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USE OF MUSHROOM WASTE TO INCREASE ANIMAL PRODUCTIVITY

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This article presents the results of research on the effectiveness of a feed additive based on a spent mushroom substrate aimed at improving animal productivity and health. The experiments were conducted on rabbits and dairy goats.

During the experiment, the effect of a mushroom substrate additive on the body weight of rabbits was studied. The experiment revealed that rabbits from the experimental group showed an average body weight gain up to 3.06 ± 0.27 kg, which is 18.6% of the initial weight. A significant body weight gain is the evidence of the positive effect of a feed additive on the animal development and digestive process. In contrast to the experimental group, the control group, receiving a traditional diet, showed a decrease in body weight by 1.9%, which indicates a possible insufficient supply of essential nutrients.

The research conducted on dairy goats of the Kamori breed using feed containing spent mushroom substrate showed a noticeable increase in milk fat content from 3.03 to 5.93%, which is 2.9% higher than the baseline indicators. These results indicate that the mushroom substrate not only improves animal growth rates but can also significantly increase the milk producing ability.

The research findings indicate that spent mushroom substrate can be effectively utilized as a feed component to enhance the productivity and health of farm animals, presenting promising opportunities for its integration into feeding practices.

Keywords: *mushroom substrate, mushroom waste, waste-free production, oyster mushroom, productivity, extrusion.*

МАЛ ӨНІМДІЛІГІН АРТТЫРУ ҮШІН САҢЫРАУҚҰЛАҚ ШАРУАШЫЛЫҒЫ ҚАЛДЫҚТАРЫН ПАЙДАЛАНУ

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Мақалада жануарлардың өнімділігі мен денсаулығын жақсартуға бағытталған пайдаланылған саңырауқұлақ субстраты негізіндегі азық қоспасының тиімділігі туралы зерттеу нәтижелері ұсынылған. Эксперименттер қояндар мен сауын ешкілерге жүргізілді.

Жүргізілген тәжірибе барысында саңырауқұлақ субстраты қоспасының қояндардың дене салмағына әсері зерттелді. Нәтижелер бойынша, тәжірибелік топтағы қояндар дене салмағының орташа өсімін 3.06±0.27 кг дейін жеткізіп, бастапқы салмағынан 18.6%-ға арттырды. Дене салмағының едәуір өсуі, азық қоспасының ас қорыту мен жануарлардың дамуына оң әсер ететінін көрсетті. Ал дәстүрлі рацион алған бақылау тобы дене салмағының 1.9%-ға төмендегенін көрсетті, бұл қажетті қоректік заттардың жеткіліксіздігін көрсетуі мүмкін.

Камори тұқымды сауын ешкілеріне пайдаланылған саңырауқұлақ субстраты бар азықты қолдану арқылы жүргізілген зерттеу сүттің майлылығын бастапқы 3.03%-дан 5.93%-ға дейін арттырғанын анықтады, бұл бастапқы көрсеткіштен 2.9%-ға жоғары. Бұл нәтижелер саңырауқұлақ субстраты жануарлардың өсу көрсеткіштерін жақсартып қана қоймайды, сонымен қатар сүт өндіруді айтарлықтай арттыра алады.

Зерттеу нәтижелері пайдаланылған саңырауқұлақ субстратын ауылшаруашылық жануарларының өнімділігі мен денсаулығын жақсарту үшін жемшөп компоненті ретінде тиімді пайдалануға болады деген қорытындыға келеді, бұл оны азықтандыру тәжірибесіне және қалдықсыз саңырауқұлақ өндірісіне енгізуге мүмкіндік береді.

Түйінді сөздер: *саңырауқұлақ субстраты, саңырауқұлақ қалдықтары, қалдықсыз өндіріс, кәдімгі аспа саңырауқұлағы, өнімділік, экструдтау.*

ИСПОЛЬЗОВАНИЕ ОТХОДОВ ГРИБОВОДСТВА ДЛЯ ПОВЫШЕНИЯ ПРОДУКТИВНОСТИ ЖИВОТНЫХ

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В статье представлены результаты исследований эффективности кормовой добавки на основе отработанного грибного субстрата, направленной на улучшение продуктивности и здоровья животных. Эксперименты проведены на кроликах и дойных козах.

В ходе проведенного эксперимента было изучено влияние добавки из грибного субстрата на массу тела кроликов. По итогам эксперимента было установлено, что кролики из опытной группы показали средний прирост массы тела до 3,06±0,27 кг, что составляет 18,6% от исходного веса. Значительный рост массы тела является свидетельством положительного влияния кормовой добавки на процесс пищеварения и развитие животных. В отличие от опытной, контрольная группа, получавшая традиционный рацион, продемонстрировала снижение массы тела на 1,9%, что указывает на возможное недостаточное обеспечение необходимыми питательными веществами.

Исследование, проведенное на дойных козах породы Камори с использованием корма с содержанием отработанного грибного субстрата, показало заметное повышение жирности молока с 3,03 до 5,93%, что на 2,9% выше первоначальных показателей. Эти результаты свидетельствуют о том, что грибной субстрат не только улучшает показатели роста животных, но и может значительно повышать молочную продуктивность.

Результаты исследования позволяют сделать вывод о том, что отработанный грибной субстрат может быть эффективно использован в качестве кормового компонента для повышения продуктивности и здоровья сельскохозяйственных животных, что открывает перспективы для его внедрения в практику кормления и безотходного грибного производства.

Ключевые слова: *грибной субстрат, отходы грибоводства, безотходное производство, вешенка обыкновенная, продуктивность, экструдирование.*

Introduction. The mushroom industry generates a virtually inexhaustible supply of a by-product called spent mushroom substrate (SMS). It is a mixture of lignocellulosic waste and residual mushroom mycelium that remains after harvesting [1, p. 865]. SMS is classified as agricultural waste and is often either landfilled, incinerated, or improperly disposed of, preventing the full utilization of its unused nutrients and mycelium [2, p. 3].

The raw materials for mushroom substrates are the same feed ingredients as corn cobs, brown rice, brown wheat, cotton seeds, and beet pulp. During the mushroom cultivation process,15-25% of the mushroom substrates are used by mushrooms, and 75-85% of the nutrient material remains in the spent mushroom substrates [3, p. 238]. Depending on the nature of the materials used for substrate preparation, the type of production system and the species cultivated, 1 kg of fresh mushrooms produces between three and five kg of SMS [4, p. 401]. In total, the mushroom industry produced approximately 64 million tons of SMS worldwide in 2018, and this figure may exceed 100 million tons by 2026. Lack of adequate waste management and poor disposal of this waste may lead to soil and water pollution and other types of environmental destruction [5, p.1]. To achieve progress and transform the organic waste generated in the edible mushroom industry, it is necessary to accelerate the global application of recycling and disposal. The global mushroom business currently faces a significant challenge in finding an effective and reasonable method of recycling this waste [6, p. 641]. The solution to this problem may be to explore new areas of SMS application, such as the production of feed, fertilizers, adsorbents, etc. [7, p. 41].

The high cost of animal feed poses a significant challenge to animal husbandry. As a result, the use of agro-industrial by-products as alternative feed resources is a practical approach in low-input systems. This strategy aims to overcome the problem of expensive conventional feeds and provide a cost-effective solution for livestock breeders [8, p. 3]. The benefits of feeding animals with mushroom waste are not limited to its nutritional value but are also associated with the bioactive compounds present in mushroom waste [9, p. 2].

Oyster mushrooms contain bioactive ingredients such as polysaccharides, β-glucans, peptides, lectins, phenolic compounds, and terpenoids. These ingredients are reported to have various health-promoting properties such as antimicrobial, anticancer, antioxidant, cholesterol-lowering, antihyperglycemic, and immunomodulatory effects, which have been confirmed in many in vitro and laboratory animal studies [10, p.104054].

Taking these facts into account, the study aims to evaluate the possibility of using spent mushroom substrate based on the oyster mushroom (*Pleurotus ostreatus*) in rabbits in terms of growth performance, as well as to study the effect of quality indicators of goat milk and biochemical profile of animals.

Theoretical and practical significance. The theoretical basis of the study contributes to the development of alternative feeds that can improve animal metabolism and productivity. The use of mushroom production waste as a feed additive allows to reduce feed costs, which can lead to an increase in animal husbandry profitability. The use of such additives can also reduce the need for synthetic additives and vitamins, which is economically beneficial for farmers. Reuse of spent mushroom substrate in feeding contributes to the utilization of agricultural waste, which can reduce the negative impact on the environment and improve the sustainability of agricultural systems.

The research purpose is to develop an effective feed formulation based on the mushroom waste utilization – spent mushroom blocks, in order to increase milk and meat productivity of animals and reduce the costs of feed production.

Research objectives:

- to develop a feed additive formulation based on spent mushroom substrate,
- to study the chemical composition of the feed additive,
- to evaluate the effect of the developed feed additive on meat productivity and milk quality indicators,
- to determine the relationship between the use of mushroom substrate and goat health indicators.

Research materials and methods. The feed additive based on spent mushroom substrate was manufactured in the production and testing workshop of NFT-KATU LLP at the facilities of the Faculty of Veterinary Science and Animal Husbandry Technology of the S.Seifullin Kazakh Agro Technical Research University Non-Profit Joint Stock Company.

Research and production studies were conducted on Flanders rabbits and Kamori dairy goats.

Groups of animals were formed according to the principle of pairs of analogues, taking into account age, body weight, breed and gender, which allowed minimizing the impact of individual differences on the experiment results. The number of animals in the groups (5 males) was selected based on limited resources, but the results can be used for preliminary conclusions. The method described in the manual "Research methods in feed production and feeding of farm animals" was used [11, p. 16]. The animals were kept in the cages of 90 × 60 × 45 cm, while the microclimate parameters remained the same for all groups. The duration of the experiment was 30 days. The study involved clinically healthy animals: their breathing was rhythmic, visible mucous membranes were pale pink, the rabbits ate food heartily.

The diet of the control group included a grain mixture (barley, oats, wheat) in a ratio of 1:1:1 in the amount of 100 g per head and hay in the amount of 80 g per head. Rabbits in the experimental group received an extruded grain mixture consisting of wheat, barley, oats and 20% mushroom flour. The feed mixture introduction rate was 100 g per head per day; hay was fed in the same quantity as in the control group.

The chemical composition of the prepared extruded supplement was as follows: protein content – 17.5%, fat – 6.5%, moisture – 13.9%. To control weight, animals were individually weighed every 7 days.

The production studies on goats were conducted at “Semenova” IE’s base. In circumstances disabling to divide animals into groups, it was decided to study the effect of enriched feed on milk quality parameters in one group of animals before and after the experiment (n=10).

The feed included extruded wheat, barley and flax, tricalcium phosphate, premix, phytobiotic BioFeed-P, wormwood extract, table salt and mushroom flour, which constituted 15%. The chemical composition of the feed was as follows: protein content – 14.5%, fat – 5.6%, cellulose – 7.79%, ash – 5.01%, starch – 48.48%. Organoleptic analysis of goat milk was performed in accordance with ST RK 1732-2007 «Milk and dairy products. An organoleptic method for determining quality indicators». The physico-chemical parameters of the milk were determined using the «Expert Super Plem Combo» milk analyzer, and the organoleptic parameters were determined using generally accepted methods in accordance with the current TR CU 033/2013 «On the Safety of milk and dairy Products». The duration of the experiment was 30 days. To assess the homeostasis of the animals’ bodies, a biochemical blood test was performed using a SMT-120V veterinary biochemical analyzer (Chengdu Seamaty Technology Co., China), and a daily visual assessment of the clinical condition of the goats was carried out.

Statistical data were summarized and analyzed using Microsoft Office Excel 2021. The methods described in the manual on the application of statistical methods "Modern statistical analysis of scientific research results in Excel" were used to analyze the results [12, p. 94].

Results. *Experiment on rabbits*

At the beginning of the experiment, the average live weight of rabbits in the experimental group was 2.67±0.25 kg, while in the control group this figure was 2.63±0.19 kg. By the end of the experiment, the weight of rabbits in the experimental group increased to 3.06±0.27 kg, which is 18.6% higher than the value observed in the control group. At the same time, a decrease in the weight of rabbits by 1.9% was noted in the control group. Nevertheless, the weight parameters recorded in both groups correspond to the minimum requirements for the live weight of rabbits of different breeds [13, p. 234].

The results obtained for the live weight of rabbits before and after the experiment are presented in Figure 1, and for weight gain – in Table 1.

Table 1 – Results of live weight gain in rabbits

Indicator	Control group	Experimental group
Live weight before the experiment, kg	2.63±0.19	2.67±0.25
Live weight after the experiment, kg	2.58±0.22	3.06±0.27
Absolute live weight gain, g	-0.05	+39.0
Relative live weight gain, %	-1.90	+14.6
Daily live weight gain, g	-0.001	+0.013

Table 1 shows that the absolute weight gain of rabbits when including feed with the addition of mushroom substrate in the diet was 39 g, while in the control group there was a negative dynamic, i.e. a weight loss of 1.9%. The relative live weight gain in the experimental group was 14.6%.

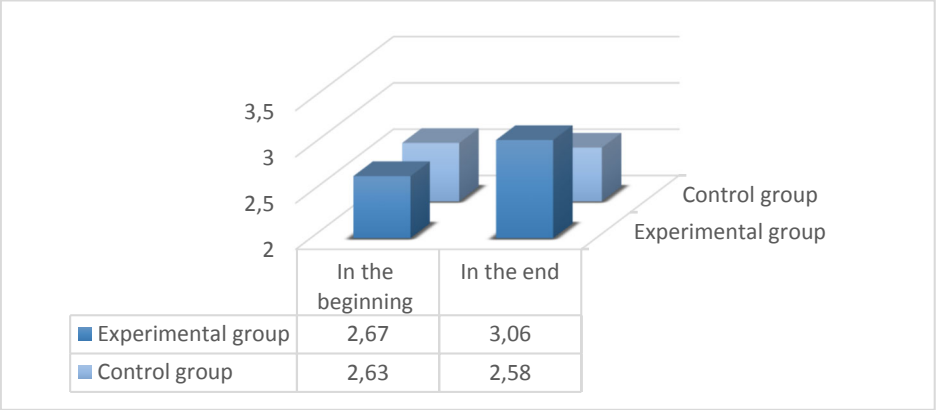

Figure 1 – Live weight of rabbits before and after the experiment, kg

The increase in body weight of rabbits in the group fed with the feed with the addition of mushroom waste can be explained by several factors. Firstly, in order to disinfect mushroom waste, it was mixed with grain components and extruded. Secondly, mushroom waste contains substances that improve the digestion and absorption of nutrients, which leads to increased bioavailability of nutrients and, as a result, to an increase in body weight. The degree of digestibility of mushroom protein reaches 90%. The content of total nitrogen in oyster mushroom is 2.4%, total proteins – 15%, iron – 0.0015%, phosphorus – 1.35%, potassium – 3.79% (from dry weight). In terms of vitamin content, oyster mushroom is at the level of meat products, and in terms of the amount of pantothenic acid, it surpasses vegetables, fruits, meat, milk and fish. In terms of biotin content, oyster mushroom is one of the richest products in this vitamin (8-76 μg/100 g). In terms of vitamin PP content, which improves blood circulation, prevents the formation of blood clots in blood vessels and improves the functioning of the liver and stomach, oyster mushrooms have no equal among cultivated mushrooms [14, p.454].

Probably, the absence of lignin in cellulose (due to its use by mushrooms), enrichment with mycelial protein and mushroom vitamins of oyster, contributes to the improvement of metabolism, acceleration of the growth process and increase in fat and muscle mass of animals.

In the control group, where the rabbits received a grain mixture as a concentrate, there could be an insufficient supply of necessary nutrients, which contributed to the decrease in the body weight of rabbits in the control group.

Thus, the difference in the dynamics of body weight gain between the experimental and control groups is due to both the biological properties of mushroom waste, feed manufacturing technology, as well as the nutritional value of the diet provided to the animals in each group.

Experiment on goats

The organoleptic parameters of milk for the entire period of the experiment corresponded to the requirements of TR CU 033/2013 «On the safety of milk and dairy products» and ST RK 1732-2007 «Milk and dairy products. An organoleptic method for determining quality indicators» (Table 2).

Table 2 – Organoleptic parameters of milk

Indicators	Characteristic
Appearance and consistency	Homogeneous liquid without sediment and protein flakes
Smell	Clean, without foreign odors, not peculiar to fresh goat's milk
Color	Light cream

The results of the experiment indicate a significant increase in the fat content in milk, reaching 5.93±0.65%. In addition, the content of lactose, the main carbohydrate in milk, at the end of the experiment was 4.89±0.12%. Lactose is an important substrate for lactic acid bacteria, which play a key role in the production of yoghurts and other dairy products. Table 3 presents the results of the physicochemical composition of goat milk.

Table 3 – Physicochemical characteristics of goat milk before and after the experiment

Indicators	**Normal range**	**Before, M±m**	**After, M±m**
Fat, %	no less than 2.5	3.03±0.59	5.93±0.65
MSNF, %	no less than 8.2	9.14±0.18	8.97±0.21
Density, kg/m^3	no less than 1027-1030	32.04±1.00	29.01±1.20
Lactose, %	4.0-5.5	5.00±0.10	4.89±0.12
Salts, %	0.6-0.9	0.76±0.01	0.75±0.02
Protein, %	no less than 2.8	3.38±0.07	3.29±0.08
pH	6.4 – 6.8	7.20±0.02	7.50±0.03
Somatic cells, thous/cm^3	750,000	385.0±103.3	1137.0±176
Note: * CU TR 033/2013 “On the Safety of Milk and Dairy Products”			

The protein content in goat milk was recorded at 3.29%, which corresponds to the regulatory requirements established in the Customs Union Technical Regulations “On the Safety of Milk and Dairy Products” (CU TR 033/2013) and GOST 32259-2013 “Whole Drinking Goat Milk. Technical Conditions”. Parameters such as fat content, density, and salt content are also within the established standards. A shift in milk pH to the alkaline side after feeding with the mushroom substrate may indicate positive changes in the metabolism of goats, as well as the fact that the feed additive ensured more efficient digestion and absorption of nutrients.

By the end of the experiment, an increase in somatic cells in goat milk was noted. The correlation between the level of somatic cells and milk fat content is explained by metabolic processes and feed quality. The increase in milk fat reflects changes in the metabolism of animals, which in turn can stimulate the production of somatic cells in the mammary gland as a response to changes in energy status.

A biochemical blood test was performed to assess the effect of the fungal substrate on animal health. A decrease in the level of ALT enzyme, which is mainly found in the liver and is used as a marker of its damage, and alkaline phosphatase indicates an improvement in liver function, which is associated with a more efficient metabolism (Table 4). There is scientific evidence that when using protected methionine as a feed additive that restores liver function, cows with subclinical mastitis recover faster [15, p. 10762].

Table 4 shows that the biochemical parameters of the goats’ blood, both at the initial stage and at the end of the experiment, remain within the physiological normal range. This indicates a stable state of health of the animals and the absence of serious disturbances in their metabolism.

Table 4 – Results of biochemical blood analysis of goats

Indicator	Unit	Normal range	Before	After
			M±m	
ALT	u/L	15-52	19.17±0.82	15.17 ±1.45
Albumin	g/l	23-36	37.27±0.80	36.07±0.99
Glucose	mmol/L	2.7-4.2	4.00±0.22	4.48±0.51
Creatinine	mmol/L	60-135	75.97±9.17	56.48±5.47
Total protein	g/l	61-75	71.0±0.14	63.25±1.40
Urea	mmol/L	4.5-9.2	4.88±0.35	4.17±0.22
Total bilirubin	μmol/л	1.7-4.3	0.58±0.17	0.65±0.17
Alkaline phosphatase	МЕ/л	61-283	157.17±30.27	99.83±20.94
Cholesterol	mmol/L	1.7-3.5	2.23±0.16	2.13±0.25

Attention should be paid to the alanine aminotransferase (ALT) activity indicator, which reached the lower limit of the norm at the end of the experiment. This change may indicate a decrease in the load on the liver, which in turn is associated with a change in the feeding regimen and an improvement in the function of this organ. A decrease in the ALT level may also indicate more efficient utilization of nutrients and less pronounced metabolic stress in animals, which will extend the economic life of the animals.

Albumin is a protein synthesized by the liver that plays an important role in maintaining blood oncotic pressure and transporting various substances. The albumin level was higher than normal at the beginning of the experiment; by the end of the experiment, the albumin level decreased, but remained within the normal range. This indicates that the feed additive contributed to a more balanced protein metabolism.

As for the glucose level, the slight deviation from the normal range is probably due to the fact that the grain component of the diet was subjected to barothermal treatment. This treatment can affect the digestibility of carbohydrates and consequently the level of glucose in the blood. This process changes the feed composition, which potentially improves its nutritional value (starch is broken down to monosaccharides and dextrins), but at the same time can lead to temporary changes in animal metabolism, reflected in the glucose level.

Creatinine is a product of muscle metabolism that is excreted by the kidneys. A decrease in creatinine levels at the end of the experiment indicates an improvement in kidney function or a decrease in muscle load, which is associated with an improvement in the overall metabolic state of the animals due to the feed additive.

The cholesterol level remained within the normal range, which indicates stable lipid metabolism.

In general, the studied biochemical parameters indicate positive changes in the health status of goats and their response to new feed components. We believe that additional observations and analyses are needed to better understand the impact of these changes on the general health condition and productivity of animals.

Discussion. Based on the literature data, it can be concluded that the use of spent mushroom blocks in the animal diet favorably affects the physiological state, productivity, and quality indicators of livestock products.

An experiment conducted on Hanwoo bulls in Korea showed that there was no significant difference in weight gain between the groups receiving compound feed with spent mushroom substrate and the groups receiving commercially available compound feed, but in terms of quality, the meat corresponded to class 1 or higher in the group receiving compound feed with 8-12% SMS [16, p. 1576].

Research by Bassonov O.A. et al. [17, p. 15] shows that feed containing spent mushroom substrate is well eaten by animals, losses during its distribution are reduced, which provides an increase in production efficiency.

Feeding young cattle with a diet that includes oyster mushroom substrate enriches their diet with useful substances and improves the digestibility of roughage. It also improves blood parameters of animals within physiological norms, including hemoglobin and erythrocyte concentration. In addition, the use of spent oyster mushroom substrate in feed production can increase the digestibility of roughage [18, p. 45].

The studies by Golushko V.M., Nadarinskaya M.A. et al. [19, p. 84] showed that the use of spent oyster mushroom straw substrate for young cattle up to 12 months of age increases the average daily weight gain of animals by 5.0%. For young cattle over 12 months of age, adding this substrate to the diet increases nutrient digestibility by 2.3-3.3% and increases average daily weight gain by 11.3%.

Due to the high moisture content, SMS tends to spoil, therefore, it must be processed quickly. This can be achieved by extrusion, which was used in our experiments.

Our previous studies showed that after extrusion in spent oyster mushroom substrates, the total number of microorganisms decreased by 3.4 times, Escherichia – by 21.2 times, yeast and fungi – by 8.5 times, and enterobacteria were completely disinfected. This indicates a significant increase in safety during barothermic (extrusion) processing of spent mushroom substrates, which allows them to be used in feed production [20, p. 100].

In 2019, scientists Tarasov S.S. et al., [21, p. 306] conducted an experiment with the use of spent oyster mushroom substrates as a feed additive for rabbits of the Soviet Chinchilla breed. The spent substrate blocks were crushed and mixed with crushed grain mixture (barley, oats, wheat 1:1:1) in a ratio of 1:9 by weight, followed by granulation. The animals were fed the resulting feed for a month; in addition to this feed, the rabbits had plenty of water and hay – meadow forbs. The control animals were fed only with a grain mixture (barley, oats, wheat 1:1:1) and hay. As a result of the experiment, it was found that the average weight of rabbits, as well as weight gain over the study period, did not differ statistically significantly with both diets ($P \geq 0.05$). Meat productivity of the studied groups also did not differ ($P \geq 0.05$) and corresponded to the norm. The authors note that the digestibility of feed in animals in the composition of which the spent straw substrate was introduced was not significantly lower.

Conclusion. The use of spent mushroom blocks can significantly reduce dependence on traditional grain crops, improve the nutritional value of feed and reduce production costs.

Problems associated with storage and processing, such as high moisture content of spent mushroom substrate, can be solved using modern technologies, such as extrusion. Additional research into the processing and use of by-products such as spent mushroom blocks will help optimize their use and improve feed safety.

Widespread introduction of mushroom industry by-products into feed production will not only increase the sustainability of agricultural systems, but also reduce the negative impact on the environment, promoting the rational use of resources. In the future, further research is needed to improve processing methods and expand the areas of application of by-products in feed production.

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СОЛТҮСТІК ҚАЗАҚСТАН ЖАҒДАЙЫНДА ӨҢДЕУ ЖҮЙЕСІНЕ БАЙЛАНЫСТЫ ТОПЫРАҚТЫҢ ТЫҒЫЗДЫҒЫ ЖӘНЕ ЭЛЕКТРЛІК ҚАСИЕТТЕРІ

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