Mathematical modeling of the sunflower cake grinding process

A B Shepelev and I E Priporov
Kuban State Agrarian University, 13, Kalinina street, Krasnodar, 350044, Russia
E-mail: shepelevab@mail.ru

Abstract. The design of an improved sunflower cake grinder is proposed, which consists in the modernization of knives in knife blocks in the form of an Archimedes Arbelo curvilinear triangle with saw-edged teeth along the perimeter of the entire surface of the cutting edge. This will allow obtaining cake in a crumbled form, depending on the type of the farm animal by constructing a mathematical model that considers physical and mechanical properties of the material, which describes the dependence of its design parameters on the factors under study that affect the technological process of its production and thereby improve the grinding quality. The article presents the mathematical model that allows determining the optimal values of the design parameters of the improved grinder. The improved sunflower cake grinder allows reducing its specific energy consumption compared to series-produced ones without deteriorating the quality of the material and to increase its performance. Based on the experimental studies conducted, the improved sunflower cake grinder allows it to be used in technological lines for the production of mixed feed with its adding in a crumbled form. The obtained design parameters of the improved grinder will be used in the further modernization of series-produced grinders for concentrated feed produced by Russian enterprises for various types of farm animals, which will allow replacing imported concentrated feed with Russian ones and thereby not depend on them due to the current situation in the world.

1. Introduction
The dynamic development of modern animal husbandry as a branch of the national economy is impossible without the use of concentrated feed. Various groups of farm animals need concentrated feed, which has significant differences both in the composition of the initial components and in granulometric characteristics [1]. In organizing the full feeding of animals, the rational use of concentrated feed is very important [2]. A significant share in the prime cost of concentrated feed is the expenses for grinding. In this regard, the research is aimed at reducing the energy intensity in their production [1, 3].

2. Materials
Optimization of their design parameters is a perspective direction for reducing the energy intensity when grinding sunflower cake in a bulk form and increasing the grinder performance [1, 4-6].

To reduce the energy intensity of the process and increase the performance of sunflower cake grinders in a bulk form, the design of the grinder (Figure 1) according to the Patent of the Russian Federation (RU 2648392) has been proposed, which has a charging hopper 2, a damper 3, a body 1, a
frame 9, an electric motor 10, a rotor 8 with discs 4 and 5, knife packages 6 with knives 7 in the form of flat geometric shapes, formed by circles.

The grinder has an even number of knife packages with knives installed parallel in a staggered arrangement, the surface of the cutting edges of which is made in the form of an Archimedes Arbelo curvilinear triangle with saw-edged teeth along the perimeter of the entire surface of the cutting edge. The height of these teeth is not less than the thickness of the process material. Thus, the teeth inclination angle is no more than 30°, and the teeth of the knives of the subsequent knife packages are directed in the opposite direction from the knives of the previous knife packages and at the same angle, and the knives are installed with the possibility of adjusting the distance between them depending on the size of the process material. Knives are selected for various feed, both in pelleted and crumbled forms.

![Figure 1. The sunflower cake grinder: a – scheme, b – knife-cutting face](image)

The technological process of the grinder, according to the Patent (RU 2648392), is conducted as follows.

When grinding the material, for example, the obtained sunflower cake, it is poured into the charging hopper 2 and the electric motor 10 is turned on, after which the damper 3 is opened. The crushed product contacts knives 7 in the form of an Archimedes Arbelo curvilinear triangle with saw-edged teeth along the perimeter of the entire surface of the cutting edge, which will improve the quality of grinding, and the entire surface of the knife cutting edge participates in the technological process and sliding cutting takes place, while the energy requirement decreases.

### 3. Results

Considering the above, a three-factor experiment was conducted, which describes the dependence of the design parameters on the factors under study:

\[
(E, W) = f(x_1, x_2, x_3),
\]

where \(E\) – grinding process energy intensity, kW·h/t; \(W\) – grinder performance in obtaining crumbled sunflower cake, t/h; \(x_1\) – crumbled sunflower cake thickness, mm; \(x_2\) – tooth inclination angle on the knife packages, deg.; \(x_3\) – number of knife packages, pcs.

Based on the results of the three-factor experiment, the regression equations were determined in coded form:

- grinder performance in obtaining bulk sunflower cake

\[
\gamma_5 = 1.426 + 0.1308x_1 - 0.11x_2 - 0.023x_3 - 0.38x_1x_2 + 0.064x_1x_3 + 0.09x_2x_3 + 0.119x_1^2 + 0.018x_2^2 - 0.23x_3^2,
\]  

(1)

- grinder energy intensity in obtaining bulk sunflower cake
\[ y_s = 2.096 + 0.0696x_1 - 0.03x_2 + 0.196x_3 - 0.188x_1x_2 - 0.336x_1x_3 + 0.24x_2x_3 - 0.056x_1^2 + 0.095x_2^2 - 0.16x_3^2, \]  
\tag{2} \]

which were validated on the basis of Fisher test [7] and were:

- grinder performance

\[ F_{calc} = \frac{0.425}{0.103} = 4.13, \]

- grinder energy intensity

\[ F_{calc} = \frac{0.7037}{0.172} = 4.09. \]

The tabular value of the Fisher criterion at 5\% significance level was \( F_{0.05} = 4.78 \). The mathematical models (1) and (2) validation have been confirmed.

As a result of processing the full-factor experiment, the regression equations in the canonical form (2-7) of dependency were obtained:

- grinder performance on the material thickness and tooth inclination angle (Figure 2):

\[ y - 1.4 = 0.119X_1^2 + 0.0259X_2^2, \]  
\tag{2} \]

or

\[ \frac{(X_1)^2}{y - 1.4} + \frac{(X_2)^2}{0.119} = 1; \]

- grinder performance on the material thickness and the number of knife packages (Figure 3):

\[ y - 1.4 = 0.119X_1^2 - 0.2379X_3^2, \]  
\tag{3} \]

or

\[ \frac{(X_1)^2}{y - 1.4} + \frac{(X_3)^2}{0.119} = 1; \]

- grinder performance on the tooth inclination angle and the number of knife packages (Figure 4):

\[ y - 1.4 = 0.0259X_2^2 - 0.2379X_3^2, \]  
\tag{4} \]

or

\[ \frac{(X_2)^2}{y - 1.4} + \frac{(X_3)^2}{0.0259} = 1; \]

- grinder energy intensity in obtaining bulk sunflower cake on the material thickness and tooth inclination angle (Figure 5):
\[ y - 2.14 = -0.056X_1^2 + 0.1426X_2^2, \]  
\[ \text{or} \quad \frac{(X_1)^2}{y - 2.14} + \frac{(X_2)^2}{-0.056} = 1; \]

- grinder energy intensity in obtaining bulk sunflower cake on the material thickness and the number of knife packages (Figure 6):

\[ y - 2.14 = -0.056X_1^2 - 0.2076X_3^2, \]  
\[ \text{or} \quad \frac{(X_1)^2}{y - 2.14} + \frac{(X_3)^2}{-0.2076} = 1; \]

- grinder energy intensity in obtaining bulk sunflower cake on the tooth inclination angle and the number of knife packages (Figure 7):

\[ y - 2.14 = 0.1426X_2^2 - 0.2076X_3^2, \]  
\[ \text{or} \quad \frac{(X_2)^2}{y - 2.14} + \frac{(X_3)^2}{-0.2076} = 1. \]

Figure 2. The dependence of the grinder performance on the bulk sunflower cake thickness and the tooth inclination angle on the knife packages
Figure 3. The dependence of the grinder performance on the bulk sunflower cake thickness and the number of knife packages

Figure 4. The dependence of the grinder performance on the tooth inclination angle on the knife packages and the number of knife packages

Figure 5. The dependence of the grinder energy intensity on the bulk sunflower cake thickness and the tooth inclination angle on the knife packages
The regression coefficients of the canonical form have the same signs, hence the response surface curves refer to the type of minimum for the equations (2) and (6) [6].

The system of contour curves equal to the performance and energy intensity of the grinder has the form of ellipses (Figure 2, Figure 6). In this case, the large axes of the ellipses are located according to the factor $X_1$ (the material thickness), which is explained by the larger, than factor $X_2$ (the tooth inclination angle of knives on the knife packages), influence on the performance and energy intensity of the grinder.

Figures 2 and 6 show the optimal values of the factors are observed with the following limits of their variation: the material thickness – 6 mm and the tooth inclination angle of knives on the knife packages – 25 degrees with a minimum of the grinder energy intensity – 2.1 kW-h/ t and its maximum performance of 1.4 t/h.

The regression coefficients of the canonical form have different signs, hence the response surface curves refer to the type of the minimax for the equations (3) - (5) and (7) [5].

The system of contour curves, equal to the performance and energy intensity of the grinder, has the form of a paraboloid.

Figures 4 and 7 show the optimal values of the factors are observed with variations: the tooth inclination angle is 25 degrees and the number of knife packages is 4 pcs. with a minimum of the grinder energy intensity of 2.15 kW-h/t and its maximum performance of 1.4 t/h.
4. Conclusion
The scientifically grounded and developed sunflower cake grinder, for which the Patent of the Russian Federation was received, has the knives in the form of an Archimedes Arbelo curvilinear triangle with saw-edged teeth affecting the sunflower cake and obtaining it in a crumbled form. Knives in the knife packages are selected for various feeds, depending on the type of farm animal, to obtain it in granular and crumbled forms.

The use of mathematical modeling of the sunflower cake grinding process to a bulk form makes it possible to determine the optimal values of the design parameters of the improved grinder: the tooth inclination angle on the knife packages is 23.48...25.76 degrees, the number of knife packages is 4...6 and the physical and mechanical properties of the material: cake thickness – 5.42...6.02 mm.

The improved sunflower cake grinder allows reducing its energy intensity to 2.14 kW-h/t and increasing its performance to 1.4 t/h without loss of quality.

Based on the experimental studies conducted, the improved sunflower cake grinder allows applying it in the modernization of technological lines for the production of compound feeds in its bulk condition.

References
[1] Savinykh P A, Palitsyn A V and Ivanov I I 2017 Study of a rotary-centrifugal feed grain grinder with various working bodies Dairy Bull. 2(26) 119-129
[2] Khapov Yu S 2017 Development of a feed chopper-mixer Modern research and developments 4(12) 518-521
[3] Sabiev U K and Pushkarev A S 2016 Comparative analysis of devices for grinding grain materials Bull. of Omsk State Agrarian University 1(21) 221-226
[4] Apazhev A K, Shekikhachev Y A, Hazhmetov L M, Fiaphev A G, Shekikhacheva L Z, Hapov Y S, Hazhmetova Z L and Gabachiyev D T 2019 Scientific justification of power efficiency of technological process of crushing of forages J. Phys.: Conf. Ser. 5502
[5] Savinyh P, Shirobokov V, Fedorov O and Ivanov S 2018 Influence of rotary grain crusher parameters on quality of finished product Engineering for Rural Development 17 131-136
[6] Ushakov Y, Shakhov V, Asmankin E and Naumov D 2019 Theoretical study results of product flow management process in hammer-type shredder working chamber Engineering for Rural Development 185-191
[7] Melnikov S V, Aleshkin V R and Roshchin P M 1980 Planning an experiment in the study of agricultural processes 168 p