Optimization of the critical parameters of the grinder in sunflower meal preparation

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Abstract. Most of the grain grinders have disadvantages, which are inherent in their unsuitability for grinding protein feeds, which include oilseed meal, for example, a sunflower meal in crumbled and pelleted forms, since a grain and a meal have different physical and mechanical properties, and a meal has the property of hygroscopicity, which is why it is necessary immediately feed it to farm animals. As a result of optimization of the work process parameters of the grinder in obtaining sunflower meal, the following optimal values have been obtained: the number of knives on the crankshaft 8...10 pcs.; the sunflower meal average particle size 23...24 mm; knife cutting angle 32...36°. At the same time, the grinder that prepares sunflower meal that meets zootechnical requirements, has been obatained, with a minimum specific energy consumption of $E = 0.41$ kWh/t, compared to series-produced ones of $0.94-1.5$ kWh/t, as well as an increased performance $Q = 5.73$ t/h, which increased by 15% due to the presence of a set of removable knife blocks with crankshafts with different journals for processing materials with different physical and mechanical properties for different farm animals.

1. Introduction

The agricultural development and the increase in animal productivity depend on the fodder base state, the selection of species, varieties of fodder crops in each particular commercial farm unit.

The imbalance in energy and protein rations not only does not contribute to the realization of the productivity potential of animals, but also increases the feed consumption. Therefore, it is necessary to direct attention to the structure of high-protein forage crops.

The main source of protein is a concentrated plant feed, which accounts for more than 90%. The farms of the regions cultivate high-protein crops [9], which include sunflower.

At present, 50-70% of all energy costs are spent on the grinding process in feed preparation for feeding animals, and this, in turn, is approximately 50% of the economic costs for their processing [1-3,6]. In connection with the development of farming, it became necessary to produce and design small-sized fodder grinders. At the moment, there is no sufficiently complete substantiation of the design parameters of the knives in the grinding unit, their energy consumption for grinding the feed [1].

The development and creation of energy-saving, highly efficient grinding machines with modernized working bodies, are central to improving the mechanical equipment for the fodder production. In this regard, the study and improvement of feed grinders and increasing the durability of their working bodies is a relevant and important objective. It is important in the machine design for the
feed preparation is to develop principles that reduce the energy consumption of feed grinding, since this indicator allows reducing the unit costs of their production [1].

The most widespread grinding machines [8,11-13] in agricultural production are hammer grinders. They are simple in design and reliable in operation [7], but their design and working process organization have a number of disadvantages, which leads to a decrease in performance and significant energy consumption in grinding the material [3,4,5].

Most of the grain grinders have disadvantages, which are inherent in their unsuitability for grinding protein feeds, which include oilseed meal, for example, a sunflower meal in crumbled and pelleted forms, since a grain and a meal have different physical and mechanical properties, and a meal has the property of hygroscopicity, which is why it is necessary immediately feed it to farm animals.

Therefore, the purpose of the study is to increase performance and reduce the specific energy consumption of grinders in obtaining sunflower meal, which is an urgent problem.

2. Materials and methods

To reduce the energy consumption of the process and increase the performance, an experimental grinder for sunflower meal, shown in Figure 1, has been proposed (the Patent of the Russian Federation № 2693260).

![Figure 1. The sunflower meal grinder: a – general view; b – with removed front cap; c – the knife (view “B”); d – the knife section view “B-B”](image)

The grinder (Figure 1 a) includes a loading hopper 1, a body frame 2, a damper 3, a set of removable knife blocks 4 with knives 5, a rotor 6 with disks 7 and 8, resting on a frame 9, an electric motor 10. Knife block 4 (Figure 1 b) is made in the form of a crankshaft 11, on the journals 12 of which the knives are in a staggered arrangement, the cutting part of which has a crescent shape and on the outer and inner sides – the blades are sharpened at an angle of not more than 40° on both sides. In this case, the crankshaft journals of the knife blocks, included in the set, have different sizes of diameter from 3 to 6 cm and lengths of 2 to 4 cm, in order to be able to process material with different physical and mechanical properties. To substantiate the choice of the diameter and length sizes of the crankshaft journals for the removable knife blocks included in the set, based on the developed methodology, the experiments on grinding sunflower meal using crankshafts in the amount of 3 pieces with different journal sizes, have been conducted. In the first crankshaft, the journals had a diameter of 3 cm and a length of 2 cm, in the second one – 4,5 cm and 3 cm, respectively, and in the third crankshaft, the journals had a diameter of 6 cm and a length of 4 cm. In grinding large meal pieces, which can represent broken plates or irregularly shaped pieces weighing 200 – 300 g, it is effective to use a knife block with a third type of a crankshaft journal, which has a diameter of 6 cm and a length of 4 cm. For further grinding of medium-sized meal pieces for farm animals feeding, it is necessary to use a second crankshaft, and for feeding the poultry where finely ground meal is required, the first crankshaft with journals of 3 cm of diameter and 2 cm of a length, is used.

The technological process of the grinder operation is carried out as follows.
The size of the material before and after processing is preliminarily determined, the corresponding knife block is installed. For grinding the material, for example, a sunflower meal, it is poured into the loading hopper and the electric motor is turned on, after which the damper is opened. The grinded product is exposed to impact of the knives (Figure 1 c, d), due to the fact that their cutting part has a crescent shape, and the blades are sharpened at an angle of not more than 40° on both sides, the sliding cutting is ensured, and grinding occurs not only in the upper, but also in the lower parts of the inner work surface of the body frame, which makes it possible to improve the grinding quality, and also due to the fact that the entire surface of the knife cutting edge is involved in the technological process, the energy consumption of the process decreases.

In grinding sunflower meal plates for cattle with an experimental grinder, the matrix of the experiment plan was implemented. The levels and variability intervals of the factors have been selected as a result of a single-factor experiment. The planning matrix and experimental results are presented in Table 1.

| Table 1. The factors and the levels of variation |
|-----------------------------------------------|
| Factor title | Factor score | Interval of factor variation | Levels of factors | Top | Base | Lower |
|---------------|-------------|-------------------------------|-------------------|-----|------|-------|
|               | coded designation | natural designation |                     |     |      |       |
| The number of knives on the crankshaft, pcs. | $x_1$ | $n$ | 2 | 8 | 10 | 12 |
| Sunflower meal average particle size, mm | $x_2$ | $L_{av}$ | 5 | 20 | 25 | 30 |
| Knife cutting angle, deg. | $x_3$ | $\alpha$ | 10 | 20 | 30 | 40 |

As an optimization criterion, the specific energy consumption of the grinder has been chosen in obtaining sunflower meal $E$ (kWh/t) and its performance $Q$ (t/h).

### 3. Results and discussions

As a result of the experimental studies, the values of the quantities have been obtained, which are presented in Table 2.

| Table 2. The planning matrix of the grinder operation for sunflower meal |
|-----------------------------|
| Item No. | Factors | Grinder specific energy consumption $E$, kWh/t | Performance in sunflower meal grinding $Q$, t/h |
|        | coded | decoded |                               |                               |
|        | $x_1$ | $x_2$ | $x_3$ | n | $L_{av}$ | $\alpha$ | | |
| 1     | +1   | +1   | +1   | 12 | 30  | 40  | 0.6 | 3.9 |
| 2     | -1   | +1   | +1   | 8  | 30  | 40  | 0.8 | 2.3 |
| 3     | +1   | -1   | +1   | 12 | 20  | 40  | 0.9 | 5.5 |
| 4     | -1   | -1   | +1   | 8  | 20  | 40  | 0.52 | 4.2 |
| 5     | +1   | +1   | -1   | 12 | 30  | 20  | 0.71 | 4.5 |
| 6     | -1   | +1   | -1   | 8  | 30  | 20  | 0.65 | 5.6 |
| 7     | +1   | -1   | -1   | 12 | 20  | 20  | 0.95 | 5.8 |
| 8     | -1   | -1   | -1   | 8  | 20  | 20  | 0.58 | 6.1 |
| 9     | +1   | 0    | 0    | 12 | 25  | 30  | 0.43 | 5.2 |
| 10    | -1   | 0    | 0    | 8  | 25  | 30  | 0.70 | 3.8 |
| 11    | 0    | +1   | 0    | 10 | 30  | 30  | 0.62 | 4.1 |
| 12    | 0    | -1   | 0    | 10 | 20  | 30  | 0.82 | 4.8 |
| 13    | 0    | 0    | +1   | 10 | 25  | 40  | 0.50 | 6.3 |
| 14    | 0    | 0    | -1   | 10 | 25  | 20  | 0.56 | 6.8 |
Regression coefficients have been estimated on a computer. Insignificant coefficients have been excluded from the model, after excluding each insignificant one, mathematical models have been obtained:

\begin{align}
E &= 0.42 + 0.03x_1 - 0.04x_2 - 0.006x_3 - 0.11x_1x_2 - 0.04x_1x_3 + 0.02x_2x_3 + 0.016x_1^2 + 0.017x_2^2 - 0.021x_3^2, \quad (1)
\end{align}

\begin{align}
Q &= 5.64 - 0.32x_1 + 0.62x_2 - 0.66x_3 - 0.06x_1x_2 + 0.54x_1x_3 - 0.22x_2x_3 - 0.88x_1^2 - 0.93x_2^2 + 1.17x_3^2, \quad (2)
\end{align}

The grinder specific energy consumption (1) is significantly influenced by the factors \(x_1\) – the number of knives on the crankshaft (\(b_1 = +0.03\)) and \(x_2\) – the sunflower meal average particle size (\(b_2 = -0.04\)). The grinder specific energy consumption decreases with a decrease in the sunflower meal average particle size and increases with an increase in the number of knives on the crankshaft. An increase in specific energy consumption is facilitated by a combination of factors \(x_1\) and \(x_2\), as well as \(x_1\) and \(x_3\), while its decrease is facilitated by a combination of factors \(x_2\) and \(x_3\).

The grinder performance (2) is significantly influenced by the factors \(x_2\) – the sunflower meal average particle size (\(b_2 = -0.62\)) and \(x_3\) – the knife cutting angle (\(b_3 = -0.66\)). The grinder performance decreases with an increase in the sunflower meal average particle size and the knife cutting angle. The performance increases with the interaction of the number of knives on the crankshaft and the sunflower meal average particle size, the sunflower meal average particle size and the knife cutting angle, and also decreases by combination of the number of knives on the crankshaft and the knife cutting angle.

The analysis of models (1) and (2) has been performed using two-dimensional sections [10].

Two-dimensional sections of the response surfaces, characterizing:

– the grinder specific energy consumption depending on:
  the number of knives on the crankshaft (\(x_1\)) and the sunflower meal average particle size (\(x_2\)) (Figure 2, a)
  \begin{align}
  Y &= 0.41 = 0.016X_1^2 + 0.17X_2^2, \quad (3)
  \end{align}

  the number of knives on the crankshaft (\(x_1\)) and the knife cutting angle (\(x_3\)) (Figure 2, b)
  \begin{align}
  Y &= 0.41 = 0.016X_1^2 - 0.022X_3^2, \quad (4)
  \end{align}

  the sunflower meal average particle size (\(x_2\)) and the knife cutting angle (\(x_3\)) (Figure 2, c)
  \begin{align}
  Y &= 0.41 = 0.17X_2^2 - 0.022X_3^2. \quad (5)
  \end{align}

– the grinder performance depending on:
  the number of knives on the crankshaft (\(x_1\)) and the sunflower meal average particle size (\(x_2\)) (Figure, 3a)
  \begin{align}
  Y &= 5.73 = -0.88X_1^2 - 0.94X_2^2, \quad (6)
  \end{align}

  the number of knives on the crankshaft (\(x_1\)) and the knife cutting angle (\(x_3\)) (Figure, 3b)
  \begin{align}
  Y &= 5.73 = -0.88X_1^2 + 1.17X_3^2, \quad (7)
  \end{align}

  the sunflower meal average particle size (\(x_2\)) and the knife cutting angle (\(x_3\))
  \begin{align}
  Y &= 5.73 = -0.94X_2^2 + 1.17X_3^2. \quad (8)
  \end{align}
Two-dimensional sections of the response surface, characterizing the change in the grinder specific energy consumption depending on: 

- **a** – the number of knives on the crankshaft ($x_1$) and the sunflower meal average particle size ($x_2$);
- **b** – the number of knives on the crankshaft ($x_1$) and the knife cutting angle ($x_3$);
- **c** – the sunflower meal average particle size ($x_2$) and the knife cutting angle ($x_3$)

The regression coefficients of the canonical form in the expressions (4), (5), (7), (8) have different signs, the center of the figures is located near the center of the experiment, and the expressions (3), (6) have the same signs and the center of the figure is near the center of the experiment [10] (Figure 1).

The analysis of the given two-dimensional sections (Figure 2) shows that with an increase in the number of knives on the crankshaft and the sunflower meal average particle size, as well as with a decrease in the knife cutting angle, the grinder specific energy consumption decreases.

The analysis of two-dimensional sections in Figure 3 shows that with a decrease in the number of knives on the crankshaft and the sunflower meal average particle size, the grinder performance increases, and with an increase in the knife cutting angle the performance decreases.

The interaction of factors with each other (Figure 2) $x_1$, $x_2$ and $x_3$ in the experimental area has a minimum specific energy consumption of the grinder $E = 0.41$ kWh/t with the value of the factors, respectively, $n = 8$ pcs., $L_{av} = 24$ mm and $\alpha = 36^\circ$. 

**Figure 2.** Two-dimensional sections of the response surface, characterizing the change in the grinder specific energy consumption depending on: 

- **a** – the number of knives on the crankshaft ($x_1$) and the sunflower meal average particle size ($x_2$);
- **b** – the number of knives on the crankshaft ($x_1$) and the knife cutting angle ($x_3$);
- **c** – the sunflower meal average particle size ($x_2$) and the knife cutting angle ($x_3$)
Figure 3. Two-dimensional sections of the response surface, characterizing the change in the grinder performance depending on: 

- \( a \) – the number of knives on the crankshaft \((x_1)\) and the sunflower meal average particle size \((x_2)\); 
- \( b \) – the number of knives on the crankshaft \((x_1)\) and the knife cutting angle \((x_3)\); 
- \( c \) – the sunflower meal average particle size \((x_2)\) and the knife cutting angle \((x_3)\).

In this case, the maximum value of the grinder performance \( Q = 5.73 \) t/h (Figure 3) is achieved with the number of knives on the crankshaft \( n = 11 \) pcs., the sunflower meal average particle size \( L_{av} = 23 \) mm and the knife cutting angle \( \alpha = 32^\circ \).

4. Conclusion

As a result of optimization of the work process parameters of the grinder in obtaining sunflower meal, the following optimal values have been obtained:

- the number of knives on the crankshaft \( n = 8...10 \) pcs.;
- the sunflower meal average particle size \( L_{av} = 23...24 \) mm;
- knife cutting angle \( \alpha = 32...36^\circ \).

At the same time, the grinder that prepares sunflower meal that meets zootechnical requirements, has been obatained, with a minimum specific energy consumption of \( E = 0.41 \) kWh/t, compared to series-produced ones of 0.94-1.5 kWh/t, as well as an increased performance \( Q = 5.73 \) t/h, which
increased by 15% due to the presence of a set of removable knife blocks with crankshafts with different journals for processing materials with different physical and mechanical properties for different farm animals.

5. References
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