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FEED ADDITIVE BASED ON DISTILLERY STILLAGE FOR PIG DIETS

Abstract

The study addresses the scientific and practical problem of improving the efficiency of using distillers dried grains with solubles (DDGS) in pig nutrition through technological processing. The relevance of the research is driven by the need to reduce feed costs, enhance nutrient utilization, and expand the use of by-products of the ethanol industry under conditions of limited traditional feed resources. The aim of the study was to investigate the feasibility of using dried DDGS in compound feeds for pigs and to develop a technological method for producing an extruded feed additive based on corn DDGS. A comprehensive literature review was conducted to summarize current approaches to pig diet formulation and the use of DDGS as an alternative feed ingredient. Experimental studies included the determination of physicochemical and functional properties of DDGS obtained from different cereal crops (corn, wheat, barley, and rye), as well as the evaluation of mixtures of corn and corn DDGS before and after extrusion processing. Nutritional value was assessed based on moisture, crude protein, crude fat, crude fiber, ash, mineral content, and amino acid composition. The results demonstrated that corn DDGS has the highest energy value, protein content, and the most balanced amino acid profile compared to other types. Mixtures of corn and DDGS in ratios of 75:25, 80:20, and 85:15 were tested, and the 80:20 ratio was identified as optimal due to stable extrusion performance and favorable nutritional characteristics. Extrusion processing significantly improved feed quality by increasing protein and starch digestibility, reducing antinutritional factors, enhancing hygienic safety, and improving physical properties such as bulk density and flowability. The developed extruded feed additive showed satisfactory physicochemical characteristics and can be effectively used in pig diets. The 1% premix recipes for pigs in the production of complete feed using dried lamb grain. The findings confirm that extrusion is a promising method for improving the feeding value of DDGS and increasing the efficiency of compound feed production. The use of DDGS contributes to resource efficiency, waste utilization, and sustainable development of the feed industry.

Key words: distillers dried grains with solubles (DDGS), extrusion, formulation, feed additive, premix, vitamins, minerals, physical and chemical properties, compound feed, farm animals (pigs).

Introduction

The modern development of animal husbandry, particularly pig production, is characterized by increasing demands for the efficient use of feed resources, improved animal productivity, and reduced production costs. In the context of global challenges associated with rising prices of conventional raw materials, instability in grain markets, and the need to ensure sustainable development of the agricultural sector, the search for alternative feed ingredients is becoming especially relevant. One of the priority directions is the utilization of by-products from the processing industry, which allows not only optimization of diet composition but also improvement of resource efficiency and environmental sustainability of production systems [1, 2].

Among such resources, distillers dried grains with solubles (DDGS), a by-product of bioethanol production, are of considerable interest, as their production volumes continue to increase due to the expansion of the bioenergy sector. The rational use of this product in feed production makes it possible to simultaneously address several issues, including waste utilization, reduction of environmental impact, and expansion of the raw material base for the feed industry. Therefore, investigating effective approaches to the use of DDGS in pig nutrition is highly relevant from both scientific and practical perspectives.

DDGS is characterized by a relatively high content of nutrients, including crude protein, fat, fiber, as well as macro- and microelements. It also contains significant amounts of essential amino acids and biologically active compounds formed during the fermentation of grain raw materials. Depending on the type of raw material (corn, wheat, barley, rye, etc.) and processing conditions, the chemical composition of DDGS may vary considerably, which affects its nutritional value and complicates its standardized use in animal diets [3, 4].

At the same time, the use of DDGS in pig feeding is associated with several limitations. These include a relatively high content of fiber and non-starch polysaccharides, variability in composition, the presence of antinutritional factors, and high moisture content in the raw product, which complicates its transportation and storage. In this regard, significant attention has been paid to technological processing methods, such as drying, pelleting, and extrusion, which improve product stability, enhance physicochemical properties, and increase nutrient digestibility.

Extrusion, as one of the promising methods of feed processing, provides intensive physicochemical modification of feed components, including starch gelatinization, protein denaturation, and partial degradation of fiber. This contributes to increased nutrient availability, improved hygienic quality, and extended shelf life of



feed products. The combination of DDGS with other components during extrusion opens up opportunities for the development of functional feed additives with predictable properties [5].

Numerous studies have focused on the formulation of balanced pig diets that meet physiological requirements for nutrients, energy, and biologically active compounds. It has been established that the efficiency of using unconventional feed ingredients, including DDGS, largely depends on their inclusion level in the diet, amino acid balance, and technological characteristics of the feed [6]. However, further research is needed to evaluate the influence of DDGS origin and processing methods on its quality parameters and nutritional value.

Literary review

Rational feeding is one of the key factors determining the productivity level of pigs, the efficiency of feed utilization, and the quality of the obtained products. Scientifically substantiated diet formulation involves taking into account the physiological requirements of animals for nutrients depending on age, body weight, production type, housing conditions, and the genetic potential of the breed.

The primary objective of formulating compound feeds for pigs is to meet their energy, protein, mineral, and vitamin requirements in a balanced ratio. For this purpose, cereal grains (corn, barley, wheat, rye), protein sources (soybean meal, rapeseed meal, sunflower meal, peas, DDGS), as well as premixes, mineral, and vitamin supplements are used.

Diets are formulated considering energy value (in MJ of metabolizable energy per 1 kg), content of crude protein, lysine, methionine + cystine, calcium, phosphorus, sodium, vitamins A, D₃, E, and trace elements. Both deficiency and excess of any of these nutrients lead to decreased productivity, impaired feed conversion, or metabolic disorders [7, 8].

Fattening diets are conventionally divided into three types:

- high-protein (balanced) diets — for intensive growth of young animals with high average daily gains (up to 800–900 g);
- energy-enriched diets — for bacon-type fattening with increased fat deposition;
- cost-effective combined diets — with partial inclusion of grain processing by-products, which reduces feed cost without significant reduction in growth performance.

The nutrient requirements of pigs vary depending on the growth stage. Therefore, in feeding practice, three main fattening phases are distinguished: starter (from weaning to 25–30 kg), grower (30–70 kg), and finisher (70–110 kg). For each phase, specific types of compound feeds are developed—starter, grower, and finisher diets (Table 1). Each feed type has its own chemical composition characteristics and is designed to ensure appropriate growth rates and muscle development.

Starter feeds are intended for piglets during the post-weaning transition

period when their digestive system is not yet fully developed. The main objective is to stimulate feed intake, stabilize intestinal microflora, and provide high energy density with good digestibility.

Starter diets typically include highly digestible grains (barley, corn, wheat), skimmed milk powder, blood plasma, soybean protein concentrate, fish meal, premixes, probiotics, and enzyme preparations. The use of organic acids (formic, fumaric) and phytogenic additives helps stabilize gastric pH and improves protein digestibility [9]. According to NRC (2021) recommendations and national feeding standards, crude protein content in starter feeds should be 18–20%, metabolizable energy 13.0–13.5 MJ/kg, and lysine content 1.2–1.3%.

During the grower phase (30–70 kg), the goal is intensive muscle mass development and efficient protein utilization. Grower diets contain higher energy levels due to increased inclusion of cereals, reduced amounts of high-protein ingredients, while maintaining amino acid balance. Crude protein content is reduced to 16–17%, and metabolizable energy is 13.0–13.3 MJ/kg. The diet is mainly based on barley, corn, wheat, soybean meal, sunflower meal, DDGS, as well as enzymes (xylanase, phytase) to improve nutrient digestibility [10].

The finisher phase is characterized by intensive weight gain and completion of muscle tissue formation. The main objective of feeding at this stage is to achieve high growth rates with minimal feed costs and to obtain meat with optimal fat content. Finisher feeds contain lower protein and higher energy levels. Crude protein content is reduced to 14–15%, metabolizable energy to 12.5–13.0 MJ/kg, and lysine content is approximately 0.8–0.9%. Excess protein at this stage is inefficient, as it increases nitrogen metabolism load and production costs. Diets typically include corn, barley, wheat, peas, mineral supplements, and a limited proportion of protein components. To improve meat quality, fats (up to 3%) are often added to finisher feeds.

Rational formulation of compound feeds for pigs involves consideration of the physiological requirements of animals at each stage of growth. Starter, grower, and finisher diets differ in their content of energy, protein, amino acids, and minerals, ensuring maximum productivity with minimal feed costs. The use of innovative feed additives and raw material processing technologies is an essential prerequisite for improving the efficiency of modern pig production.

Table 1 – Approximate nutritional requirements of compound feeds for pigs at different fattening stages

Indicators	Starter, to 25–30 kg	Grower, 30–70 kg	Finisher, 70–110 kg
Metabolizable energy, MJ/kg	13.2-13.6	13.0-13.2	13.2-13.4
Crude protein, %	18.0-20.0	16.0-17.0	14.0-15.0
Lysine, %	1.2-1.3	0.9-1.0	0.7-0.8
Methionine + cystine, %	0.7	0.65	0.6
Calcium, %	0.8	0.7	0.6
Phosphorus, %	0.6	0.5	0.45
Crude fiber, %	4.0	5.0	6.0
Crude fat, %	4.0-5.0	3.0-4.0	2.5-3.0

**Table 2 – Comparative chemical composition of wet and dry distillers grains [8, 11, 12]**

Indicators	Wet Distillers Grain (WDG)	Dried Distillers Grains with Solubles (DDGS)
Moisture content, %	65–75	8–12
Crude protein, %	7–9	26–32
Crude fiber, %	6–9	7–10
Crude fat, %	3–4	8–12
Nitrogen-free extractive substances (NFE), %	10–15	35–40
Ash, %	2–4	4–6
Metabolizable energy, MJ/kg	4.0–5.0	11–13
Crude protein in terms of dry matter, %	22–28	26–32
Amino acids, % of dry matter;		
Lysine	0.6–0.7	0.8–1.0
Methionine	0.25–0.30	0.45–0.55
Threonine	0.45–0.55	0.7–0.9
Tryptophan	0.15–0.18	0.20–0.25
Microelements, %:		
Phosphorus	0.5–0.7	0.8–1.0
Calcium	0.05–0.1	0.1–0.2
Magnesium	0.15–0.25	0.25–0.3
Potassium	0.8–1.0	1.0–1.2

A properly balanced diet promotes optimal animal growth, reduces feed conversion ratio per unit of weight gain, improves meat quality, and contributes to the environmental sustainability of production systems. The improvement of pig diets through the use of modern technological solutions and alternative feed ingredients represents one of the key directions for enhancing the efficiency of the sector.

Recent studies indicate that the efficiency of nutrient utilization in fattening largely depends on the structure of compound feeds (particle size reduction, pelleting, extrusion) as well as the presence of biologically active components such as enzymes, organic acids, phyto-genic additives, prebiotics, and antioxidants [8, 9]. Such ingredients improve protein and energy digestibility, reduce the risk of intestinal disorders, and increase live weight gain.

Distillers dried grains with solubles are a valuable by-product of ethanol production from starch- or sugar-containing raw materials (grains, potatoes, molasses, etc.). They represent a nutritionally valuable feed ingredient for livestock due to their high content of protein, essential amino acids, and energy-rich compounds. In animal and poultry nutrition, two forms of DDGS are commonly used: wet (fresh) and dry (dried or granulated) [11].

Wet distillers grains are rich in protein, fiber, and energy; however, their high moisture content limits storage stability and practical use without additional processing. They are mainly utilized on livestock farms located near ethanol plants. Wet distillers grains are typically fed to cattle and pigs as a moist feed component. They stimulate appetite and contribute to increased milk yield and weight gain.

Dried distillers grains represent a concentrated source of protein, energy, fat, and phosphorus. They are convenient for transportation and storage and are most commonly incorporated into compound feeds. Inclusion levels may reach 10–15% in pig and cattle diets and 5–7% in poultry diets. They are often used as a protein–vitamin feed supplement.

Table 2 presents a comparative overview of the chemical composition of wet and dry distillers grains. The values may vary depending on the raw material and processing technology; however, they reflect typical average indicators. Thus, the most promising form is dried distillers grains with solubles, which is widely used in modern compound feed production.

The choice of DDGS type is of considerable importance, as its nutritional value and digestibility depend on the raw material used for ethanol production (corn, wheat, barley, rye, etc.). Table 3 presents the advantages

Table 3 – Advantages and disadvantages of different types of dried distillers grains with solubles [13–15]

Types of DDGS	Advantages	Disadvantages
Corn DDGS	1. High energy value and good protein digestibility. 2. Pleasant taste and aroma (high palatability for pigs). 3. Optimal amino acid profile for fattening.	1. Possible lysine deficiency (partially degraded during drying). 2. Requires supplementation with methionine or enzymes.
Wheat DDGS	1. Higher crude protein content compared to corn DDGS. 2. Contains more phosphorus, B-group vitamins, and yeast residues.	1. High fiber content → lower digestibility in young pigs. 2. Poor pellet quality at high inclusion levels in the formulation.
Barley DDGS	Contains β -glucans, which have a positive effect on intestinal microflora.	Very high fiber content and low energy value, leading to reduced feed conversion efficiency (FCR).
Rye/triticale DDGS	Rarely used, mainly as a locally available raw material.	1. Elevated levels of antinutritional compounds (pentosans, phytates); 2. Requires mandatory extrusion or enzymatic treatment.



and disadvantages of different types of dried distillers grains with solubles when used in pig nutrition.

Table 4 presents a comparative composition of distillers dried grains with solubles derived from different cereal crops, along with the recommended inclusion levels in pig diets.

Table 4 – Comparative composition of DDGS from different crops and recommended inclusion rates in pig nutrition [13–15]

Indicators	Types of DDGS			
	Corn DDGS	Wheat DDGS	Barley DDGS	Rye / triticale DDGS
Crude protein, %	27–30	28–32	26–28	25–27
Crude fat, %	8–10	5–6	3–5	3–4
Crude fiber, %	7–8	9–11	10–12	10–13
Metabolizable energy, MJ/kg	12.5–13.0	11.5–12.0	10.5–11.0	10.0–10.5
Lysine, %	0.8–0.9	0.7–0.8	0.6–0.7	0.5–0.6
Methionine, %	0.5	0.4–0.5	0.4	0.3–0.4
Tryptophan, %	0.2	0.18–0.2	0.15–0.18	0.12–0.15
Vitamins of group B	B1, B2, B3, B6, niacin	B1, B2, B3, B6	B1, B2, B3	B1, B2
Minerals	P, K, Mg	P, K	P, K	P, K
Recommended rate for piglets, %	5–8	5–7	3–5	3–5
Recommended rate for fattening, %	10–25	10–20	10–15	5–10
Recommended rate for sows, %	10–15	8–12	5–10	5–8

Many researchers have conducted studies on the effects of using distillers dried grains with solubles on pig productivity (Table 5).

The analysis of Tables 3, 4, and 5 indicates that corn DDGS is the most suitable for pig fattening and for use in mixtures with phytogenic additives, due to its high energy value and good protein digestibility. Wheat DDGS can be considered an alternative, particularly when combined with enzyme preparations to reduce the negative effects of high fiber content. Barley and rye DDGS are used more limitedly because of their lower energy content and higher fiber levels; however, they may be included in feed mixtures after extrusion or enzymatic treatment.

Thus, pig diets should be not only nutritionally adequate but also economically balanced, taking into account the local availability of raw materials. The use of by-products from the food and ethanol industries (including DDGS, distillers grains, and wheat bran) allows for a

Table 5 – Effect of using distillers dried grains with solubles on pig productivity [11–14]

Study	DDGS inclusion level in the diet	Main results
Linneen S.K., 2008 (USA)	10–15% DDGS in compound feed for finishing pigs	Increase in average daily gain by 5–8%; reduction in feed cost by 7%
Thomas E. Burkey et al., 2009 (USA)	30% corn DDGS	Slight decrease in feed conversion ratio (by 2–3%); no effect on meat quality
Lifang Wang, 2016 (Canada)	15% wheat DDGS	Improved appetite and skin condition; reduced feed consumption per 1 kg of weight gain
Stein, 2016 (U. Illinois)	20–25% DDGS	Decreased content of saturated fatty acids in meat; increased proportion of polyunsaturated fatty acids

reduction in feed cost without compromising productivity, which is confirmed by recent scientific studies [10].

In recent years, considerable attention has been paid to the use of alternative protein sources such as DDGS, lupin, peas, rapeseed meal, as well as phytogenic additives, which contribute to improved protein digestibility, stabilization of intestinal microbiota, and reduced use of antibiotics. A promising direction is the extrusion processing of grain mixtures and distillers grains, which improves their nutritional value, reduces antinutritional factors, and enhances nutrient digestibility.

Extrusion technology is currently one of the key thermal processing methods for grains and compound feed production for young farm animals, poultry, fur animals, and fish. This technology not only improves the nutritional value and digestibility of feed components but also produces a feed with specific physical properties that meet the physiological requirements of different animal species and feeding conditions.

The extrusion process involves forcing a moistened and plasticized mass through forming dies under conditions of elevated temperature (110–160 °C), pressure (2–4 MPa), and a short residence time (10–30 s). Prior to processing, grains or feed mixtures are typically adjusted to a moisture content of 18–28%, depending on the formulation. Two main types of extrusion are distinguished: dry (conventional) and wet (cooking) extrusion.

In dry extrusion, grains are used in their natural or slightly moistened state (18–22%). The resulting extrudate has a low moisture content (approximately 13–14%), eliminating the need for additional drying.

Such extruders can process both whole and ground grains. Processing whole grains typically requires more energy and reduces equipment productivity. Ground grains are easier to extrude; however, fine particles may cause overheating inside the screw chamber and destabilize machine operation. Therefore, it is recommended to use particle sizes above 1 mm and to remove fine fractions prior to processing.



For specialized feeds, such as those for fish (salmon), dogs, or cats, wet (cooking) extrusion is applied. In this case, the raw material has higher moisture content (22–25%), and drying is required after pellet formation. Although this technology is more energy-intensive, it allows the production of pellets with different shapes, structures, and densities.

In Ukraine, one of the leading manufacturers of extrusion equipment is “CherkasyElevatorMash,” which specializes in industrial extruders for the feed industry.

Distillers dried grains contain valuable protein, but also include phytic acid, protease inhibitors, and non-starch polysaccharides that reduce nutrient digestibility. In addition, a portion of the protein in DDGS is bound to fiber structures formed during fermentation. To improve its utilization, extrusion processing is recommended, which allows:

- reduction of antinutritional factors by 25–40% (trypsin inhibitors, phytates, phenolic compounds);
- increased availability of amino acids, particularly lysine and methionine;
- improvement of protein digestibility by 8–12% and faster enzymatic hydrolysis in the gastrointestinal tract;
- improved hygienic quality through the reduction of pathogenic bacteria and fungi;
- decreased moisture content and improved pellet formation during feed production;
- increased average daily gains by 5–8% with a stable feed conversion ratio.

Table 6 – Biochemical changes during extrusion of a distillers grains mixture

Change	Result
Protein denaturation	Facilitates enzymatic hydrolysis and increases amino acid availability
Starch gelatinization	Improves energy value and palatability
Disruption of yeast cell wall residues	Releases β -glucans and mannan-oligosaccharides (prebiotics)
Destruction of microflora and mycotoxins	Reduces the risk of feed contamination
Partial carbohydrate caramelization	Enhances feed palatability for pigs

Thus, the optimal inclusion level of distillers dried grains with solubles (DDGS) in grain mixtures is 10–20%. Pre-extrusion treatment of grain-DDGS mixtures represents a promising approach for improving pig feed technology. It enhances the nutritional value and bioavailability of proteins, reduces antinutritional factors, improves feed hygienic quality, and increases animal productivity without the use of growth stimulants [16, 17].

Formulation of the problem

Despite the significant potential of distillers dried grains with solubles as a source of nutrients, there remains a scientific and practical problem related to the

limited efficiency of its use in pig nutrition. This is caused by the variability of its chemical composition depending on the type of grain raw material, limited nutrient digestibility, technological challenges in processing, and insufficient development of methods for enhancing its biological value.

A comprehensive investigation of DDGS as a feed ingredient is therefore highly relevant, particularly the assessment of its quality indicators depending on the type of grain raw material, as well as the development of effective technological solutions aimed at improving its feed value. Of particular interest is the development of extruded feed additives based on corn DDGS, which allows the combination of the advantages of secondary raw materials with modern processing technologies.

The aim of the study is to investigate the method of using dried distillers grains with solubles in compound feed production for pigs. To achieve this aim, the following research objectives were set:

- based on the analysis of literature and patent sources, to summarize the nutritional characteristics of pig diets, as well as the properties and methods of using distillers dried grains with solubles in feed production;
- to evaluate the quality indicators of dried distillers grains obtained from different cereal crops;
- to develop a technological method for producing an extruded feed additive based on corn distillers dried grains with solubles;
- to calculate the recipe of premixes for pigs in the production of complete feed using dried lamb grain,

Materials and methods

According to the defined objective, the study objects included dried distillers grains with solubles obtained from different cereal crops, as well as a feed additive based on them before and after the extrusion process.

A set of generally accepted and standardized methods was used to determine the physicochemical and functional characteristics of dried distillers grains of corn, wheat, barley, and rye origin. In addition, mixtures of corn with corn distillers grains prior to extrusion were analyzed, as well as the resulting extruded feed additive.

Calculation and optimization of premix recipes and feed additives were carried out using the BestMix program.

The physical properties of the extruded product were evaluated using key indicators that determine processing conditions and the efficiency of technological operations. These indicators included moisture content, bulk density, flowability, and angle of repose, which characterize the physic technological properties of the material.

The chemical composition analysis included the determination of crude protein, crude fat, crude fiber, crude ash, macroelements, fatty acid profile, and amino acid composition.

Calculation and optimization of premix and feed additive recipes were carried out using the BestMix program. Based on the obtained physicochemical and biochemical data, conclusions were drawn regarding the effectiveness of the developed feed additive in the production of complete feed for farm animals (pigs).



Results of the study and their discussion

Based on the selected research methods, the quality indicators of dried distillers grains with solubles obtained from different cereal crops were determined, and a technological method for producing an extruded feed additive based on corn DDGS was developed.

Study of quality indicators of dried distillers grains from different cereal crops

A comparative study of the chemical composition of corn, wheat, barley, and rye DDGS is important, as it allows improvement of animal feeding efficiency, reduction of compound feed cost, enhancement of the quality of products from the ethanol industry, and substantiated expansion of DDGS use as a valuable feed ingredient. The content of protein, essential amino acids, fats, and fiber differs significantly among various crops.

In the experimental samples, nutritional value was determined based on moisture content, crude protein, crude fat, crude fiber, crude ash, calcium, phosphorus, and amino acid composition.

Table 7 presents the data on the chemical and amino acid composition of corn, wheat, barley, and rye DDGS.

Table 7 – Quality indicators of corn, wheat, barley, and rye dried distillers grains with solubles

Indicators	DDGS			
	corn	wheat	barley	rye
Moisture content, %	10.00	10.00	10.00	10.00
Crude protein, %	21.6	20.1	19.00	16.50
Crude fat, %	10.70	7.60	5.00	8.20
Crude fiber, %	10.40	10.50	12.00	11.20
Crude ash, %	4.70	4.70	2.90	1.30
Calcium, %	0.17	0.18	0.16	0.13
Phosphorus, %	0.29	0.69	0.30	0.43
Lysine, %	0.61	0.42	0.60	0.42
Methionine + cystine, %	0.80	0.70	0.68	0.58
Threonine, %	0.82	0.68	0.69	0.59
Tryptophan, %	0.17	0.19	0.32	0.28

Based on the comparison of the chemical composition of corn, wheat, barley, and rye DDGS, it is possible to determine which type is most suitable for use in pig feeding. The evaluation is based on key indicators relevant to pig production: energy content (fat), protein, lysine, fiber, and phosphorus levels. The analysis shows that corn DDGS has the highest energy and protein value, as well as a more favorable amino acid profile compared to other crops. Wheat DDGS can serve as a source of phosphorus but contains less energy and protein. Barley and rye DDGS have higher fiber content, which partly limits their use at high inclusion levels; however, they may be beneficial in diets for adult animals.

Thus, the obtained data highlight the importance of combining different types of DDGS or adjusting compound feed formulations, taking into account nutritional

differences in order to ensure an optimal amino acid balance, energy value, and mineral composition of diets.

Corn DDGS is the most suitable option for pigs, as it provides the highest energy value, the greatest protein concentration, the most favorable amino acid composition, and an acceptable level of fiber. It is the most versatile and economically efficient option for starter feeds (at low inclusion levels), fattening diets, and sow feeding.

Development of a technological method for producing an extruded feed additive based on corn distillers dried grains with solubles

Based on the conducted literature review and experimental studies, it was established that the optimal raw material for producing an extruded feed additive for pigs is a mixture of corn and corn distillers dried grains with solubles (DDGS). This approach makes it possible to address protein, energy, and phosphorus deficiencies, reduce feeding costs, and utilize by-products of ethanol production.

Experimental samples of mixtures with different ratios of ground corn grain and corn DDGS were prepared: 75:25, 80:20, and 85:15, respectively. Prior to extrusion, the chemical composition of the mixtures was determined (Table 8).

Table 8 – Chemical composition of corn and corn DDGS mixtures before extrusion

Indicators	A mixture of corn and corn DDGS in the ratio of		
	Sample No. 1 75:25	Sample No. 2 80:20	Sample No. 3 85:15
Moisture content, %	11.50	11.60	11.70
Crude protein, %	10.84	10.12	9.40
Crude fat, %	5.71	5.38	5.05
Crude fiber, %	4.50	4.11	3.72
Calcium, %	0.06	0.05	0.04
Phosphorus, %	0.26	0.26	0.26

Extrusion of a mixture of corn grain and dried distillers grains with solubles (DDGS) is an effective method for increasing feed nutritional value and improving physicochemical properties. Prior to extrusion, corn grain and corn DDGS were ground to a particle size of 1.5–2.0 mm and mixed to obtain a homogeneous blend, which was then conditioned to a moisture content of W = 18–20%.

As a result of the experiment, sample No. 2 was identified as the most suitable for further investigation. Sample No. 1 exhibited sticking and burning in the extruder screw due to the higher fat and fiber content in the mixture. Increased fat content led to reduced adhesion to the screw and leakage of unformed product through the die gap. A higher fiber level reduced the plasticity of the material. Extrusion of sample No. 3 proceeded satisfactorily; however, it had a less favorable chemical composition and a lower proportion of corn DDGS compared to sample No. 2.

**Table 9 – Physical properties and chemical composition of the extruded feed additive**

Indicators	Value
<i>Physical properties:</i>	
Moisture content, %	12.60
Angle of repose, °	38.00
Flowability, cm/s	4.60
Bulk density, kg/m ³	480.00
<i>Chemical composition, %:</i>	
Crude protein	10.73
Crude fat	5.65
Lauric acid (C12:0)	0.01
Myristic acid (C14:0)	0.01
Palmitic acid (C16:0)	0.51
Palmitoleic acid (C16:1 ω7)	0.01
Stearic acid (C18:0)	0.06
Oleic acid (C18:1 ω9)	0.79
Linoleic acid (C18:2 ω6)	2.28
Crude fiber	3.78
Crude ash	1.86
Lysine	0.29
Methionine + cystine	0.40
Threonine	0.37
Tryptophan	0.08
Arginine	0.47
Isoleucine	0.34
Leucine	0.49
Valine	0.47
Histidine	0.29
Phenylalanine	0.48
Tyrosine	0.33
Phenylalanine + tyrosine	0.81
Glycine	0.40
Calcium	0.05
P	0.26

At the next stage, the physical properties and chemical composition of the developed extruded feed additive (sample No. 2) were determined (Table 9).

The analysis of the data presented in Table 4.3 indicates that the developed extruded feed additive is characterized by satisfactory physical properties and an enriched chemical composition as a result of the extrusion process. In addition, protein and starch digestibility are improved, antinutritional factors are inactivated, hygienic quality is enhanced, and transportation and storage are facilitated.

When producing complete feed for pigs using extruded feed additives, if necessary, a 1% premix is added to the composition, the composition of which for different fattening periods is given in Table 10.

Table 10 – Composition of 1% premix for pigs

Indicators	Starter 25–30 kg	Grower 30–70 kg	Finisher 70–110 kg
Vitamin A	5950000	1000000	1000000
Vitamin D ₃	600000	200000	200000
Vitamin E	3200	1000	0
Vitamin K ₃	300	200	200
Vitamin B ₁	300	100	70
Vitamin B ₂	1200	400	400
Vitamin B ₃	1000	1000	1000
Vitamin B ₄	15000	30000	30000
Vitamin B ₅	3000	1500	1500
Vitamin B ₆	300	100	100
Vitamin Bc	5	10	10
Vitamin B ₁₂	4.4	2.5	2.2
Vitamin H	5	10	10
Vitamin C	20	20	20
Fe	2600	6000	6000
Mn	6000	3500	3500
Zn	6000	7500	7500
Cu	7500	800	800
Co	25	5	5
I	105	27	27
Se	5	5	5
Lysine	15000	15000	15000
Methionine	20000	10000	10000

Conclusions

A comparative analysis of dried distillers grains with solubles from different cereal crops showed that corn DDGS is the most suitable for pig feeding due to its high energy value, protein content, and balanced amino acid composition. The study confirmed that the nutritional value of DDGS varies depending on the type of raw material, which necessitates optimization of feed formulations to ensure proper nutrient balance. The optimal ratio of corn to corn DDGS in the mixture for extrusion was determined to be 80:20, which ensures process stability and favorable physicochemical characteristics of the final product. Extrusion processing significantly improves the quality of the feed additive by increasing nutrient digestibility, reducing antinutritional factors, improving hygienic indicators, and enhancing technological properties.

The developed extruded feed additive based on corn DDGS has satisfactory physical and chemical characteristics and can be effectively used in pig diets to reduce feed costs without compromising productivity. The content of B vitamins in the extruded feed additive based on corn DDGS allows reducing their concentration in premixes in the production of complete feed for farm animals. The use of DDGS as a secondary raw material contributes to resource efficiency, environmental sustainability, and economic viability of compound feed production.



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КОРМОВА ДОБАВКА З ВИКОРИСТАННЯМ ПІСЛЯСПИРТОВОЇ БАРДИ В РАЦІОНАХ СВИНЕЙ

Анотація

Дослідження присвячене вирішенню науково-практичної проблеми підвищення ефективності використання післяспиртової барди у годівлі свиней шляхом застосування технологічної обробки. Актуальність роботи зумовлена необхідністю зниження собівартості кормів, підвищення рівня засвоєння поживних речовин та розширення використання побічних продуктів спиртової промисловості в умовах обмеженості традиційної кормової сировини. Метою дослідження було обґрунтування доцільності використання сухої післяспиртової барди у складі комбікормів для свиней та розробка технологічного способу виробництва екструдованої кормової добавки на основі кукурудзяної барди. Проведено комплексний аналіз літературних джерел з метою узагальнення сучасних підходів до формування раціонів свиней та оцінки можливостей використання барди як альтернативного кормового інгредієнта. Експериментальні дослідження включали визначення фізико-хімічних і функціональних показників барди різних зернових культур (кукурудзи, пшениці, ячменю та жита), а також оцінку сумішей кукурудзи з кукурудзяною бардою до та після екструзійної обробки. Поживну цінність визначали за вмістом вологи, сирого протеїну, жиру, клітковини, золи, макроелементів та амінокислот. Встановлено, що кукурудзяна барда має найвищу енергетичну цінність, вміст протеїну та найбільш збалансований амінокис-



слотний склад порівняно з іншими видами. Досліджено суміші кукурудзи та барди у співвідношеннях 75:25, 80:20 та 85:15, при цьому оптимальним визначено співвідношення 80:20, яке забезпечує стабільність процесу екструджування та високі поживні характеристики продукту. Екструзійна обробка сприяє суттєвому покращенню якості кормової добавки: підвищенню перетравності білка і крохмалю, зниженню вмісту антипоживних речовин, покращенню санітарних показників і фізичних властивостей (сипкість, об'ємна маса). Розроблена екструдована кормова добавка характеризується задовільними фізико-хімічними показниками та може ефективно використовуватися у годівлі свиней. Розраховані рецептури 1% преміксів для свиней на різних етапах відгодівлі при виробництві повнораціонних комбікормів з використанням сухої післяспиртової барди. Отримані результати підтверджують перспективність застосування екструзії для підвищення кормової цінності барди та ефективності виробництва комбікормів. Використання післяспиртової барди сприяє ресурсозбереженню, утилізації відходів і сталому розвитку комбікормової галузі.

Ключові слова: післяспиртова барда, екструджування, рецептура, кормова добавка, премікс, вітаміни, мінерали, фізичні та хімічні властивості, комбікорм, сільськогосподарські тварини (свині).

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TECHNOLOGY FOR THE PRODUCTION OF BINARY PREMIXES

Abstract

The article presents the results of the development and industrial testing of the technology for the production of binary premixes for farm animals and poultry. The existing technology for the production of premixes with a productivity of 2.5 t/h at the Mega Korm LLC feed mill was analyzed and the main technological limitations that affect the homogeneity of the finished product, the accuracy of component dosing and the efficiency of equipment use were identified. The influence of the physical properties of fillers on the mixing process and the degree of filling of the working chamber of the horizontal mixer was established. The developed 0.2% base blend consisted primarily of limestone meal (88.07%) and a concentrated mixture of vitamins A, D3, E, B-complex vitamins, biotin, and vitamin K3. Quality assessment showed that all produced premixes met the requirements of applicable technical documentation. Moisture content ranged from 2.5 to 6.4%, average particle size was 0.43–0.46 mm, and the angle of repose exceeded 40°, indicating that the products should be classified as difficult-flowing materials. A new technological scheme for the production of binary premixes is proposed, which involves the use of highly concentrated 0.1% and 0.2% premix-bases (blends) for the subsequent production of a wide range of vitamin, mineral and vitamin-mineral premixes. The technology is based on the separation of automatic and manual component dosing lines, the use of high-precision weighing dispensers, a bar coding system and automated control of technological operations. The developed scheme takes into account the requirements of the NA-SSR system and the ISO 22000:2018 standard for identifying hazards, determining critical control points, and ensuring production traceability. Experimental batches of binary premixes were manufactured under production conditions and the optimal mixing modes of the components were determined. It was established that the most effective parameters of the mixer are the mixing duration of 120 s and the working body rotation frequency of 68 min⁻¹. The physical properties and quality indicators of the obtained premixes were studied. It was established that the finished product meets the requirements of the regulatory and technical documentation in terms of homogeneity, moisture, flowability, and sanitary condition. The use of binary premixes allows to increase production productivity, ensure a more uniform distribution of biologically active substances in compound feeds, simplify recipe management, and reduce production costs. The results of the research indicate the feasibility of implementing binary premix technology at modern feed mills as an effective tool for improving product quality, zootechnical efficiency of feeding and economic competitiveness of production.

Keywords: premix, binary premixes, blend, feed additives, biologically active substances, vitamins, formulation, feed, technology, dosage, mixing, homogeneity, physical and chemical properties, farm animals, broiler chickens, quality.