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Theoretical And Experimental Aspects Of The Grinding Process The Soaked Soybean Grain.

Vladimir Jur'evich Frolov*, Vladimir Stanislavovich Kurasov, Denis Petrovich Sysoev, and Georgiy Georgiyevich Klasner.

Kuban State Agrarian University named after I.T. Trubilin, Kalinina str., 13, Krasnodar 350044, Russia.

ABSTRACT

The article proposes a constructive-technological scheme of a grinder of soaked soybean grain, provides theoretical substantiations of the main structural and operating parameters of the device being developed and experimental studies of the processes of grinding grain and extracting soy protein into an emulsion.
Keywords: soaked grain grinder, soy protein, protein emulsion, abrasive disc.

***Corresponding author**

INTRODUCTION

The increase in livestock and poultry production is possible due to an increase in the content of protein components in the feed.

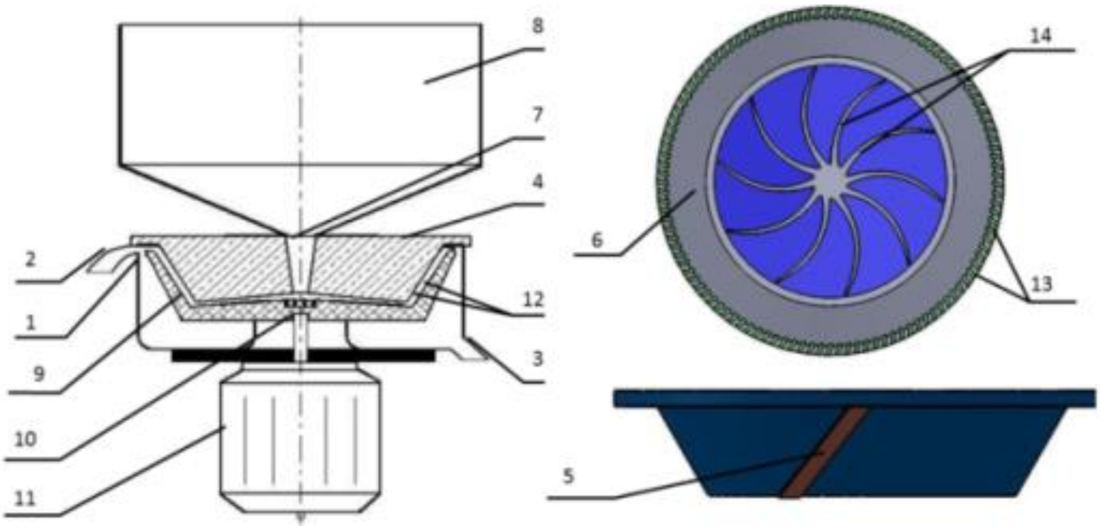
Analysis of the nutritional value of the main fodder crops showed that soybean grain can solve the problem of protein and protein deficiency in the diet of animals. Soybean grain contains 36% protein, 17.3% fat, 34.9% carbohydrates, and its nutritional value is 1.45 feed units, and soy protein is rich in amino acids and minerals. Such a set of substances and vitamins when fed to animals significantly increases the biological value of rations and provides an increase in their productivity. However, soybeans, although they have a high nutritional value, cannot be fed raw due to the fact that they contain biologically active anti-nutritional substances that can cause allergic, endocrine and rachitic disorders [3, 4]. The content of these anti-nutritional substances can be reduced to a safe concentration by processing grain into high-protein feed using heat treatment.

The preparation of soy milk, which in its biological value is not inferior to the whole, cow's milk, is considered to be a promising direction for preparing soybean grain for feeding to farm animals [9].

However, the use of soybean milk in diets for feeding farm animals in the management of personal subsidiary farms or small livestock farms is not large, due to the lack of universal small-sized and low-energy equipment for processing grain for animal feed. In this regard, there is a need to develop a constructive-technological scheme of a universal device capable of combining such technological operations as grinding, protein extraction, separation into liquid (milk) and solid (okara) fractions.

MATERIALS AND METHODS

The analysis of technologies and methods for the preparation of soy milk, involving the use of commercially available equipment, made it possible to develop devices (patents of the Russian Federation No. 2614777, No. 2621274, No. 161559, No. 163069) processing soybean grain for animal feed. A distinctive feature of the proposed method of processing soybean grain, implemented in the developed device (Figure 1), is the combining of several technological operations associated with the grinding of grain material, followed by mixing with water to extract protein into an emulsion and separation into milk and okara [1, 3, 8].



1 - frame, 2 - opening for the outlet of Okara, 3 - opening for collecting soy milk, 4 - upper static abrasive disk, 5 - cleaning scraper, 6 - sieve, 7 - grinding chamber feeder, 8 - loading hopper, 9 - lower movable abrasive disk, 10 - electric drive shaft, 11 - electric drive, 12 - holes in the sieve, 13 - guide grooves, 14 - curvilinear guide channels

Figure 1: Constructive-technological scheme of a grinder soaked soybean grain

As the final products of the processing of soybean grain in accordance with the proposed technology, we obtain easily digestible protein feeds with good amino acid composition, such as soy milk, “Tofu” cottage cheese, and soybean meal.

On the basis of the analysis of the working process, for the preparation of high-protein feeds developed by a shredder, it is necessary to obtain analytical dependencies to substantiate its main design and operating parameters [2, 5, 6, 7].

Grain is affected by gravity$P = mg$ (g – acceleration of gravity) and centrifugal force. Gravity can be decomposed into rolling force.$F_{ск} = mg\cos\beta$ and the force of normal pressure $N = mg\sin\beta$ (Figure 2).

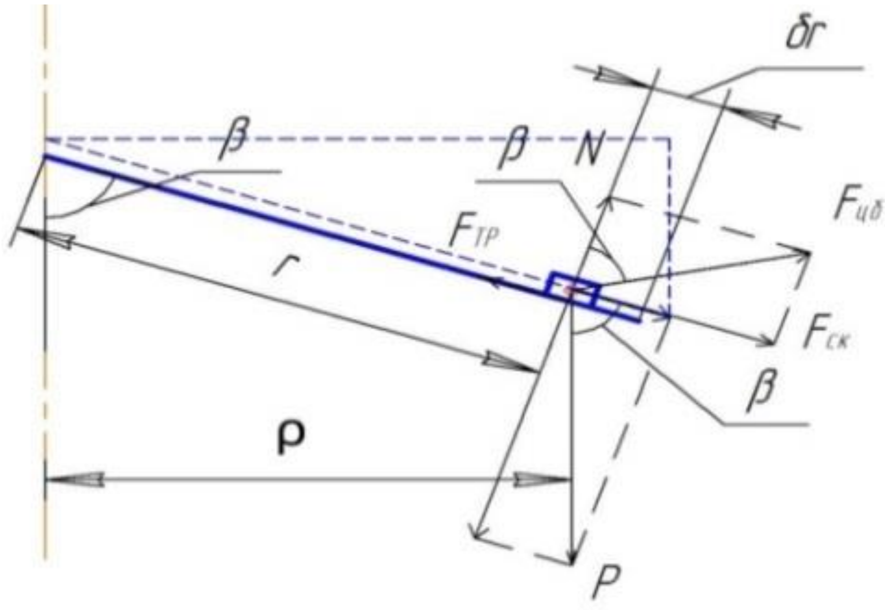


Figure 2: Forces acting on a grain when it moves in the radial direction

Centrifugal force is horizontal and equal to:

$$F_{цб} = m\omega^2\rho = m\omega^2 r\sin\beta, \qquad (1)$$

m – grainweight, kg;
ρ – grain density, kg/m^3;
ω – angular velocity of disk rotation, rad/s.

The total force acting along the generatrix of the cone surface is equal to:

$$F_r = mg\cos\beta + m\omega^2 r\sin^2\beta. \qquad (2)$$

The force of the normal pressure the grain on the surface of the cone:

$$N = mg\sin\beta - m\omega^2 r\sin^2\beta\cos\beta. \qquad (3)$$

Hence the radial component of the friction forces$F^r_{тр}$equals:

$$F^r_{fr} = -fN = -f(mg\sin\beta - m\omega^2 r\sin\beta\cos\beta), \qquad (4)$$

f – coefficient of friction the grain on the abrasive surface.

Force *N* work does not produce, so elementary workδA_r when moving grain at a distance δr by $\delta\vartheta = 0$, equals:

$$\delta A_n = (F_r + F_{fr}^{r})\delta r, \quad (5)$$

or

$$(mg\cos\beta + m\omega^2 r\sin^2\beta)\delta r - f(mg\sin\beta - m\omega^2 r\sin\beta\cos\beta)\delta r. (6)$$

In the reference system associated with a rotating cone, the equation of motion is:

$$r = r_0 ch((bt) - 1), (7)$$

$$\varphi = \frac{q^2t^2}{2}. \quad (8)$$

It should be noted that in a fixed reference system the angle of rotation of the grain is equal to: $\vartheta = \omega t - \varphi$.

I.e. angles ϑ and φ counting in different directions.

From equality (7) and (8) we find the equation of the trajectory of the grain:

$$r = r_0(ch(\frac{b}{a}\sqrt{2\varphi}) - 1). (9)$$

As a result of the study, a graph of the trajectory of the movement of the grain (Figure 3) was constructed with $\frac{b}{a} = \frac{1}{\sqrt{2}}$ (since magnitudes$f, sin\beta, cos\beta$less than one, they will not be taken into account in further detailed consideration of grain movement).

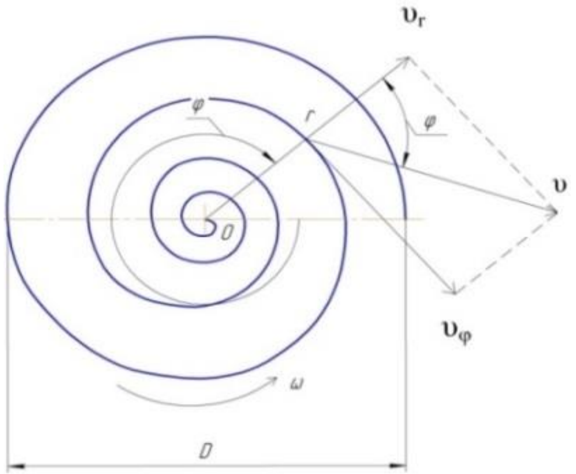


Figure 3: The movement trajectory of grain in the reference system associated with a rotating cone

For a given time direction, the angle is counted clockwise. With increasing r speed$\upsilon_r$grows approximately linearly $\upsilon_r = br$, hence the term $\frac{gfrsin\beta}{2\upsilon_r}$ remains constant with increasing r, and the remaining terms increase according to the proportional law.

The volumetric capacity of the grain chopper in the soaked *Q* form is determined by the geometry of the installation and the radial component of the grain velocity, which is the same in both the fixed and moving reference systems.

$$Q = \pi D Z \upsilon_r, (10)$$

Z – the size of the gap between the disks, mm;

υ_r – grain linear velocity, m/s.

Mass performance Q defined as:

$$G = \rho \cdot Q, \quad (11)$$

ρ – density of soybean grain, kg/m^3.

To estimate the expended power, we proceed from the fact that the magnitude of the kinetic energy of rotation of an abrasive disk in one full turn is approximately equal to the energy of rotation itself. With this assumption, the power spent on the grinding process:

$$N_g = E_к \cdot \omega, \quad (12)$$

$E_к$ – kinetic energy, J;
ω – angular speed of the disk, rad/s.

In sofar as $E_к = \frac{1}{2} \cdot J \cdot \omega^2$ (где$J = m \cdot r^2$), that equation (12) can be written as:

$$N_g = \frac{1}{2} \cdot m \cdot r^2 \cdot \omega^3. \quad (13)$$

The analytical dependences obtained as a result of theoretical studies express a functional relationship between the constructive and regime indicators affecting the process of grinding grain. These dependencies make it possible to identify the qualitative and quantitative aspects of the influence of these factors with certain assumptions and assumptions. Therefore, theoretical conclusions about the significance of the influence of individual factors on the grinding process of soybean grain, followed by protein extraction, require experimental verification.

In experiments to study the process of grinding soybean grain with subsequent protein extraction, taking into account the requirements for processing lines for preparing soy milk, it is necessary to check the theoretical background and confirm the dependencies, as well as to clarify the initial data for choosing the optimal design and operating parameters of the soaked soybean grain grinder [2, 3].

The studies were divided into two stages and carried out on an experimental installation of a soaked soybean shredder (Figure 4) in a laboratory-production environment.

Figure 4: General view of the grain grinder in a soaked form with interchangeable abrasive discs

At the first stage, the study of the physicomechanical properties of soybean grains after soaking in water was carried out. It is necessary to establish the dependenceofthedensitychange(**ρ**) and strength of the soaked grain material (**J**), moisture change (**W**) and masses (**m**) from the time of soaking, as well as the completeness and quality of the output of soy protein in the extrent (**G**) from hydronic module (**η**) (volume of water supplied) and temperature (**t**) supplied water.

The second stage was devoted to the study of the preparation of soy milk and the optimization of the main factors influencing the process, as well as solving the problem of determining the optimal design-mode parameters of the soybean grinder and its main characteristics.

In experimental studies the following tasks were solved:

- determine the physicomechanical properties of soaked soybean grain;
- to study the influence of the design-mode parameters of the grinder of soaked soybean grain on its productivity, energy intensity of the grinding process;
- to study the quality indicators of the process, namely the extraction of protein into the emulsion.

A prototype was made (Figure 4), on the basis of which a number of multifactor experiments were conducted in order to experimentally substantiate the design-mode parameters of the shredder.

To measure the energy characteristics of the device used K-505. Laboratory flasks and a VLTK-500 electronic balance were used to measure the quantitative protein yield. To change the speed of the electric motor, a rheostat built into the experimental setup was used. The temperature of the extractant was measured with a mercury thermometer with a scale up to 130 ° C. The gap between the abrasive discs was measured with a caliper. The volume of the obtained extractant was measured with a beaker with a scale.

The main optimization criteria for the process of abrasion of soaked soybean grain were selected: protein yield to the extractant (*G*), chopper productivity (*Q*) and energy consumption per process (*N*). The factors influencing the technological process are (table 1): the gap between the grinding wheels coated with abrasive (h); roughness (Ra); rotational speed (ω) of the lower disk; the angle of curvature (α) of the guide grooves [3, 4].

Table 1: Factors and levels of their variation

Level	Factors			
	Angular velocity of rotation of the lower disk ω, rad/s	Abrasive Roughness R_a, um	Groove Direction Angle α	The gap between the discs h, mm
	X_1	X_2	X_3	X_4
Upper (+1)	172	50	α-120°	5
Primary (0)	169	250	α-90°	4
Lower (-1)	141	450	α-60°	3

RESULTS AND DISCUSSION

Experimental studies of changes in the physicomechanical properties of soybean grain from the time of soaking were carried out on the VILANA soybean variety, which is widespread in the Krasnodar Territory. From the grain material were taken 6 servings, each of which consisted of 10 grains. The length of the soybean grain was 6 mm. The weight of 10 grains of soybean is 1.767 g, and the volume of 10 grains is 1.4 ml. Experimental studies were carried out at room temperature (20–22 ° C), and the initial grain moisture was 10%.

According to the experimental data obtained, the following dependencies were constructed: changes in mass (m), volume (v) and length (L), as well as changes in grain density, on the duration of soaking (Figures 5-6).

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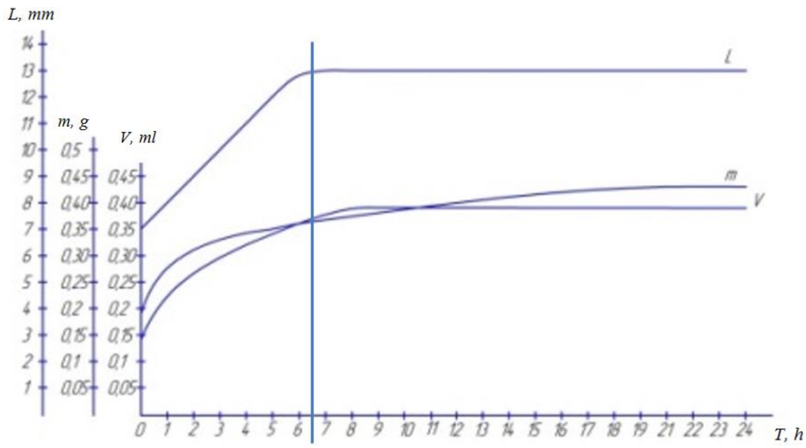

Figure 5: Dependence of changes in mass (m), volume (v) and length (L) of grain on the soaking duration

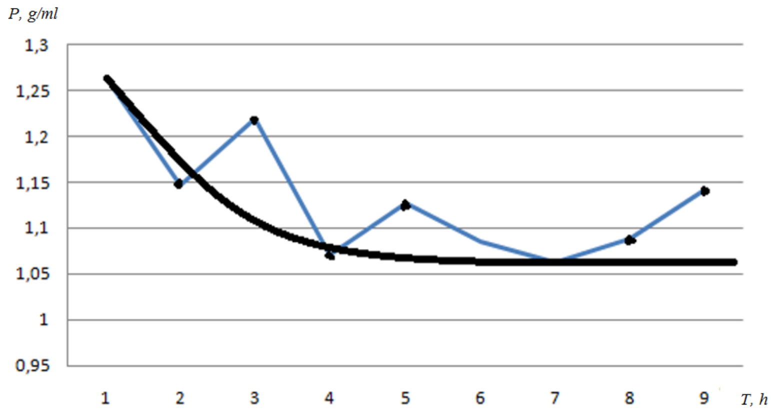

Figure 6: The graph of the density change from the soaking duration

Analyzing the graphs (Figures 5-6), we can conclude that: after 6-7 hour soaking, the grain length increased from 6 to 13 mm, while the mass and volume of the grain are m = 0,36 g, $V = 0{,}34 \cdot 10^{-6}$ m^3, and the grain density was ρ= 1,088 g/ml. Further interaction of grain with water is ineffective, the process of increasing the volume of grain is somewhat stabilized. So at 24 h soaking grain m = 0,434g, V = $0{,}38 \cdot 10^{-6}$ m^3,ρ= 1,102g/ml. Therefore, the optimal time (T) of keeping the grain material in water is 6-7 hours.

Protein extraction is based on the physicochemical properties of the diffusion dissolution of organic compounds. Drinking water acts as an extractant in the developed technology.

From the analysis of the graph (Figure 7), it can be seen that the active saturation of the extractant with protein proceeds to a hydronic module 1:10, after which, with an increase in the hydro module, the saturation of the extractant somewhat stabilizes and only leads to an increase in the total water volume and, consequently, an increase in energy costs. In this regard, we take a rational value of the hydronic module in the ratio of 1:10.

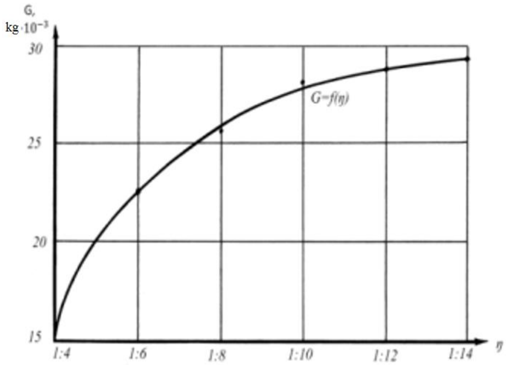

Figure 7: Dependence of the change in the protein yield in the extractant G on the hydromodule η

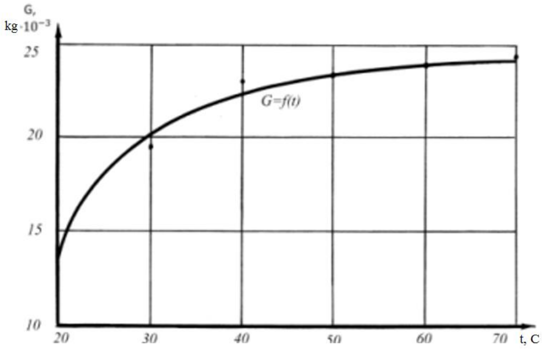

Figure 8: Dependence of the change in the protein yield in the extractant G on the temperature t

After conducting experimental studies on the dependence of the effect of the temperature of the supplied water acting as a protein extractant (Figure 8), it was found that as the temperature rises, the number of protein compounds deposited in the extractant increases. However, on reaching a temperature above 70 °C, soy protein acquires an incomprehensible form (protein denaturation occurs) for the digestive system of farm animals, hence, the optimal temperature range should be considered 55–60 °C.

To carry out the experiment and find the criteria for optimizing the process, the Planett-Berman plan was chosen. To assess the influence of factors on the process, second-order regression equations were obtained according to the experiment data (Statistica v. 5.5 StatSoft (USA):

$N_1 = 1{,}5581 – 0{,}00019\ \omega – 0{,}00011\ R_a – 0{,}1076\ \alpha_3 – 0{,}10863\ h – 0{,}00001\ \omega h + 0{,}00001\ R_a\alpha + 0{,}0006\ \alpha h + 0{,}00897\ \alpha^2 + 0{,}013897\ h^2$

$T_2 = 70{,}5946 – 0{,}00513\ \omega + 0{,}0343\ R_a – 10{,}01193\ \alpha – 21{,}30593\ h + 0{,}0008\ \omega h + 0{,}0031 R_a h + 0{,}0134\ \alpha h – 0{,}0001\ R_a^2 + 1{,}0943\ \alpha^2 + 1{,}96527\ h^2$

$g = –83{,}4565 + 0{,}0236\ \omega + 0{,}017367\ R_a – 8{,}61847\ \alpha – 3{,}9973\ h + 0{,}000006\ \omega R_a – 0{,}000032\ \omega \alpha – 0{,}001\ \omega h + 0{,}0007 R_a \alpha – 0{,}016 R_a h – 0{,}0261\ \alpha h – 0{,}00007\ R_a^2 + 1{,}0806\ \alpha^2 + 1{,}11143\ h^2$

Optimum coordinates were obtained and response surfaces were constructed, as well as a compromise problem was solved between the three main optimization criteria - protein yield to the extractant, productivity and energy consumption for the process.

Figure 9: Cross-section the surface of the protein in the extractant on the x1 plane (ω) from x4 (h)

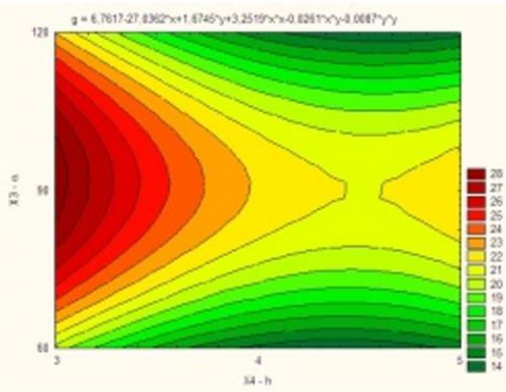

Figure 10: Cross-section the surface of the protein in the extractant on the x4 plane (h) from x3 (α)

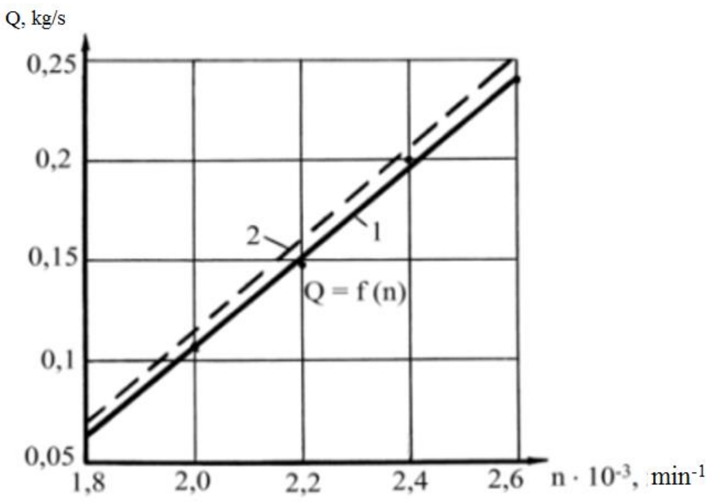

Figure 11: Influence of the lower disk speed (n) on the chopper performance (Q 1 –expert; 2 – theory).

An analysis of the dependencies shown in Figures 9-10 shows that to achieve the highest protein yield (*G*) to the exagent, the rotational speed (*ω*) values of the lower abrasive disk should be within ω = 157….172 rad/s, the gap between the abrasive discs should be h = 3…3,26 mm, the value of the applied abrasive should be within R_a = 260…450 um, and the curvature angle of the curved groove is α = 80°…105°.

After analyzing the dependence (Figure 11), we can conclude that with an increase in the frequency of rotation of the lower abrasive disk of the chopper from 1800 to 2600 min^{-1}productivity increases from 0.1 to 0.25 kg/s. The discrepancy between theoretical and experimental data does not exceed 5%.

CONCLUSION

1. As a result of the analysis on the nutritional value of feed, it was found that the use of high-protein feed based on soy (soy milk) in animals and poultry feed is most effective, since soybean grain contains 17.3% fat, 26.5% carbohydrate and 34.9% protein, and feed value is 1.45 feed units.
2. As a result of the analysis of technologies and devices for the preparation of protein feeds with the use of soybeans, a promising direction for their improvement has been identified, providing for preliminary soaking of the grain in water.
3. Based on the patent analysis of technologies and technical means for the preparation of high-protein fodder using soybeans, we propose a waste-free technology for the processing of soybean grain. The main element of the developed technology is a device for grinding soybean grains in a pre-soaked form. The technical novelty is confirmed by patents of the Russian Federation No. 2614777, No. 2621274, No. 161559, No. 163069.

4. As a result of theoretical studies, the following were obtained: the main design-mode parameters of the soaked soybean shredder; the equation of grain motion along the surface of curvilinear grooves of a truncated cone; set of drive characteristics.
5. As a result of experimental studies, rational parameters were established for the process of grinding grain in a soaked form, followed by protein extraction: the time for soaking the grain is 6–7 hours; hydronic module $\eta = 1:10$; the temperature of the supplied water for protein extraction is $t = 55–60°C$; roughness of the applied abrasive $R_a = 420…450$ um; the gap between the abrasive grinding wheels $h = 3.7$ mm; groove angle$\alpha = 95°$, rotation frequency of the lower abrasive disc $\omega = 141$ rad/s.
6. To confirm the theoretical premises, experimental studies of the effect of the rotational speed of the moving disk (n) on performance (Q) were carried out, while the discrepancy between the data obtained by theoretical and experimental studies does not exceed 5%.

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