds to the excess change of the test plot "BC" of the torque change.

The dough after kneading changes as a dispersed system consisting of solid, liquid, and gaseous phases with changing rheological properties.

Depending on the taste of the dough – up to 36–38 %, it can be selected as a lyophobic-lyophilic system, for example, pasta dough has a taste of 30–31 % (up to 18 % taste – this is a purely lyophobic system that is used in the production of extruded products) when selecting. The composition of the dough, for example, is up to 43–45 % – this is already a lyophilic-lyophobic system, for example, bakery dough. In the presence of 36–38 %, the steepest dough is obtained – this is lamb dough, while an equilibrium state is observed between lyophobic-lyophilic and lyophilic-lyophobic manifestations. The wafer dough may already be a lyophilic system under the previous assumption. Classification of a dispersed system according to the intensity of interaction between the dispersed phase and the liquid medium.

The novelty of the work reveals that water is supplied with a jet along the wall of the bowl in a laminar flow, and the flour is gradually wetted quickly and in a dry increase – the increased water absorption capacity of the dough. The experiment was carried out on a laboratory mixer. With this method of water consumption according to the schedule, you can see a visible curve, this is because there is a qualitative transition from the dispersed phase to another.

Fig. 3 shows a family of curves for changing the magnitude of the torque M_t during kneading at different values of the rotational speed of the kneading bodies nm.

As can be seen from Fig. 3, with an increase in the rotation of the kneading bodies from 1.0 s^1 to 4.0 s^1, the extreme maximum value of M_t, which characterizes the moment of dough readiness, comes earlier, and the extreme value becomes more pronounced.

The influence of the duration of wheat dough kneading on the change in the specific intensity of kneading at different rotational speeds of the kneading bodies is given in Fig. 4.

As can be seen from Fig. 4, when the rotational speed increased, the kneading of wheat dough also leveled up and decreased with the duration of some time.

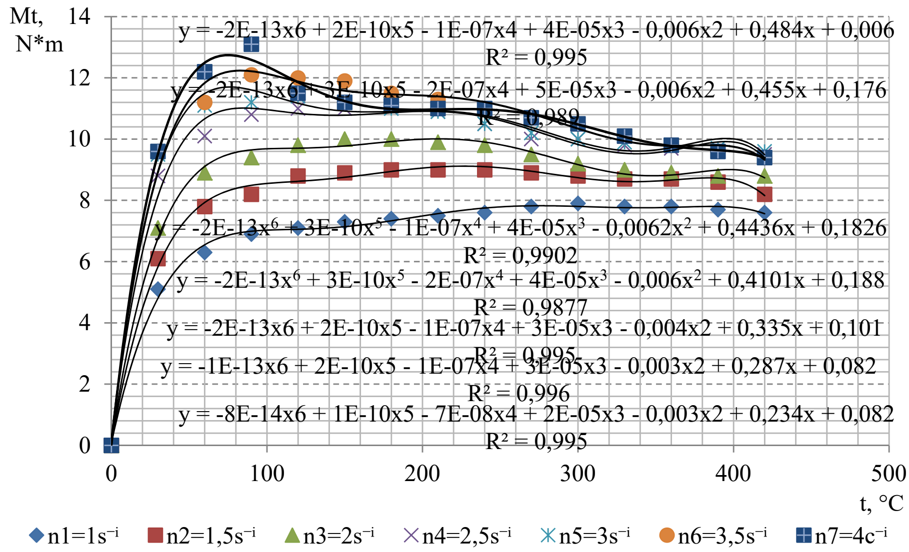

Fig. 3. Influence of the duration of wheat dough kneading on the change in the torque on the drive of the kneading bodies of the kneading machine at different rotational speeds

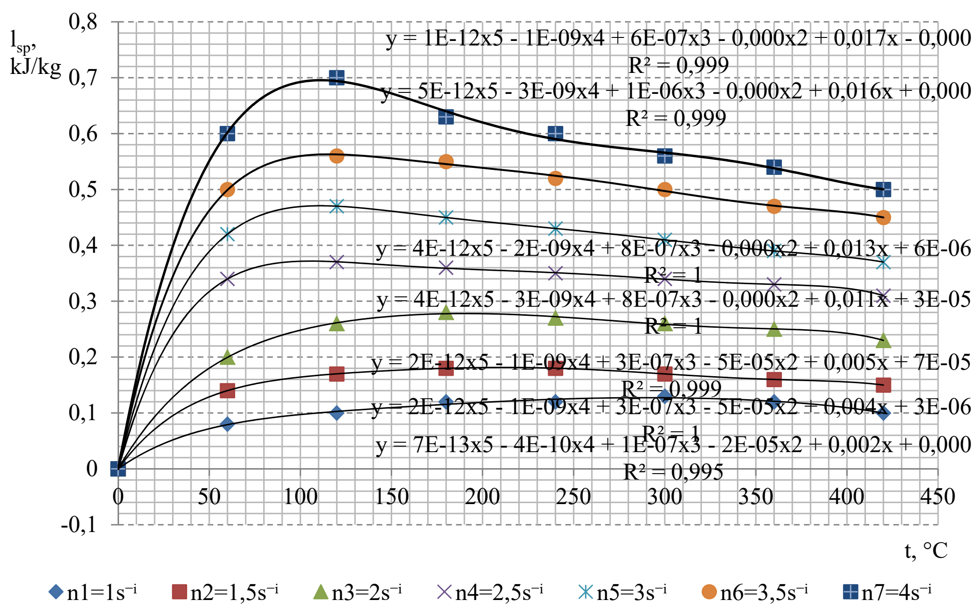

Fig. 4. Influence of the duration of wheat dough kneading on the change in the specific intensity of kneading at different rotational speeds of the kneading bodies

5. 2. Identified wheat dough parameters by the Farinograph M567

The kinetics of changes in A_{sp} depending on the rotational speed of the kneading elements is shown in Fig. 5. It must be emphasized that to obtain comparable values of A_{sp}, calculations are made until the dough is ready $t^{\#}_{knead}$. This curve shows the existence of a section that is insensitive to changes in the rotational speed of the kneading bodies; the presence of this section is a sure sign of the formation of special dough properties under the selected kneading modes. Trial baking confirms obtaining the best quality of bread, stably associated with the mode corresponding to the inflection point on the curve $A_{sp}=s$(nm).

The physical meaning of the criterion μ is as follows. Wheat dough during the kneading process experiences stresses that change cyclically over time. This occurs as a result of the fact that the dough is, when the kneading body is rotated by 3600, in various local zones of deformation impact – these are compression, tension, shear, twisting, and bending deformations. At variable stresses, after a certain number of cycles μ, which are determined by the product of the rotational speed of the kneading bodies (nm, s^{-1}) and the duration of dough kneading until ready ($t^{\#}_{knead}$, s), the gluten framework of the dough is destroyed, the moment of the beginning of the destruction of which is fixed by the extreme value of the change in torque or the specific intensity of the batch.

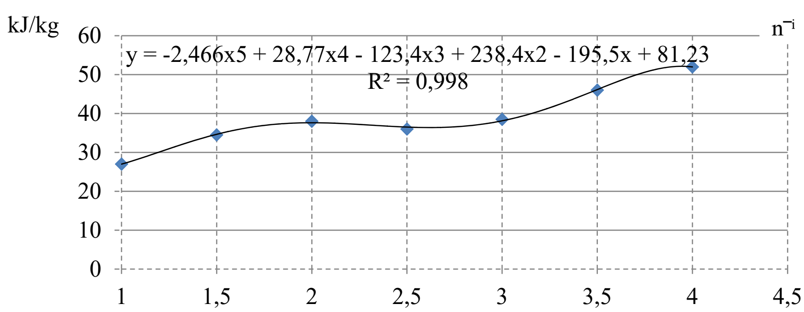

Fig. 5. Measurement of the amount of mechanical energy spent on the formation of wheat dough structure, depending on the rotational speed of the kneading bodies

Table 1

Parameters of the dough kneading process and bread quality

No.	Wheat dough kneading parameters				Bread quality
	Dough kneading mode		Technological criteria		Scoring
	Number of cycles	RPM	Energy consumption, kJ/kg	RPM	Points
1	1.0	290	26.2	290	77
2	1.5	210	33.3	315	80
3	2.0	165	38.4	330	84
4	2.5	124	37.2	310	89
5	3.0	100	38.0	300	82
6	3.5	95	46.0	333	79
7	4.0	90	52.0	360	73

This table also shows that an increase in the dough kneading intensity leads to a reduction in the kneading time from 290 s at nm=60 rpm to 90 s at nm=240 rpm. The optimal duration of the dough kneading $t^{\#}_{knead}$ was 124 s.

Therefore, the nature of the change in the specific intensity of dough kneading, which contributed to obtaining the best quality bread at a kneading body rotational speed of 150 rpm, is optimal.

Thus, the A_{sp} and μ indicators are the main technological criteria that allow you to set the optimal dough kneading mode nm and $t^{\#}_{knead}$, considering the baking properties of the raw materials and the dough recipe, and thereby ensure the optimal rheological properties of the dough mass.

The nature of the relationship between the amount of energy spent on the formation of the dough structure and the moisture content in it does not change, but there is a "drift" of the minimum extremum depending on the baking properties of the flour and the dough recipe (Table 2). However, in each specific case, the minimum value of the specific work reveals the optimal value of dough moisture (Fig. 7).

5. 3. Parameters of the dough kneading process and bread quality obtained during and after the process

Fig. 6 shows the change in the indicator of the number of cycles of dough deformation μ depending on the rotational speed of the kneading bodies. The nature of the change in μ from nm is the same as A_{sp} from nm.

Table 1 shows the values of A_{sp} and μ depending on the dough kneading mode.

It can be seen from Table 1 that an increase in the intensity of dough kneading as a result of an increase in the rotational speed of the kneading bodies leads to an increase in energy costs from 26.2 kJ/kg at nm=60 rpm to 52.0 kJ/kg at nm=240 rpm. The optimal amount of energy A_{sp} spent during dough kneading, based on the analysis of bread quality, corresponds to 37.2 kJ/kg at nm=50 rpm.

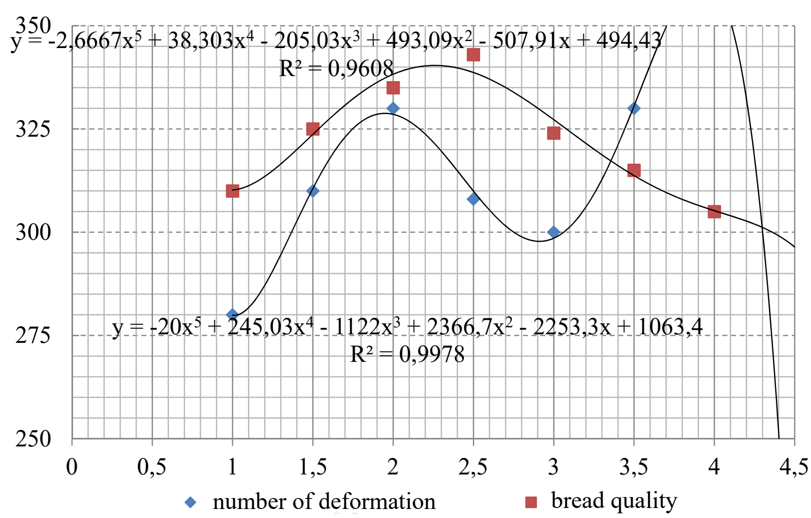

Fig. 6. Influence of the rotational speed of kneading bodies on changes in the number of deformation cycles until the dough is ready and bread quality

Table 2

Technological properties of wheat flour samples

No.	Flour quality indicators	Wheat flour samples			
		1	2	3	4
1	Moisture content of flour, %	12.3	11.9	10.2	12.7
2	Crude gluten content, %	30.0	26.8	30.0	31.0
3	Total deformation of gluten, IDK unit	40	112	75	78
4	Gas generating capacity, cm^3 (CO_2)	920	944	1042	1054

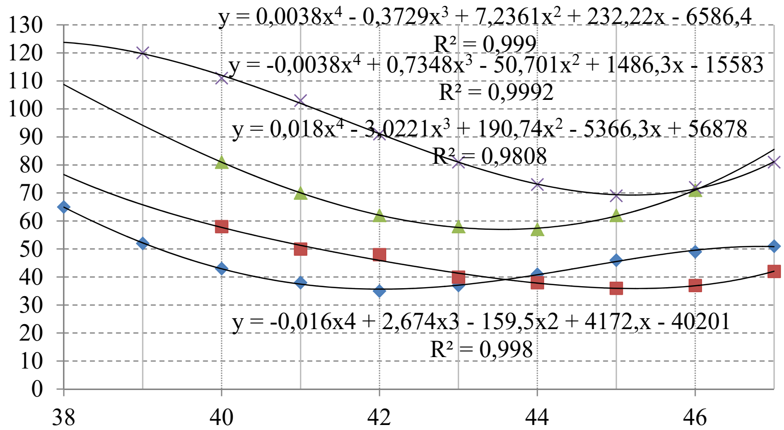

Fig. 7. Influence of dough humidity on the change in the amount of mechanical energy spent on the formation of its structure during kneading (■ — sample 1, ■ — sample 2, ■ — sample 3, x — sample 4)

Regardless of the baking properties of the flour and the dough recipe, the optimal value of dough moisture (the minimum value of the amount of energy spent on the formation of the dough structure) corresponds to the same consistency, controlled using the Farinograph device – 640–650 f. This value of the integral indicator of the rheological properties of the dough allows, in the production of bakery products, determining the water absorption capacity of flour (WACf), considering its baking properties and the dough recipe, and, accordingly, to set the optimal moisture content of the dough. When water is supplied with a jet along the bowl's walls, it has an excellent effect on the water absorption of the dough.

6. Discussion of the results of the rheological properties of wheat dough during its kneading based on the developed parametric model

In previously known methods of dough kneading, water is supplied directly from above or through special channels. The difference of this study is that water is supplied along the walls of the kneader during dough kneading, which provides better results shown in this study. To obtain dough from wheat flour with this method, the developed procedure of the parametric model was used to identify rheological changes during the dough kneading and changes in the dough consistency index in all its stages, which makes it possible to use it to control the rheological properties of dough during its kneading.

The rheological properties of dough not only determine the processing properties but also affect the quality of final products.

To control the rheological characteristics of the kneaded dough, considering the properties of the processed flour and the dough recipe, the following technological criteria can be used:

– M_t – absolute value of the torque on the drive of the kneading bodies of the kneading machine at the stage of dough kneading, N*m;

– sp – relative value of the specific intensity of dough kneading, kJ/kg;

– A_{sp} – amount of energy spent on the formation of the dough structure during kneading, kJ/kg;

– μ – number of dough deformation cycles.

Optimization of the rheological properties of the kneaded dough is carried out based on the analysis of the dynamics of changes in M_t or strokes, which set the amount of water for kneading the dough and the moment of its readiness during kneading, and the kinetics of changes in A_{sp} or μ, allowing to set the rotational speed of the kneading bodies, providing the necessary level of moisture connection with the structural components of the dough during kneading and obtaining optimal rheological properties of the dough, causing the best quality indicators of finished bakery products.

The results obtained in this research showed that the formation of wheat dough at the kneading stage is primarily reduced to the formation of a vector of numerical parameters that uniquely describe its rheological properties. The definition of these parameters is the metrological basis for building a rheological test model.

With an increase in the rotational speed of the kneading bodies, processes occur faster, due to the intensity of the deformation effect of the kneading bodies on the dough and the amount of mechanical energy spent in this case, which in turn causes the formation of a certain coagulation-crystallization structure of the dough. At the same time, the level of quality of the obtained bakery products was different and its best indicators corresponded to the rotational speed of the kneading bodies of 2.5 s^{-1}.

One of the main control parameters of dough kneading, which determines its rheological behavior and the efficiency of all subsequent technological operations of the wheat bread production process, is the amount of water G_v. Its content in the dough regulates the rate of physical, colloidal, biochemical, and microbiological processes and, as a result, determines the texture indicators of finished bakery products.

Using the method described above for optimizing the dough kneading mode when adjusting its moisture content by adding one or another amount of water, the kinetics of A_{sp} change from dough moisture content W_d was determined (Fig. 7). The graph shows that regardless of the baking properties of flour (Table 2) and the dough recipe, equation $A_{sp}=s(W_d)$ has the form of a parabola (extremal function) with an extremum minimum. Thus, an increase in the moisture content of the dough to 45 % (on the example of the flour of sample 1) resulted in the consumption of mechanical energy, a further increase in the moisture content from 45 to 48 % caused an increase in the energy intensity of the process.

When determining the relationship between regulatory influences on the state of wheat dough biopolymers and the coefficients of the rheological model, it will allow controlling the physicochemical and organoleptic properties of the dough and, as a result, the quality of finished bakery products.

The limitation of this study is the absence of other previously conducted research works regarding the dough kneading procedure with different water supply, therefore, it must be considered when trying to apply in practice. However, when applying the current study data into practice, it must be noticed that the study was carried out only with wheat flour.

Further development of this study will be directed to finding the suitability of the developed parametric model procedure with different types of flour and investigating its effect on the quality of various bakery products.

7. Conclusions

1. In this study, factors and parameters indicated by the parametric model were defined. Thus, the proposed model could be widely used during the wheat dough kneading process to determine maintaining the mass of water and its intensity at a constant level of the mass of the kneaded dough, considering the processed flour.

2. The applicability of the developed procedure was studied during kneading the dough and getting it from the finished product on a Farinograph M567, where the results showed that with an increase in the rotational speed of the kneading bodies, the processes proceed faster, which is due to the intensity of the deformation effect of the kneading bodies on the dough and the level of the amount of mechanical energy spent in this case, which in turn causes the formation of a certain coagulation-crystallization structure of the dough. When the dough kneading body is rotated by 3600, in various local zones of deformation impact – these are compression, tension, shear, twisting, and bending deformations.

3. The dough and bread obtained based on the developed procedure were checked for quality. The data presented that the nature of changes in the specific intensity of dough kneading, which contributed to obtaining the best quality bread at a kneading body rotation frequency of 150 rpm, is optimal. The dough kneading intensity leads to a reduction in the kneading time from 290 s at nm=60 rpm to 90 s at nm=240 rpm. The optimal duration of dough kneading $t^{\#}_{knead}$ was 124 s. Thus, the A_{sp} and μ indicators are the main technological criteria that allow you to set the optimal dough kneading mode nm and $t^{\#}_{knead}$, considering the baking properties of the raw materials and the dough recipe, and thereby ensure the optimal rheological properties of the dough.

References

1. Erkebaev, M. Zh., Kulazhanov, T. K., Medvedkov, E. B. (2006). Osnovy reologii pischevykh produktov. Almaty, 298.
2. Erkebaev, M. Zh., Medvedkov, E. B., Gadzhiev, T. I,, Seydekhanov, A. S., Erzhanov, N. M. (2007). Intensifikatsiya protsessov mekhanicheskoy obrabotki pischevykh mass. Almaty, 298.
3. Erkebaev, M. Zh., Medvedkov, E. B., Isabekova, L. S., Mateev, E. Z. (2014). Azyқ-tүlik өnimderiнің reologiyalyқ negizderi. Almaty, 256.
4. Bobkov, V. A. (2008). Vliyanie funktsional'nykh komponentov na reologicheskie svoystva pshenichnogo testa. Konditerskoe i khlebopekarnoe proizvodstvo, 12, 14–15.
5. Menli, D. (2003). Muchnye konditerskie izdeliya. Sankt-Peterburg: GIORD, 558.
6. Puchkova, L. I., Polandova, R. D., Matveeva, I. V. (2005). Tekhnologiya khleba, konditerskikh i makaronnykh izdeliy. Sankt-Peterburg: GIORD, 557.
7. Zheng, H. H. (1998). Rheological properties of wheat flour dough. Massey University, 137.
8. Lindborg, K. M., Trägårdh, C., Eliasson, A.-C., Dejmek, P. (1997). Time-Resolved Shear Viscosity of Wheat Flour Doughs – Effect of Mixing, Shear Rate, and Resting on the Viscosity of Doughs of Different Flours. Cereal Chemistry Journal, 74 (1), 49–55. doi: https://doi.org/10.1094/cchem.1997.74.1.49
9. Martinant, J. P., Nicolas, Y., Bouguennec, A., Popineau, Y., Saulnier, L., Branlard, G. (1998). Relationships Between Mixograph Parameters and Indices of Wheat Grain Quality. Journal of Cereal Science, 27 (2), 179–189. doi: https://doi.org/10.1006/jcrs.1997.0156
10. Janssen, A. M., van Vliet, T., Vereijken, J. M. (1996). Fundamental and Empirical Rheological Behaviour of Wheat Flour Doughs and Comparison with Bread Making Performance. Journal of Cereal Science, 23 (1), 43–54. doi: https://doi.org/10.1006/jcrs.1996.0004
11. Kuktaite, R., Larsson, H., Johansson, E. (2007). The Influence of Dough Mixing Time on Wheat Protein Composition and Gluten Quality for Four Commercial Flour Mixtures. Wheat Production in Stressed Environments, 543–548. doi: https://doi.org/10.1007/1-4020-5497-1_66
12. Faubion, J. M., Dreese, P. C., Diehl, K. C. (1985). Dynamic rheological testing of wheat flour doughs. Rheology of Wheat Products, 91–116.
13. Safari-Ardi, M., Phan-Thien, N. (1998). Stress Relaxation and Oscillatory Tests to Distinguish Between Doughs Prepared from Wheat Flours of Different Varietal Origin. Cereal Chemistry Journal, 75 (1), 80–84. doi: https://doi.org/10.1094/cchem.1998.75.1.80
14. Zheng, H., Morgenstern, M. P., Campanella, O. H., Larsen, N. G. (2000). Rheological Properties of Dough During Mechanical Dough Development. Journal of Cereal Science, 32 (3), 293–306. doi: https://doi.org/10.1006/jcrs.2000.0339