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Thermomechanical processing of components of combined feeds by the expansion method

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ABSTRACT

The availability of high-quality combined feed largely determines the level of economic development in animal husbandry and poultry farming since, in the structure of the cost of livestock products, feed costs reach 65 – 70%. At the same time, the authors of this article aim to compare the current situation around the feed industry in the Republic of Kazakhstan with a similar situation in the Russian Federation, as the formation of this industry in our countries has common roots. Thermomechanical processing methods are proposed to implement deep physicochemical changes in the protein-carbohydrate complex of components of combined feeds. As a result, the quality of the combined feeds improves. Starch gelatinization occurs, and starch grains transition into a more digestible form, contributing to its better assimilation. Bacterial contamination decreases, and coliform bacteria, colon bacillus, mould fungi, and salmonella are destroyed.

Keywords: feed industry, combined feeds, extrusion, expansion, exhibit

INTRODUCTION

On behalf of the President of the Republic of Kazakhstan, a large-scale project, "Development of meat animal husbandry for 2018 – 2027", is being implemented in Kazakhstan, the main task of which is to increase the number of beef cattle for the production of products for export. Subsidies for purchasing livestock, feed, and breeding work are rising annually. Based on the results of this project, existing regional and zonal laboratories of the feed industry will be recreated, meeting modern requirements, the main tasks of which are to analyze veterinary indicators and prevent the receipt of substandard (substandard) raw materials. At the same time, the critical bet in the program is on the development of farms, which should become the leading "players" in the industry. At the same time, the provision of jobs for the rural population will increase from 100 thousand to 500 thousand. Beef and lamb production will grow from 0.6 million tons to 1.6 million tons, while the industry's export revenue will increase to 2.4 billion US dollars.

In recent years, Kazakhstan has significantly reduced the production and consumption of combined feeds, premixes, and various feed additives, without which the productivity, fertility, and safety of young animals decrease significantly, and the quality of livestock products deteriorates. The quality of livestock products profitability of the industry decreases. All these factors are caused not only by a small proportion of highly productive livestock but also by poor feeding and poor quality of the feed produced. The area of sowing of grain crops decreased by 40%, including grain-forage - by 70%. The areas of forage crops were sharply reduced - by more than 4 times. The yield of fodder crops remains low, and the collection of fodder units from 1 ha does not exceed 2.5 – 6.0 kg/ha. The lack of protein in animals' diets leads to overspending of feed by 30 – 40%, increasing its cost. When young animals, during the period of adaptation of the enzymatic system of the food tract, the plant part of the combined feed is poorly absorbed. The use of moisture-thermal and barothermomechanical processing (expansion, extrusion, micronization, granulation, flocking, steaming) of cereals and legumes, as well as vacuum spraying and draining of feed raw materials with thermolabile components (multi-enzyme complexes, vitamins, fat, amino acids, etc.), will allow the production of highly efficient, environmentally friendly, highly nutritious, easily digestible combined feeds of a new generation (with programmable properties). As a result, a synergistic effect of improving the quality of combined feeds is provided. During baro-thermal processing, under the influence of moisture and heat, starch gelatinization and the transition of starch grains into a more digestible form occur, contributing to its better assimilation. In addition, bacterial contamination decreases, and coliform bacteria, *E. coli*, mold fungi, and salmonella are destroyed **[1]**, **[2]**, **[3]**.

At the same time, the volume of feed products in the Republic of Kazakhstan and the Russian Federation, after a well-known decline in the perestroika years, has grown since 2001. Thus, the production of combined feed in the Russian Federation, according to statistics from 9.8 million tons in 2002, amounted to 30.4 million tons in 2012 and increased more than three times. About half of the demand for protein-vitamin-mineral concentrates (PVMC) and premixes is produced at enterprises of the Russian Federation. The rest is supplied from abroad. But it should be taken into account that in the production of premixes, imported raw materials are almost 100%, and in the production of PVMC – 75% **[4]**, **[5]**, **[6]**.

Before 2008, premixes and PVMC were imported to Kazakhstan from abroad. But recently, the volume of these products in Kazakhstan has been growing annually. In 2010, the production of PVMC increased 2.6 times compared to 2008 – up to 22 thousand tons, and in 2011 – up to 28 thousand tons. The same growth rates are observed in the production of premixes, which in 2011 amounted to 12.2 thousand tons, an increase of 36.6% compared to 2010. However, the achieved level of combined feed production does not meet the needs of animal husbandry both quantitatively and qualitatively.

Therefore, the development of technology for preparing a concentrated protein supplement is based on a mixture of legumes and oilseeds to balance the amino acid composition, providing special heat treatment to increase nutrition and reduce antinutritional factors.

Scientific Hypothesis

The idea of the research is a scientifically based selection of technological methods to process all components of raw materials that make up the combined feed, to maximize their assimilation by the digestive tract of farm animals and birds. To do this, it is planned to use the following technological operations: scientifically based selection of feed mixture components, their steaming with subsequent expansion, cooling of the expansion product expandate (product expansion) with simultaneous evaporation of moisture, and subsequent vacuum spraying with thermolabile components.

The main scientific hypothesis: scientific justification of the choice of the formula composition of the mixture for the production of highly nutritious, easily digestible combined feeds of a new generation for the normalized feeding of farm animals and birds; study of the basic laws of the processes of moisture-thermal and barothermomechanical processing of highly digestible combined feeds of a new generation; selection and justification of rational parameters of the process of obtaining highly digestible combined feeds of a new generation; substantiation of the composition and method of application of thermolabile components (enzymes, vitamins, amino acids, fat) for obtaining easily digestible combined feeds of a new generation for normalized feeding of farm animals and birds; conducting a comprehensive assessment of the quality of highly nutritious, easily digestible combined feeds of a new generation with a designed composition and nutritionally balanced components; determination of the effectiveness of the use of highly digestible combined feeds of a new generation on various groups of farm animals and poultry to identify the dynamics of weight gain growth, reduction of fattening time, reduction of animal and poultry mortality, reduction of feed conversion.

The research strategy is based on a combination of analytical, statistical, empirical, and experimental research methods and a scientifically based choice of approaches to the application's order, sequence, and completeness.

To implement the proposed hypothesis, generally accepted and special methods of mathematical statistics, a systematic approach, and methods of comparative analysis were used. Information processing and analysis methods were also used, including sociological, organoleptic, physicochemical, microbiological and instrumental methods.

MATERIAL AND METHODOLOGY

According to world experience, and research by domestic and foreign scientists, there are two directions for increasing the nutritional value and digestibility of combined feeds: by introducing various enriching and balancing additives and premixes into the combined feed, as well as through such types of moisture-heat treatment of grain components of combined feed as extrusion, expansion, micronization **[4]**, **[5]**, **[6]**.

During expansion, the product is subjected to temperature treatment from 80 to 130 °C and pressure up to 40 MPa, depending on the product type, but for a concise period, since the total duration of the product passes through the expander is no more than six seconds. Processing parameters such as humidity, temperature, pressure, and flow rate affect the physical characteristics in the expander **[7]**, **[8]**, **[9]**. During expansion, the product is also subjected to short-term (4 – 5 sec) thermal steam exposure, followed by compression in the expander to a pressure of 3.0 MPa. At the expander's exit, the product's melt falls into the low-pressure area. At this moment, the product appears to swell, connections at the cellular level are broken, starch is modified, and the availability of carbohydrates for the action of digestive enzymes increases **[10]**, **[11]**.

The main task of expansion is to obtain homogeneous products with a narrow range of sizes **[12]**, **[13]**. The expansion process ensures the destruction of pathogenic bacteria, prevents the development of pathogenic microflora, mould, etc., partial hydrolysis of starch, and preservation of natural and injected vitamins. This follows based on the analysis of the works of Sharshunov V. A., Shirov Yu. P., Lukhta N. V. and other authors **[14]**, **[15]**, **[16]**, **[17]**.

The product processing process in the expander takes place in four zones. The product is mixed and moved along the screw in the I zone, and its compaction begins. In zone II, there is an increase in pressure, compression, and destruction of particles. In zone III, a further pressure increase and temperature increase, and the product passes into a viscoplastic state (into a melt). And finally, in the IV zone, the melt is forced through the holes of the output head (Figure 1).

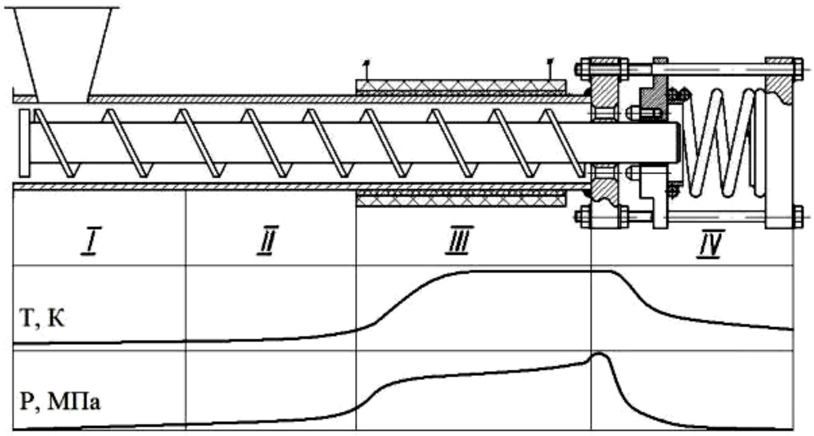


Figure 1 Product processing zones in the expander and combined dependences of temperature and pressure changes of raw materials during movement in the expander working chamber.

Samples

Protein supplement based on a mixture of legumes and oilseeds; amino acid composition of highly digestible combined feeds of a new generation with programmable properties; components of combined feeds to increase nutritional value and reduce antinutritional factors, subject to special heat treatment.

Chemicals

Determination of the chemical composition of the feed (mass fraction of protein, starch and fiber content, and ash content).

Animals and Biological Material

Farm animals were used to implement the study. All animal care procedures were carried out following the Guidelines for the Maintenance and Care of Animals. The animals were provided with food and water. A 12-hour light-dark cycle was maintained in the room. Temperature (22 ±2 °C) and humidity (55 – 60%) were monitored daily.

The measures envisaged in the framework of our study were implemented following humanity towards animals and high ethical standards concerning their well-being.

Instruments

The Chopin Alveograph (France), Farinograph-AT company Brabender (Germany), Case drying SESh-3M (Russian Federation), and The Infrascan-105 "KAN" analyzer (Russian Federation) were used in this research.

Laboratory Methods

The research was carried out at the Kazakh-Japanese Innovation Center (hereafter – KJIC) of the Kazakh National Agrarian Research University. KJIC allows carrying out fundamental, exploratory, and applied scientific research in various branches of the agro-industrial complex. By Order No. 228-OD dated 03/18/2020, the National Accreditation Center LLP KJIC was accredited for compliance with the ST RK ISO/IEC 17025-2018 "General requirements for the competence of testing and calibration laboratories".

Scientific equipment and unique scientific stands and installations of the centre for collective use, "Control and Management of Energy-efficient Projects", located at the Voronezh State University of Engineering Technologies, were also used.

The sequence of research: the implementation of a literary review and patent search, justification of the choice of the sequence of technological operations in the developed technology for the production of highly digestible combined feeds of a new generation with programmable properties, the study of kinetic patterns of the processes under study, justification of the choice of rational parameters, the development of the compounding composition of combined feeds, conducting a comprehensive assessment of the quality of combined feeds for various types of farm animals.

Description of the Experiment

Number of samples analyzed: We analyzed 30 samples.

Number of repeated analyses: Repeated analyses = 3.

Number of experiment replication: Triple.

Design of the experiment: The most important experiments of such basic processes as mixing of the main feed components, their moisture-heat treatment (humidification and steaming with hot steam), extrusion, drying-cooling, and vacuum spraying of liquid components on the surface of extruded granules were carried out at the original installations. In the course of the research, the main kinetic patterns of the processes under study were identified, and the most significant factors affecting the intensity and efficiency of their course were determined. The nature of the influence of the most significant factors on the change of the following main technological parameters is also established: 1) the uniformity of the distribution of the components of the mixture and the influence on the kinematic and design parameters of the mixer for the mixing process; 2) the nature of the temperature and pressure changes along the length of the working chamber of the extruder for the extrusion process; 3) the nature of the change in temperature and humidity of the extruded granules for the drying-cooling process and 4) the nature of the change in pressure (vacuum) in the working chamber of the vacuum sprayer and the intensity of diffusion of liquid components deep into the porous granules for the vacuum spraying process.

The methodological basis of the research includes a complex of general scientific (analysis and synthesis, verification of the truth of theory by referring to practice, interpretation of the results obtained, etc.) and private, scientific (abstract-logical method, modelling, empirical method, statistical-probabilistic method, etc.) methods of cognition.

IR spectroscopy, atomic absorption spectroscopy, capillary electrophoresis, high-efficiency gas chromatography, acid hydrolysis, etc., were used to determine the content of vitamins, amino acids, and other quality indicators of highly digestible combined feeds **[7]**, **[26]**, **[27]**, **[28]**.

Basic information was obtained on the original installations to study the processes of moisture-heat treatment (humidification and steaming), extrusion, drying-cooling, and vacuum spraying to solve the project's tasks.

The obtained information arrays of experimental data were processed using modern software products (Mathcad, Statistica, etc.) to ensure their reliability and reproducibility.

Scientific statements, conclusions, and recommendations are based on fundamental physical laws. They are consistent with the theoretical concepts generally accepted in this field of research. The reliability of the research and the results of the conducted research are based on proven mathematical methods. The calculated ratios obtained are subjected to thorough experimental verification. At the same time, we rely on the experimental data we have obtained and the kinetic regularities of the processes under study (mixing, moisture-heat treatment, extrusion, drying-cooling, vacuum spraying). All scientific statements, conclusions, and recommendations are substantiated and confirmed by experimental studies and fully comply with the data of the experimental protocols.

The degree of reliability of the results of the conducted research is confirmed by a deep study of the literature sources on the topic of research, the formulation of the necessary number of experiments, and the use of modern instrumental methods of analysis. Applied computer programs are used for the mathematical processing of research results.

Statistical Analysis

The ultimate goal of the study is to create a new-generation highly digestible combined feed with controlled properties due to the use of the technology of effective use of thermomechanical treatment of components of combined feed by expandation. To achieve the aim of the study, generally accepted and special methods of mathematical statistics, a systematic campaign, and comparative analysis methods were used. Information processing and analysis methods, such as sociological, organoleptic, physicochemical, microbiological, and instrumental, were also used.

RESULTS AND DISCUSSION

The processing of grain and other components of combined feed in extruders provides a profound transformation of the structure and properties of materials. There is complete gelatinization of starch, the content of dextrins and other low-molecular carbohydrates increases, and the attack of proteins by enzymes increases; all of this contributes to complete assimilation of the nutrients of the combined feed and with less energy consumption for the digestive process. The range of components of combined feeds and ready-made extrudates is expanding significantly.

However, the extrusion process requires high energy consumption: its specific consumption is 120 – 150 kWh/t. Therefore, specialists were actively searching to develop an equally effective but a less energy-intensive variant of thermomechanical processing of products, including feed production. The result of this search was the development of a new expander device. The principle of operation of the expander and its basic design is similar to an extruder. The difference is that the product is pressed out not through a die with dies but through an annular gap, the value of which is regulated by a special hydraulic system. Steam is supplied to the expander casing, which also provides the product's heating.

Due to such changes, the specific energy consumption for expansion is reduced by 2.0 – 2.5 times compared to extruded and is 25 – 60 kWh per 1 ton of raw materials.

An additional advantage of the expander is introducing up to 20% fat and up to 20% molasses into the expander. In contrast, the fat input cannot be higher than 5% during extrusion because the extrudate granules lose connectivity and crumble.

The pressure in the expander reaches 10 MPa. The product is heated to 170 °C. As a result, starch is completely gelatinized and hydrolyzed, proteins are denatured and split, and organic complexes of proteins and fragments of starch molecules are also formed. The nutritional properties of the exhibit are high.

In total, the advantages of the technology that uses the expander are as follows **[1]**, **[2]**, **[3]**, **[4]**:

– the quality of the granule is improved primarily in the case of hard-pressed components;

– less energy is spent on the production of the expandate (product expansion), and the cost of the product is lower than conventional pellets;

– the expandate (product expansion), as a rule, can be used directly instead of granulated combined feed;

– it becomes possible to introduce a large amount of feed fat, molasses, fish hydrolysate, and liquid protein feeds into the combined feed;

– during the expansion process, vitamins and other biologically active additives are not destroyed, and their feed value is preserved in the expected order of magnitude;

– salmonella, bacteria, and fungi are destroyed, and the combined feed is obtained free of microbial contamination;

– starch is completely gelatinized, and its macromolecules are split into low-molecular fragments, as a result of which the nutritional value of the combined feed increases significantly;

– the activity of proteinase inhibitors in those products where they are contained (soy and other legumes) is sharply reduced; this allows the use of legumes in a significant amount as components of combined feeds, providing the necessary protein content in the combined feed;

– due to the high sanitary purity of the combined feed, the use of any preservatives is not required.

In addition, expanders require a small area for their placement, so they can be used in most feed mills or workshops.

Thus, according to domestic and foreign experts, expanders are currently the most economical and efficient way to produce combined feeds, compared to extrusion and double granulation.

The advantage of expanded products is the shape of small or medium grits, which allows you to reduce product losses during transportation and feeding. The sterilization of products achieved during the expansion process is critical in conditions of unstable sanitary quality of raw materials arriving at factories **[18]**, **[19]**. The creation of innovative technology for the production of expanded combined feeds adapted for various animals will increase the requirements for the quality of combined feeds, and broaden the range of raw materials and the product range **[20]**, **[21]**. A new method of moisture–heat treatment of grain crops - expansion or pressure conditioning ("High-Temperature-Short–Time Conditioning") - short-term hydrothermal treatment of grain in an expander, which allows you to get an expanded structured product ready for use, has become increasingly popular in recent years **[7]**, **[8]**, **[9]**. The principle of operation of the expander is similar to that of an extruder, but the product is pressed out not through the holes of the matrices, but into an annular gap. An auger is installed on the expander, with the help of which the product is moved and additionally warmed up due to friction forces up to 85 – 100 °C **[12]**, **[13]**, **[14]**. The compressed product is discharged through a conical diffuser equipped with a locking cone, which regulates the value of the output annular gap and the value of the working pressure on the product. At the exit of the expander, as a result of a sharp pressure drop, the moisture in the product evaporates, and the product increases slightly in volume. In addition, the expanded combined feed is subjected to coarse grinding on a blade crusher and sent for granulation or cooling **[19]**, **[21]**. The main technological and market trends in the industry under consideration are the following leading Western and Russian firms (Amandus Kahl (Germany), Sprout-Matador (Denmark), Zheng Chang (China), Buhler (Switzerland), Wenger, April, TRONKA-AGROTECH, Arsenal, etc.) **[22]**, **[23]**, **[24]**, **[25]**, **[26]**.

Scientists from many countries of the world have conducted a number of studies on the splitting of starch during grain processing on various types of equipment, proving the preferential properties of expandate (product expansion) as an expansion product. The splitting of starch improves digestion in animals. Therefore, the problem of starch splitting is most relevant to piglets.

A large proportion of the split starch allows piglets to digest starch even before it enters the colon – thereby eliminating the cause of diarrhea, and the stabilization of the gastrointestinal tract is especially important for small animals.

Figure 2 shows the indicators of the degree of starch cleavage during expansion. The splitting of starch helps to improve digestion in animals **[27]**, **[28]**, **[29]**.

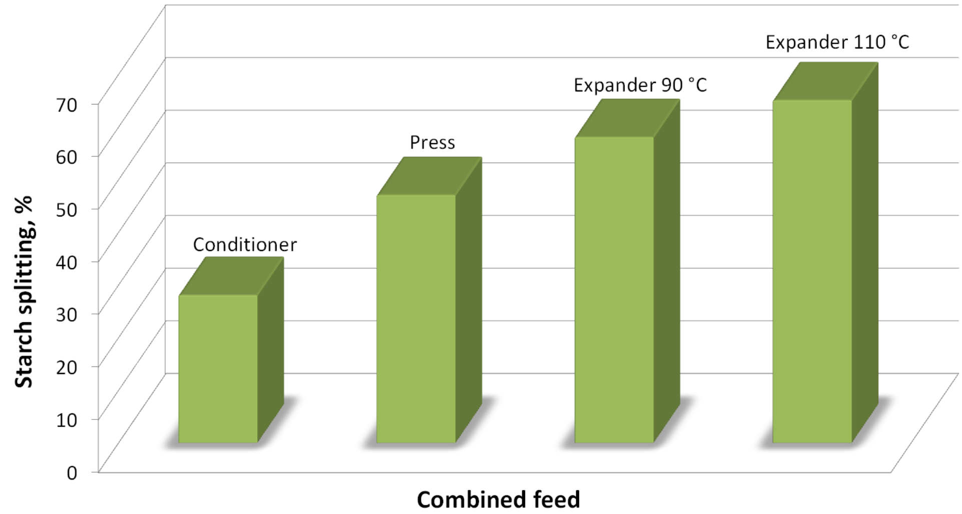
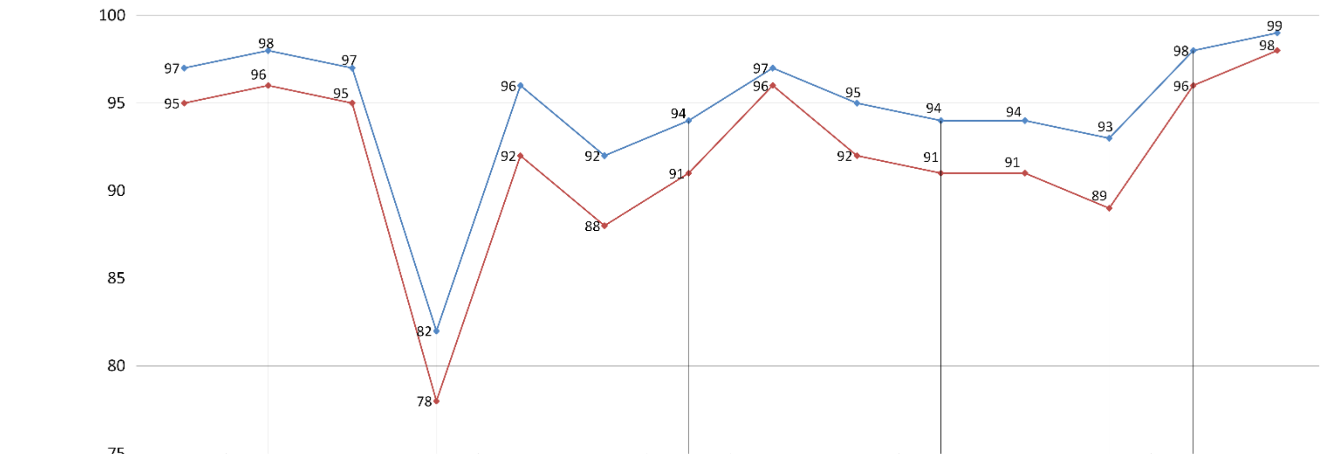


Figure 2 Dependence of starch splitting during processing on various types of technological equipment.

The disinfection principle is based not only on heat treatment but also on the dynamic effect during the passage of the product through the working area of the expander.

The expansion process affects the safety of biologically active substances introduced into combined feed with premix. First of all, this applies to the vitamin complex.

Figures 3-5 show the residual activity of vitamins in the expanded combined feed with various processing methods.



	A encapsulated	D_3 encapsulated	E acetate	K_3	B_1 mononitrate	B_2 riboflavin	B_6 pyridoxine	B_{12} cobalamin	Pantothenic acid	Folic acid	Biotin	Niacin	C Ascorbic acid phosphate	Choline Chloride
Expander 101-105 ºC	97	98	97	82	96	92	94	97	95	94	94	93	98	99
Expander 111-115 ºC	95	96	95	78	92	88	91	96	92	91	91	89	96	98

Figure 3 Residual activity of vitamins after feed processing on the expansion, %.

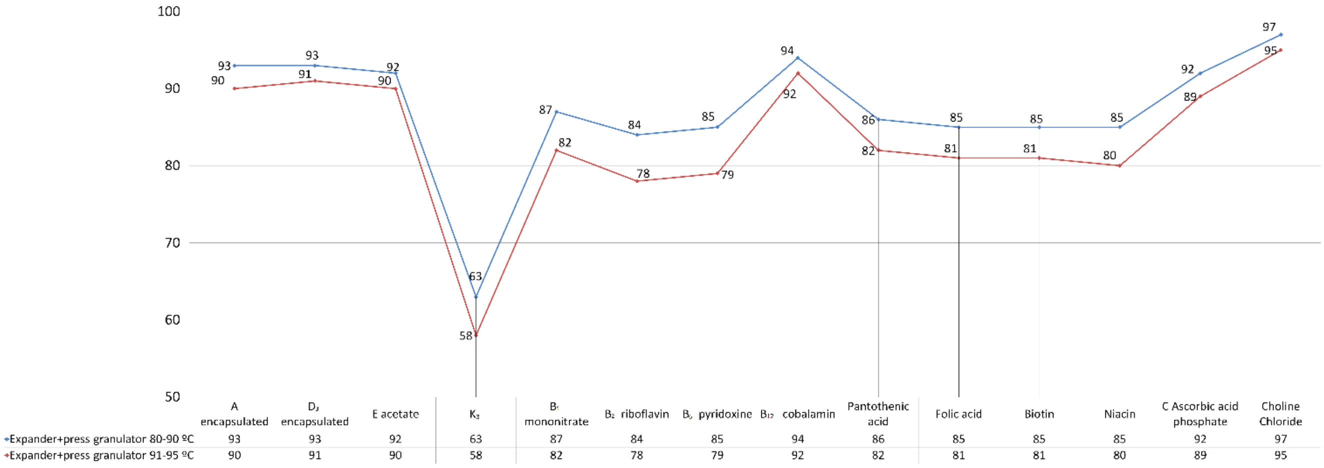


Figure 4 Residual activity of vitamins after feed processing on expansion+ pressing + granulation, %.

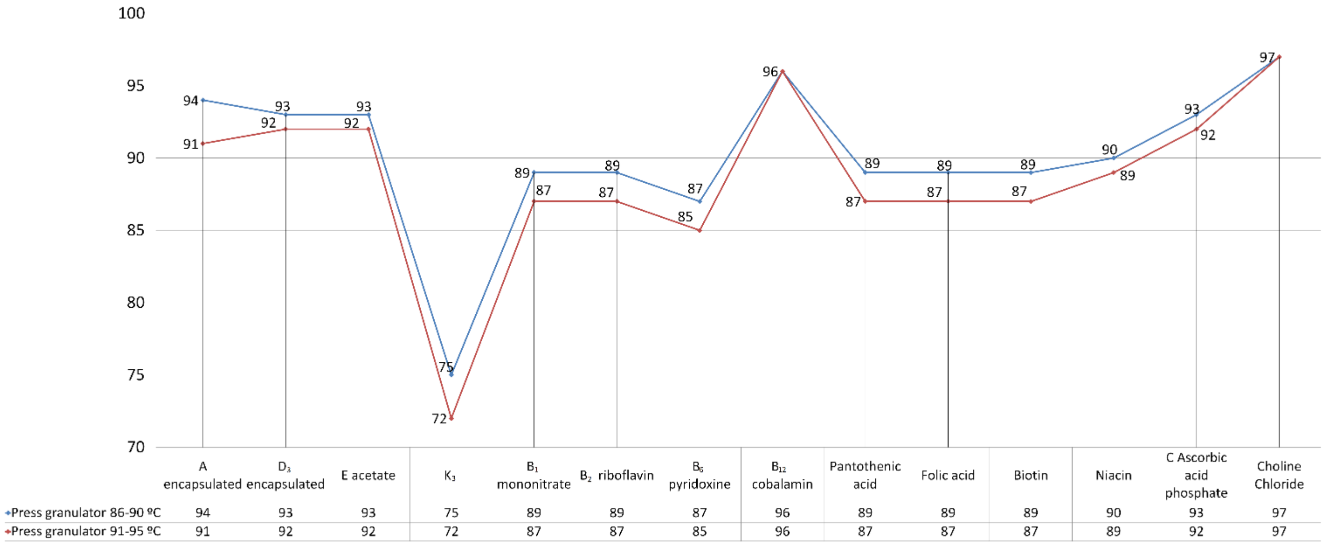


Figure 5 Residual activity of vitamins after feed processing on a granulation + pressing, %.

An analysis of the dependency graphs in Figures 3, 4, and 5 shows the following. The residual activity of vitamins (in %) was established during the expansion of combined feeds in comparison with other methods of feed processing. For example, when expanding (Figure 3) combined feeds at a temperature of 101 – 105 °C, the residual activity of most vitamins ranges from 92 to 99%, except for vitamin K_3, the residual activity of which is 82%. And suppose the expansion process of combined feeds is carried out at a temperature of 111 – 115 °C. In that case, the residual activity of most vitamins ranges from 88 to 98%, except for vitamin K_3, the residual activity of which is 78%.

The above indicators of the residual activity of vitamins during the expansion of the combined feeds differ favorably compared to the processing of feed by expansion-pressing granulation (Figure 4) at appropriate temperatures of 80 – 90 °C and 91 – 95 °C. The same difference is observed compared to feed processing of feed by pressing granulation (Figure 5) at the corresponding temperatures of 86 – 90 °C and 91 – 95 °C.

Another proof of the high efficiency of expansion is the determination of the stability of biologically active components (amino acids) after expansion. Figure 6 shows the content of amino acids before and after expansion under different temperature conditions of feed processing.

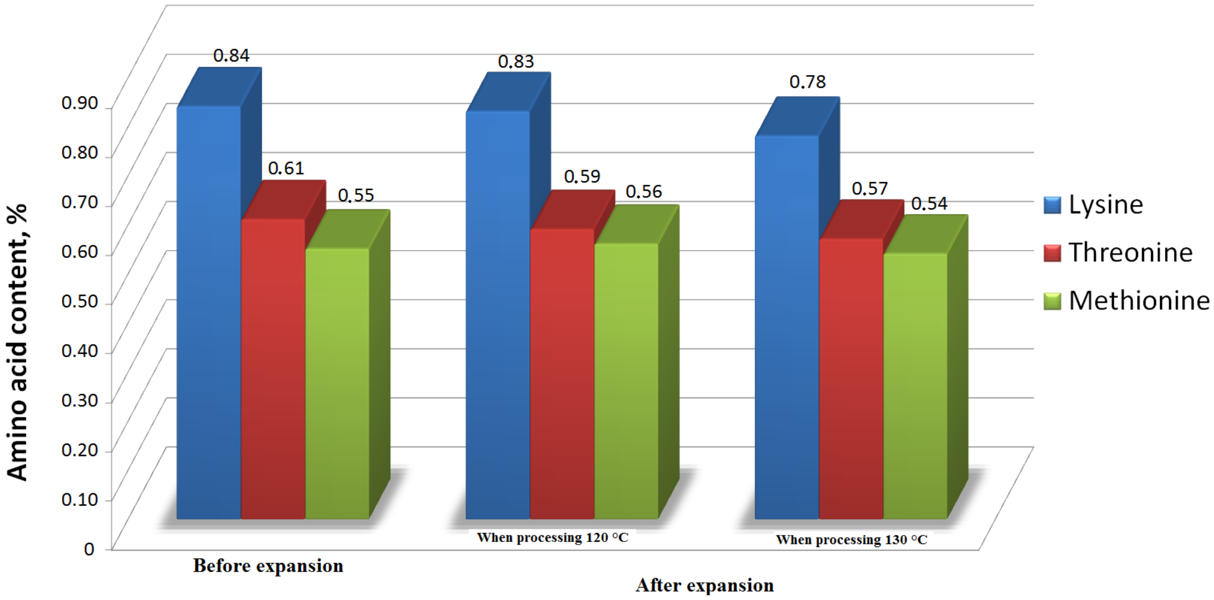


Figure 6 Amino acid content before and after expansion.

The economic efficiency of expanded combined feeds compared to similar loose, and granular combined feeds are confirmed by the following results of our studies on fattening pigs (from 9 to 30 kg) with various combined feeds (Table 1) and feeding laying hens with various combined feeds (Table 2) **[7]**, **[20]**.

Table 1 Indicators of pig fattening (from 9 to 30 kg) with various combined feeds.

Indicators	Loose combined feed	Granular combined feed	Expanded combined feed
Feed consumption, g/day	1007	955	922
Increase in body weight, g/day	473	470	476
Feed costs per 1 kg of weight gain	2.13	2.03	1.94

The economic efficiency when fattening pigs with expanded combined feeds compared to loose and granular combined feeds is as follows (Table 1): feed consumption (g/day) – with expanded combined feed 922 g/day, while with loose and granular combined feed 1007 and 955 g/day, respectively; increase in live weight (g/day) – 476 g/day, 473 and 470 g/day, respectively; the use of feed per 1 kg weight gain is with expanded combined feed 1.94, whereas with loose and granular combined feed 2.13 and 2.03, respectively.

Table 2 Results of feeding laying hens with various combined feeds.

Indicators	Loose combined feed	Expanded combined feed
Number of eggs	289	302
Egg weight, g.	18.11	18.65
Feed consumption, g/day	115.9	108.6

When feeding laying hens with expanded combined feed compared to loose combined feed, the following results were obtained (Table 2): an increase in the number of eggs by 13 more, by weight of eggs by 0.54 g more. At the same time, the savings in feed consumption are 7.3 g/day.

At the same time, there are several misconceptions in the literature about the negative impact of expansion. These misconceptions are explained by the fact that at high temperatures of 150-240 °C and prolonged exposure to them, the protein content in the grain decreases, as well as the availability of lysine decreases **[5]**, **[10]**, **[21]**. At the same time, the operating temperature of the expander is 80-130 °C, and the processing time is no more than 6 seconds **[8]**, **[12]**, **[22]**. Short-term processing at high temperatures means better assimilation of the combined feed, which affects the fattening indicators. This experience was confirmed by research conducted by the University of Göttingen, one of the Saxony feedlots **[11]**, **[12]**.

It is also known that feeding the exhibit leads to a significant decrease in drinking water consumption, manure, and a decrease in nitrogen content in manure. It is also essential that is possible to obtain a "coarse grinding" structure when expanding.

Thus, the final result of our research is the creation of a new generation of highly digestible combined feeds with adjustable properties through the use of technology for the effective use of thermomechanical processing of components of combined feeds by the expansion method.

CONCLUSION

The use of expandate (product expansion) produced due to thermomechanical processing of components of combined feeds by the expansion method is promising and has significant advantages. The utilization rate of expanded combined feed per 1 kg of weight gain compared to loose combined feeds increases by 9%. The expansion process affects the safety of biologically active substances introduced into the combined feed with the premix. This applies primarily to the vitamin complex. We have established the residual activity of vitamins (in %) during the expansion of combined feeds compared to other feed processing methods. So, for example, when expanding the combined feed at a temperature of 101 – 105 °C, the residual activity of most vitamins ranges from 92 to 99%, except for vitamin K_3, the residual activity of which is 82%. And suppose the expansion process of the combined feed is carried out at a temperature of 111 – 115 °C. In that case, the residual activity of most vitamins ranges from 88 to 98%, except for vitamins K_3, the residual activity of which is 78%. The above indicators of the residual activity of vitamins during the expansion of combined feeds differ favorably in comparison with the processing of feed by expansion + pressing-granulation at appropriate temperatures of 80 – 90 °C and 91 – 95 °C and with the processing of feed by pressing-granulation at appropriate temperatures of 86 – 90 °C and 91 – 95 °C. The economic efficiency of expanded combined feeds compared to similar loose, and granular combined feeds is confirmed by our research results on fattening pigs (from 9 to 30 kg) with various combined feeds and feeding laying hens with various combined feeds. The economic efficiency when fattening pigs with expanded combined feeds compared to loose and granular combined feeds is as follows: feed consumption (g/day) – with expanded combined feed 922 g/day, while with loose and granular combined feed 1007 and 955 g/day, respectively; increase in live weight (g/day) – 476 g/day, 473 and 470 g/day, respectively; the use of feed per 1 kg weight gain is with expanded combined feed 1.94, whereas with loose and granular combined feed 2.13 and 2.03, respectively. When feeding laying hens with expanded combined feed, compared with loose combined feed, the following results were obtained: an increase in the number of eggs by 13 pcs more, by the weight of eggs by 0.54 g more. At the same time, the saving of feed consumption is 7.3 g/day. The final result of our research is the creation of a highly digestible combined feed of a new generation with adjustable properties through the use of technology for the effective use of thermomechanical processing of components of combined feeds by the expansion method.

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