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STUDY OF FEED GRANULATION PROCESS BASED ON SYSTEM ANALYSIS – JUSTIFICATION OF OPTIMIZATION CRITERIA

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Abstract. *The article analyzes the process of granulation of animal feed and identifies the main criteria for optimizing this process. In order to increase the productivity of animals, the use of balanced feed is considered important. Feed granulation technology not only replaces traditional feed, but also allows the use of industrial waste (corn, sunflower residues, etc.). This process provides animals with better digestion and high feed efficiency. The results of the study show that the protein and feed unit digested when using granulated feed are maintained at a higher level than other traditional feed types. The article analyzes the stages, structural and management parameters of this technological process, and is also modeled by various system approaches (morphological, functional, information). As an optimization criterion, indicators of process energy efficiency and grain quality are taken. The efficiency of the process is measured by the amount of energy used in the granulation line, the weight and quality of the output. The article also presents functional descriptions and equipment control mechanisms to improve the granulation process. Thus, this study offers practical solutions for the systematic analysis and optimization of the granulation process of compound feeds, and emphasizes the importance of analyzing and modeling equipment based on the aggregate system.*

Keywords: granulated feed, feeding process, process analysis, aggregate system, feed processing equipment, system approach

BADANIE PROCESU GRANULACJI PASZY W OPARCIU O ANALIZĘ SYSTEMOWĄ – UZASADNIENIE KRYTERIÓW OPTYMALIZACJI

Streszczenie. *Artykuł analizuje proces granulacji paszy dla zwierząt i określa główne kryteria optymalizacji tego procesu. Aby zwiększyć wydajność zwierząt, za ważne uznaje się stosowanie zbilansowanej paszy. Technologia granulacji paszy nie tylko zastępuje tradycyjną paszę, ale także pozwala na wykorzystanie odpadów przemysłowych (kukurydza, pozostałości słonecznika itp.). Proces ten zapewnia zwierzętom lepsze trawienie i wysoką wydajność paszy. Wyniki badań pokazują, że białko i jednostka paszowa trawiona przy stosowaniu granulowanej paszy utrzymują się na wyższym poziomie niż w przypadku innych tradycyjnych rodzajów paszy. Artykuł analizuje etapy, parametry strukturalne i zarządzania tym procesem technologicznym, a także jest modelowany przy użyciu różnych podejść systemowych (morfologicznych, funkcjonalnych, informacyjnych). Jako kryterium optymalizacji przyjęto wskaźniki efektywności energetycznej procesu i jakości ziarna. Efektywność procesu mierzy się ilością energii zużytej w linii granulacyjnej, masą i jakością produktu końcowego. W artykule przedstawiono również opisy funkcjonalne i mechanizmy sterowania urządzeniami w celu usprawnienia procesu granulacji. W ten sposób niniejsze badanie oferuje praktyczne rozwiązania w zakresie systematycznej analizy i optymalizacji procesu granulacji mieszanek paszowych oraz podkreśla znaczenie analizy i modelowania urządzeń w oparciu o system agregacyjny.*

Słowa kluczowe: pasza granulowana, proces żywienia, analiza procesu, system agregatów, urządzenia do przetwarzania pasz, podejście systemowe

Introduction

To ensure the high productivity of animals, it is particularly important to feed them with balanced and high-quality feeds [4]. Balanced feeding creates the conditions necessary for the optimal implementation of metabolic and synthetic processes in the animal's body. To achieve this, it is essential to prepare complete feed mixtures by effectively utilizing the existing feed resources of the regions. Feed production is not limited to traditional arable land but also involves the use of plant residues and food and light industrial waste in the process.

Under normal conditions, some residues are not well-accepted by animals, which hinders the full utilization of the ration. To address this issue, the preparation of granular feeds by mixing various plant residues, protein-rich additives, and industrial waste has proven to be an effective method. Studies show that the use of granular feeds increases productivity and provides a higher level of digestibility compared to traditional types of feed [5].

The application of modern scientific and technological innovations has necessitated the development of the feed pelleting process. Pelleted feeds offer advantages in terms of both nutritional quality and energy efficiency. A deeper study of the stages of this process and the identification of optimal control methods remain relevant for researchers. This article provides an analytical and functional description of the technological process of feed pelleting and substantiates the criteria for its optimization. Proposals for the management and improvement of the process are presented using a systematic approach.

Relevance of the study. Enhancing animal productivity and ensuring their healthy nutrition are among the key goals of the modern agricultural sector. Providing high-quality and balanced feeds not only meets the needs of the animal organism but also improves the efficiency of feed production. Moreover, the efficient use of local resources – such as biological residues and industrial waste – in feed production holds particular importance for both environmental sustainability and economic benefits. The preparation of pelleted feeds stands out as an important innovative solution in this regard.

In the modern era, the higher efficiency and digestibility of pelleted feeds compared to traditional feeds have increased the relevance of this technology. Additionally, optimizing the pelleting process allows for greater productivity in feed production by reducing energy and labor costs. The application of modern scientific and technical advancements, as well as information technologies, further highlights the development and improvement of feed processing technologies.

The systematic analysis of the pelleting process and the identification of optimization criteria are crucial for enhancing economic efficiency in animal husbandry. This article aims to contribute to solving existing challenges in this field by proposing a systematic approach to the feed pelleting process, based on the results of scientific research. Thus, the issues of improving the quality and efficiency of pelleted feeds, as well as optimizing production processes, underscore the importance of this study [3].

Scientific novelty of the research. The scientific novelty of this study is reflected in the following main aspects:

Application of a systemic approach: The study analyzes the feed pelleting process not only as separate stages but as an integrated technological line. Through a systematic approach, the interrelationships between technological, management, and structural parameters are examined. A deeper understanding of the process is achieved using morphological, functional, and informational models.

Determination of innovative optimization criteria: Unlike traditional methods, this study introduces an optimization criterion that achieves an optimal balance between energy consumption, quality indicators, and productivity in the preparation of pelleted feeds. This approach enables the production of high-quality products with minimal energy consumption.

Investigation of Local Resource Utilization Potential: The research explores the use of biological residues and industrial waste (e.g., corn husks, sunflower heads, grape pomace) in the production of pelleted feeds. This is considered a scientific innovation as it contributes to both environmental sustainability and economic efficiency.

Modeling of equipment as an aggregate system: The study includes the modeling of equipment used in feed processing as an aggregate system and proposes mathematical algorithms for process control. This approach enhances the automation of the pelleting line and improves the quality of process management.

Synergy between energy efficiency and productivity: The research examines the interaction between energy efficiency and product quality in the use of pelleted feeds. Determining the optimal values of various control parameters and their application to the system are highlighted as innovative solutions.

Perspective of digital technology application: The study investigates and proposes the application of digital control technologies for process automation and real-time monitoring. This approach is presented as a significant technological innovation in advancing the industry.

1. Systematic analysis of the feed pelleting process

The process of pelleting feed is one of the important technologies for increasing the efficiency of feeding in livestock farms. The purpose of this process is to prepare balanced and highly nutritious feed for animal nutrition. Pelleting not only facilitates the digestibility of feed but also increases the economic efficiency of production by optimizing the use of raw materials. Through this technology, various types of raw materials, including plant residues and industrial waste, are converted into a unified feed, which is beneficial both ecologically and economically.

The preparation of pelleted feed is a multi-stage and complex process. It is important to efficiently regulate each stage – preparation, moistening, pressing, cooling, and sorting of raw materials. Effective process management requires the proper coordination of technological parameters. Analyzing the functional and constructive characteristics of each component of the pelleting line, as well as studying the interactions between these stages, necessitates a systematic approach.

The systematic analysis process encompasses not only individual stages but also the entire technological line, taking into account the functional and morphological structures of the subsystems within it. This approach increases process efficiency by assessing the impact of each stage. As a result of systematic analysis, controlled parameters – such as the moisture and temperature levels of raw materials, the pressure of the press, the productivity of the equipment, and energy consumption—are determined optimally. This enhances production efficiency and creates conditions for obtaining higher-quality feed.

In the measures taken to achieve high animal productivity, special attention should be paid to feeding animals with full-value and balanced feeds [4]. Such feeding ensures the provision of complex nutrients, normalizes metabolism, and supports synthetic processes in the body. To achieve this, producers and scientists must develop effective methods for preparing full-ration pressed feed mixtures by fully utilizing the local feed resources of each region and creating a solid feed base for every farm. Feed preparation is not limited to the efficient use of fodder fields; it also enables the effective use of biological residues from cereal crops, corn stalks, sunflower husks, and waste from food and light industries, including grape skins, grape and fruit pomace, molasses, and whey, in the overall feed balance [9].

Usually, even when these components are mixed with concentrated feeds, they are poorly consumed by animals, and the ration is not fully utilized [6]. These shortcomings are eliminated by preparing granular feed from a mixture of the aforementioned plant residue flour, concentrated feeds, protein- and vitamin-rich feeds, and food and light industrial waste.

From this perspective, increasing the share of granulated feed in the total volume of concentrated feed production is one of the most pressing issues. It is well known that the efficiency of using granulated feeds is 8–12% higher than that of dispersed concentrated feeds.

The development of granulated concentrated-mixed feed production, both technologically and technically, has made it essential to intensify and improve this field by leveraging modern scientific and technical achievements, including information technologies.

The results of several studies indicate that granulated feed preserves more than 1.5 times the feed units and digestible protein compared to feeds prepared using other methods. When using granular feed, it is possible to utilize 90% of the feed units and 80% of the digestible protein. For comparison, these figures are 50% and 40% in dry grass, 70% and 75% in silage, and 63% and 53% in grain, respectively.

The preparation of granular feeds replaces traditional methods of preparing both bulk and concentrated feeds. The main advantage of granulation is that straw, concentrated feeds, and mineral additives can be ground into flour, mixed with grass flour in specific proportions, and granulated. Moreover, freshly cut feed can be dried, ground, mixed with other components, and granulated in a single technological process [1].

2. Justification of the optimization criterion

Optimization of processes is of great importance for the efficient organization of feed production and for increasing animal productivity. Optimization criteria in the preparation of pelleted feeds play a critical role in enhancing the efficiency of the technological process and ensuring the economical use of energy and resources. A well-managed pelleting process not only improves product quality but also reduces production costs by maximizing the utilization of raw materials.

The primary goal of the optimization criterion is to balance the technological, energy, and quality indicators of the pelleting line. Various parameters – such as the moisture and temperature levels of raw materials, pressing intensity, equipment design parameters, and energy consumption – require precise adjustment. The main objective is to identify the optimal mode that ensures the production of high-quality and durable pellets with minimal energy usage [8].

Correctly selecting optimization criteria is essential for achieving technical and economic efficiency in pelleted feed production. Optimization focuses on managing the entire technological line effectively rather than concentrating solely on individual processes. This comprehensive approach creates a balance among energy consumption, product output, and pellet quality, making feed utilization in livestock farms more beneficial.

This study aims to enhance the efficiency of the feed production process by substantiating and applying optimization criteria. The approaches presented involve in-depth analysis of technological processes and determination of optimal values for controlled parameters. These advancements align feed production with modern standards, ensuring economic viability [7].

Analysis of the key stages in the technological process of feed pelleting reveals that the predominant approach to its study involves obtaining analytical and empirical dependencies to describe individual stages. However, analytical methods often yield complex formulas with low accuracy because they exclude several factors influencing the process. This traditional method does not enable the holistic study of the entire technological line for granular feed preparation as an integrated system [2].

Optimization of processes is crucial for the efficient organization of feed production and enhancing animal productivity. Optimization criteria in pelleted feed preparation are essential not only for improving the technological process but also for ensuring the economical use of energy and resources. A well-managed pelleting process enhances product quality and reduces production costs by maximizing the utilization of raw materials.

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To describe the process more deeply and comprehensively, clarify regularities, and determine the interaction between its elements and the environment, a systematic approach is more appropriate. This method provides an algorithm for modeling the process [6]. Typically, three types of system descriptions – morphological, functional, and informational – are constructed.

Figure 1 depicts the morphological system of the "granular feed production line." This system is considered an element of a larger system, such as a "feed processing plant," and has external relations with it. The morphological description in Figure 1 enables the system to be divided into smaller subsystems (aggregates), which can be easily studied and quantitatively analyzed during the subsequent functional analysis phase [4].

The functional description of the technological line for the preparation of granular feed can be constructed in the form of an aggregate system (A-system). Such a system reflects the system of machines and processes implemented in it.

The functional description of the technological line can be constructed in the form of an aggregate system (A-system). This system (Fig. 2) differs in that the system of machines and processes implemented in it are reflected.

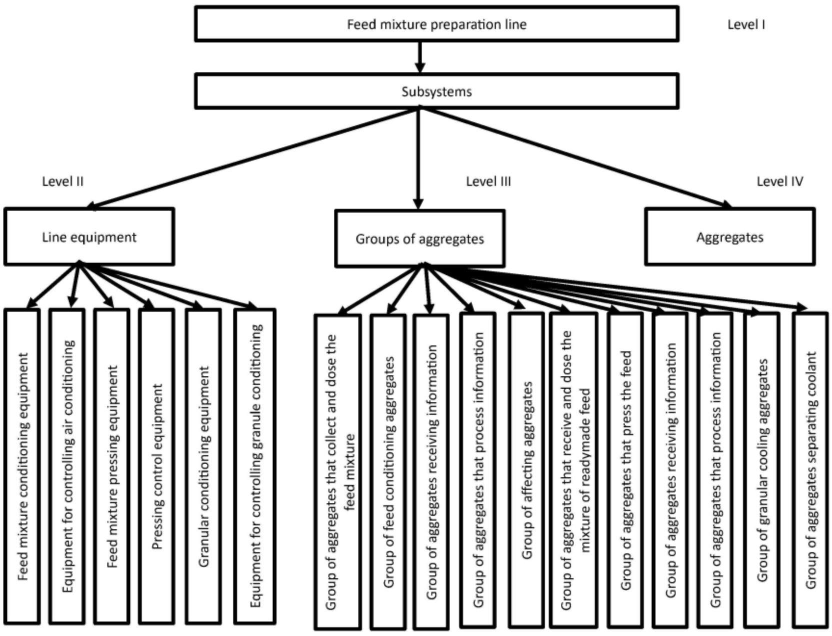

Fig. 1. Morphological scheme of the line for preparing feed mixture granules

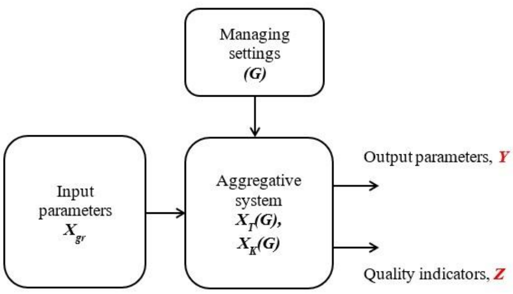

Fig. 2. Model of the aggregate system (X_T – process technological parameters, X_K –process design parameters)

This system is constructed with the following:

- vector of input parameters ($X_{gir,1}$) characterizing the properties of the initial feed mixture. The aggregates of this vector include: humidity (W) and temperature (t^0), heat transfer (λ), heat capacity χ, friction coefficient ($f_{sürl}$) and b, the input to system A also implies the entry of a humidifier – X_{gir2} (water, steam), binders – $Xgir_3$ (molasses, bentonite), heat – $Xgir_4$, cooling air flow – $Xgir_5$.
- vector of technological parameters characterizing the granulation process under the condition of feeding the feed mixture ready for pressing with moisture content W_T and temperature t_T to the press with a load Q_{yq}.
- vector of constructive parameters (X_k). It is composed of: the ratio of the length of the matrix channel (L/d), the shape of the pressing channel (the opening angle of the hole head (ψ), etc.
- a vector of control parameters (G) affecting the technological process. This includes the feed mixture supply efficiency (Q_{yem}), the heat input intensity (Q_{ist}), the humidifier efficiency (Q_{nem}) (water, steam, binder material), the intensity of the impact of the working bodies on the feed mixture and finished granules, the gap between the roller and the matrix, etc.
- output vectors (Y). The aggregates of this vector include: the technological indicator – the mass output of finished granules (Q_{den} – line efficiency), the energy indicator – the specific

energy consumption of the granulation process (N_{xus}) and the quality indicators of finished granules (Z), grinding (K_{ovx}), Density (ρ), moisture (W), etc. factors affecting the granulation process.

The output of most granular feeds is carried out under conditions of constant or slowly changing parameters. Therefore, from a practical point of view, the optimization of a static model of the process is of greater interest. In this case, the dynamic accumulations of granular feed and stop modes or the change in the parameters $X_{gir}(t)$, $X_T[G_T(t)]$,$X_h[G_k(t)]$ can be ignored. Therefore, it is assumed that,

$$X_T(t) = X;\ G(t) = G;\ Y(t) = Y \quad (1)$$

Then the general model of the process is as follows, which is considered useful for solving the optimization problem

$$Y = \varphi[X_{gir};\ X_T(G_T);\ X_k(G_k)] \quad (2)$$

The operation of the aggregate system is carried out according to the functional scheme (Fig. 3).

The feed mixture and the slurry from the sorter (X_{gir}) enter the collecting hopper from the outside (from the dosing devices and the mixing screw) according to the recipe given. The feed mixture flow is fed from the hopper to the dosing screw, and from there to the conditioning mixer. The control signals g_{T1}, g_{T2} ensure uniform feeding of the feed mixture. From the outside, the conditioning mixer is fed with a wetting agent (X_{gir2}), binders (X_{gir3}) and (X_{gir4}).

The control signals g_{T3}, g_{T4}, g_{T5}, g_{T6} regulate the supply of moisture, heat, binders and uniform moistening of the feed mixture, respectively. The conditioned feed mixture is fed to the press-granulator by flow or by force. Here, the feed mass is filled into the channels of the press by the rotation of two rollers and a vertical matrix (mold). With the help of g_{T7} – control signals, it is possible to change the gap between the roller and the matrix. This allows you to adjust the quality indicators of the granules, the energy consumption of the process and the granule output. The granule flow from the press enters the cooling column. A cooling air flow (X_{gir5}) is supplied to it from the environment. A heated air flow (Yq) is discharged from the cooling column to the environment. The g_{T8} control signals regulate the air supply. The granules cooled in the cooling column are transferred to the sorter or granulator. Here, the last ungranulated mass is separated from the granules and fed to the collecting bunker.

The frequency of the granulator shaft is regulated by the g_{T9} control signal. The finished granules are loaded onto the transport vehicle outside the sorter or granulator.

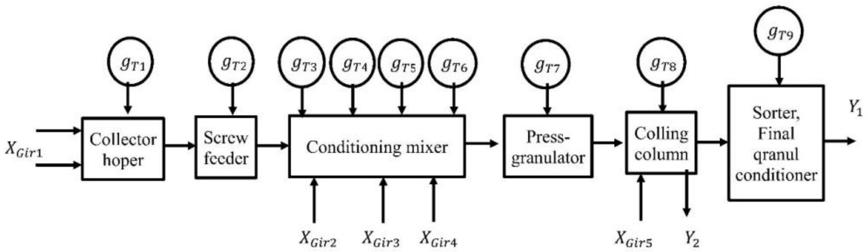

Fig. 3. Functional scheme of the aggregate system

3. Information model of the optimal parameters search system

The determination of the optimal parameters of the technological regime and the development of its reporting methodology can be carried out on the information model (Fig. 4).

Here, the feed granulation line in the form of an aggregate system, the measurement system of the output parameters of the line (X, X_T, X_k); an electronic calculator that obtains a mathematical model of the process by experimental statistical processing based on special mathematical support and optimizes it according to the selected criteria and gives the optimal values of the regulated factors ($Xgir$, X_T, X_k); a system that provides control effects (G) are described.

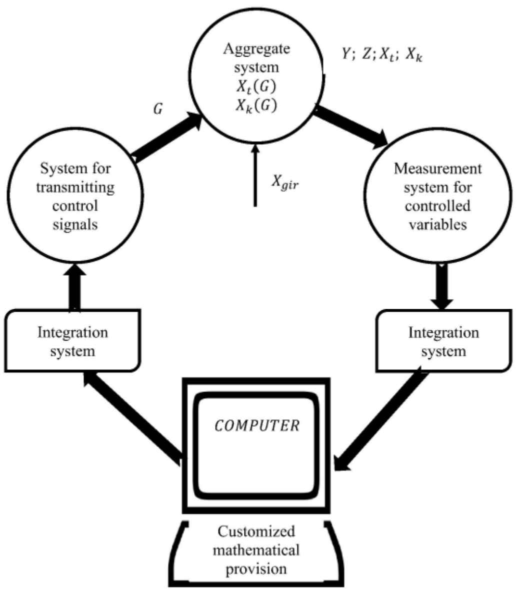

Fig. 4. Information model of the optimal parameters search system

The developed model can be considered useful for practical use in the following ways:

- development and use of the optimal technological mode of preparing granular feed according to the selected criteria according to the given recipe;
- use in the design of structures with optimal characteristics (the gap between the roller and the matrix, the ratio of the length of the matrix channel to its diameter, etc.) or their adjustment options.

Thus, it can be noted that the control of the technological process of producing high-quality granulated feed consists in regulating the feed rate of the mass fed to the press-granulator and its properties (X_{gir}-vector), regulating the process conditions [$X_T(G_T)$]-vector, and changing the equipment parameters [$X_k(G_k)$] in order to obtain a finished product with any desired properties with minimal labor and energy consumption. In other words, the control should support the selected optimal mode of the process.

As an optimal mode, it is usually intended to select a pair of process parameters that provide the best value of the optimization criterion and make it possible to evaluate them quantitatively. It is difficult to select the optimal granulation mode for the output granulate flow according to all criteria. Therefore, it is more expedient to formulate a criterion that is generalized from a number of specific criteria and allows one to judge the operation of the system. In this regard, specific energy capacity is accepted as a generalized indicator as a criterion reflecting the efficient operation of the equipment for the joint evaluation of the factors controlled by the energy and quality indicators of the granulation process:

$$A_{sp} = \frac{N_{sp\cdot k}+N_{sp\cdot p}+N_{x\ddot{u}s\cdot qr}}{K_{qr}\left(1-\frac{K_{ovx}}{100}\right)} \quad (3)$$

where $N_{sp.k}$ – specific energy capacity of conditioning, kW×h/ton; $N_{sp.p}$ – specific energy capacity of pressing, kW×h/ton; $N_{sp\cdot qr}$ – specific energy intensity of ready grains conditioning, kW×hour/ton; K_{qr} – final feed mixture granulation factor; K_{ovx} – Rubbing factor, %.

This optimization criterion combines the technological, energy and quality indicators of the feed mixture granulation line. This indicator is usually applied by researchers in the process optimization method by the experimental design method. Because in this method it is possible to choose a mode that ensures the minimum energy consumption of the process under the conditions of high granulation and minimum churning.

It is considered appropriate to accept expression (3) as an optimization criterion when there are no strict zootechnical requirements for the quality indicators of granular feed. Considering that the mathematical expression we have developed for optimization purposes puts forward a number of strict requirements for the quality of granular feed, we accept the minimum energy consumption for the entire granulation process as an optimization criterion for future studies:

$$N_{sp}=\frac{E_k+E_{qr}+E_{kqr}}{Q_{qr}} \tag{4}$$

where E_k, E_{qr}, E_{kqr} – are the energy consumption for conditioning, granulation (pressing) and conditioning of the finished granule, respectively, kW; Q_{qr} – is the mass output (productivity), tons/hour.

The following formulas can be used to determine the level of abrasion (K_{ovx}) and density (ρ) from the quality indicators of the particles:

$$K_{ovx}=\frac{M_1-M_2}{M_1}\cdot 100 \tag{5}$$

$$\rho=\frac{M}{V^1}\cdot 10^3 \tag{6}$$

where M_1 – mass of feed given for pelleting. kg; M_2 – mass of granules, kg; M – mass of granules loaded into a measuring container filled with gasoline, kg; V^1 – volume occupied by granules in a measuring container, cm^3.

The controlled variables $X_T(G_T)$ and $(X_k(G_k))$ that provide the minimum of the optimization criterion and the desired quality of the granules are considered optimal.

Thus, based on a systematic analysis, it was possible to deeply and comprehensively study the working process for the granulation line of a full-ration feed mixture, to clarify the factors affecting the selected optimization criterion and the quality indicators of the granules.

The study of the equipment for granulating the feed mixture in the form of an aggregate system allowed to obtain a full functional description of its operation and, on this basis, to model the process. In order to solve optimization problems, it is necessary to experimentally study the line in the form of an aggregate system in order to verify the model itself.

4. Conclusion and recommendations

Conclusion: The results of the study show that the process of pelleting feeds is an effective method for increasing the efficiency of animal nutrition. Pelletized feeds are better digested than traditional feeds, protein retention is ensured at a high level, and animal productivity increases. This process also allows for the efficient use of various local feed resources – plant residues and industrial waste. Thus, pelleting not only increases the quality of nutrition, but also serves economic and environmental efficiency.

Optimization of technological and management parameters of the process in the production of pelletized feeds allows for maximum productivity with minimal energy consumption [2]. The analytical and functional approaches presented in the study create conditions for a better understanding and management of this process. As a result of determining the optimization criteria, pelletized feed production can be organized more precisely and efficiently in terms of technology [2].

Suggestions: Application of optimization algorithms: Mathematical models and algorithms should be more widely applied to optimize technological and management parameters in the preparation of pelleted feeds. This will allow for maximum productivity with minimal energy consumption.

Expanding the use of local resources: The use of plant residues, industrial waste and other alternative resources in feed production should be increased. This will both reduce costs and contribute to environmental sustainability.

Modernization of equipment: To increase the efficiency of the pelleting process, technological equipment should be improved in accordance with modern scientific and technical achievements. This will both increase production efficiency and reduce labor costs.

Application of information technologies: With the automation of processes and the introduction of digital control systems, the pelleting line can be more precisely controlled and monitored in real time.

Strengthening research and development: Scientific research should be continued and work should be carried out on new innovative solutions in order to increase the quality and energy efficiency of pelleted feeds.

Standardization of product quality: Quality control and certification mechanisms should be strengthened to ensure that pelleted feeds meet zootechnical requirements.

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