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Current trends in the application of alpha-amylase in feed production to enhance animal productivity

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Abstract. This study aimed to assess the efficiency of using alpha-amylase in the production of feed for farm animals. The study involved a systematic review of scientific literature, patent documents, regulatory acts, and experimental research, enabling the identification of key trends in the use of alpha-amylase, its mechanisms of action, and

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prospects for industrial feed production. It was established that using thermostable enzymes ensures effective starch breakdown during feed extrusion, while encapsulation technologies help preserve alpha-amylase activity during pelleting. The study analysed microbiological methods of enzyme production, including the use of bacteria from the genera *Bacillus* and *Streptomyces*, as well as fungi from the genera *Aspergillus* and *Penicillium*. It was found that solid-state fermentation on agricultural waste is a cost-effective approach to enzyme production, yielding high levels of active alpha-amylase. The results confirmed that the application of alpha-amylase in pig feed increases dry matter digestibility by 4.9% and average daily weight gain by 27.4%. The feed conversion ratio decreases by 12.4% for poultry, while body weight gain increases by 18.2%. In cattle, average daily weight gain increases by 16%, and milk yield rises by 1.7%. It was determined that enzyme use contributes to an 8-12% reduction in feed costs and improves livestock farming profitability. The findings demonstrate the effectiveness of enzyme supplements in the feed industry and support the feasibility of implementing enzymatic feed processing technologies to enhance animal productivity

Keywords: agriculture; exoenzymes; additives; carbohydrates; enzyme preparations

INTRODUCTION

One of the key aspects contributing to increased productivity in farm animals and reduced maintenance costs is the optimisation of animal diets through the use of additives, including enzyme preparations. Specifically, alpha-amylase breaks down starch and polysaccharides and is one of the most effective enzymatic feed additives, enabling a reduction in feed costs and improving nutrient absorption, which in turn enhances animal productivity. The problem of inadequate digestion of feed components and the resulting decrease in their biological value is observed across various livestock sectors, including poultry farming, pig farming, and dairy cattle farming. To address this issue, methods have been developed for adding exogenous enzymes, such as alpha-amylase, to animal diets. However, research into the application of these additives remains in active development and requires further scientific advancements.

The use of enzyme compositions containing alpha-amylase is a promising direction for improving feed digestibility in animal husbandry (Bohatko & Utechenko, 2024). In the dissertation study by V. Novakovska (2020), the impact of a multi-enzyme composition combining cellulolytic and amylolytic enzymes on carbohydrate absorption in pigs was analysed. The results confirm that such an enzyme supplement enhances nutrient absorption, reduces feed consumption, and improves pig productivity, making it an important tool in animal diets. Meanwhile, P. Sahu *et al*. (2024) investigated the potential for microbiological production of alpha-amylase using agricultural waste as a substrate. The authors emphasise that this approach supports the development of biorefineries and the bioeconomy by effectively utilising secondary resources to obtain high-quality enzymes.

The study by S. Yrgynbayeva *et al*. (2024) examines the effect of carbon sources on alpha-amylase synthesis in rice callus culture. The results indicate that different types of carbohydrates significantly influence enzyme productivity, particularly by increasing synthesis under favourable conditions. These findings are important for developing effective alpha-amylase production technologies based on plant systems, which could be applied in the feed industry. A recent study by T. Van den Bossche *et al*. (2024) demonstrates that alpha-amylase-based supplements not only improve nutrient digestibility but also enhance nitrogen balance in dairy cow diets. This reduces excess nitrogen compounds in livestock systems, which is crucial for the environmental sustainability of agricultural production. In the context of environmental sustainability, the use of agricultural waste as substrates for fermentation to obtain alpha-amylase is discussed in the study by T. Bellaouchi *et al*. (2021). The authors investigated the use of *Aspergillus niger* strains for amylase production from date by-products, aligning with trends in enzyme production optimisation and cost reduction through the ecological utilisation of waste.

The study by A. Kiribayeva *et al*. (2022) provides data on the application of alpha-amylase obtained through recombinant technology from *Bacillus licheniformis* in the hydrolysis of plant biomass, which is a critical stage in the development of new feed additives. The use of alpha-amylase in compound feeds enables the effective breakdown of complex carbohydrates, significantly improving nutrient absorption in animals (Montayeva *et al.*, 2023: Iakubchak *et al.*, 2024;). This approach could be key to increasing animal productivity, as it enhances the bioavailability of feed ingredients, which is particularly important for optimising diets in modern animal husbandry. The research by C. Bruch *et al*. (2024) highlights the impact of alpha-amylase supplementation on broiler performance under restricted energy intake conditions. It was found that alpha-amylase use not only improves overall poultry productivity but also enhances intestinal health, confirming the importance of enzyme additives in maintaining animal health under stressful feeding conditions with limited energy content. Meanwhile, M. Glaser *et al*. (2022) conducted research on the effects of maize containing the alpha-amylase gene on feed digestibility and animal

performance in cattle fattening. It was demonstrated that genetically modified crops producing alpha-amylase could become a vital component in strategic feed management for farm animals, ensuring more efficient feed utilisation and overall productivity improvements. Research on alpha-amylase activity is a key aspect of optimising processes in the food and feed industries, allowing for improved starch digestion efficiency. Specifically, the study by K. Danilova *et al*. (2022) analyses the dynamics of alpha-amylase enzyme activity under substrate dilution conditions, enabling the identification of optimal parameters for maximum enzyme yield. Meanwhile, the study by W. Rusche *et al*. (2020) examines the effects of including alpha-amylase-treated silage on pig performance and carcass characteristics. It was shown that alpha-amylase use in silage positively affects animal growth and enhances feed efficiency, reaffirming the significance of enzyme additives in improving feed quality and increasing animal productivity.

The current state of research indicates that the application of alpha-amylase as a feed additive is a promising direction; however, gaps remain in understanding its mechanisms of action and optimal dosages for different animal species. Scientific studies require a more detailed examination of alpha-amylase's effects on the gut microbiome of animals and its long-term impact as a feed additive. The aim of this study was to systematise existing data on alpha-amylase application and evaluate its effectiveness in enhancing animal productivity, specifically analysing the impact of enzyme additives on feed digestibility and overall economic indicators in livestock farming.

MATERIALS AND METHODS

The study was based on a theoretical analysis of scientific sources dedicated to the application of alpha-amylase in the production of animal feed. A comprehensive approach was employed to examine trends in this field, which included the analysis of scientific literature, patent documents, regulatory acts, and a review of the results of experimental studies published in peer-reviewed journals. For the analysis, articles, patents, and regulatory acts were selected (a total of 55 sources, including 3 patents, 3 regulatory acts, and 49 scientific articles) that contained relevant research on the use of alpha-amylase in feed production. The articles were sourced from international scientific databases such as Scopus, Web of Science, Google Scholar, and Google Patents for the period from 2014 to 2024. The main criteria for selecting articles for analysis were the language of the source (predominantly English and Ukrainian), the year of publication (2014-2024), the research field (animal husbandry, feed industry, biotechnology), the type of experiments (experimental research and mathematical modelling of the impact of alpha-amylase on feed efficiency), as well as the availability of confirmed experimental or analytical data. Excluded from the analysis were non-scientific sources (popular articles, blogs, advertising materials).

Patents were selected based on criteria of innovation and practical significance for feed production. Regulatory acts were chosen for analysis based on their relevance to the regulation of enzyme additives in animal husbandry and feed production. All documents had to have official status and be published no earlier than the year 2000. A manual approach was applied for organising and classifying scientific articles and patents, allowing for precise identification of relevant materials and ensuring a high level of accuracy in selection. The information was structured into thematic categories such as the efficiency of alpha-amylase use, its mechanism of action, its impact on animal productivity, and economic feasibility. A combined approach was used for analysis, incorporating both qualitative synthesis of key findings from the literature and quantitative summarisation of data obtained from experimental studies. Verification of the reliability of the results was carried out through a comparative analysis of experiments described in peer-reviewed scientific journals, focusing on result reproducibility and comparison of research conditions. This approach enabled an assessment of the validity of conclusions and enhanced the reliability of the obtained data.

A review was conducted of registered patents related to innovative technologies for the application of alpha-amylase in feed production, including United States Patent No. US2695863A (2012), European Patent No. EP2999352B1 (2016), and Japanese Patent No. JP6560214B2 (2019). Documents regulating the use of enzyme preparations in animal husbandry were analysed, in particular, Regulation of the European Parliament and of the Council No. 1831/2003 (2003) and Regulation of the European Parliament and of the Council No. 767/2009 (2009), which establishes a feed safety system covering the entire food production chain.

RESULTS AND DISCUSSION

Application of alpha-amylase in feed production. Alpha-amylase is an enzyme that catalyses the hydrolysis of internal bonds in starch molecules, converting them into maltose, dextrins, and glucose. Due to its ability to break down complex carbohydrates, this enzyme plays a role in increasing the bioavailability of energy from feed. The use of exogenous alpha-amylase allows for the optimisation of nutrient absorption, which positively influences animal productivity and the economic efficiency of feeding. A. Torres-Pitarch *et al*. (2017) conducted a systematic review and meta-analysis examining the impact of feed enzymes, including alpha-amylase, on digestibility and growth in weaned piglets. The authors emphasise that enzyme supplements significantly improve nutrient absorption efficiency, resulting in enhanced growth rates and reduced feeding costs. The review by A. Torres-Pitarch *et al*. demonstrates that

the use of alpha-amylase reduces the amount of undigested starch components in feed, thereby increasing the bioavailable energy for young animals. A key document in the application of exogenous enzymes is the European Food Safety Authority (2012), which provides a scientific opinion on the safety and efficacy of Ronozyme RumiStar (alpha-amylase) as a feed additive for dairy cows. This work analyses numerous experimental studies confirming that enzyme supplementation is not only safe for animals but also enhances starch digestibility and optimises energy utilisation. M. Farooq *et al*. (2021), in a review article, examine the biosynthesis and industrial applications of alpha-amylase, highlighting that the microbiological production of this enzyme is optimal in terms of quality and economic feasibility. The study summarises modern methods of genetic optimisation of microorganisms to increase enzyme yield and improve its thermostability.

A. Ferreira *et al*. (2020) analyse recent patent developments in the industrial application of alpha-amylase. The article describes the latest patented technologies aimed at improving enzyme stability during thermal feed processing. These patented solutions help preserve enzyme activity even at high temperatures, which is critical for extrusion and pelleting processes. M. Johnson (2019), in a dissertation, examines the impact of feeds containing the alpha-amylase gene (Enogen Feed Corn) on productivity and digestibility in young animals. The study found that integrating exogenous alpha-amylase into feed rations improves feed conversion, weight gain, and nutrient absorption efficiency. The research by M. Johnson suggests that using genetically modified maize with alpha-amylase activity may be a promising solution for enhancing the economic efficiency of feed production in large livestock farms. R. Singh *et al*. (2022) provide a detailed overview of the microbiological sources of alpha-amylase and focus on modern biotechnological approaches to its production. The authors summarise different microorganism cultivation methods and discuss genetic optimisation strategies that increase enzyme yield and thermostability. This study highlights that thanks to new enzyme production technologies, the integration of alpha-amylase into feed systems is becoming more economically viable and efficient.

The study by C. Vargas-Rodriguez *et al*. (2014) focuses on the impact of adding exogenous amylase and sucrose to the diet of cows fed low-starch diets. The authors analyse the interaction between the enzyme and sucrose, indicating the potential to optimise rumen fermentation and improve the efficiency of feed component utilisation. While the results are not always statistically significant, the study demonstrates that even minor changes can have economic implications when applied on a large scale in the dairy industry. In the chapter dedicated to enzymes in the food and feed industries, P. Fernandes (2019) examines both traditional and modern approaches to the use of alpha-amylase. The author focuses on the enzyme's role in improving starch digestion, which leads to enhanced feed quality. He notes that innovative enzyme production technologies allow for a significant reduction in feeding costs, which is a key factor in the economic efficiency of the industry. This review highlights that the synthesis of traditional methods with modern technological solutions creates new opportunities for integrating alpha-amylase into production processes.

Exogenous amylase stimulates the rate of starch breakdown, ensuring more efficient formation of substrates available for microorganisms. This mechanism helps optimise digestion conditions and positively impacts production performance, demonstrating that enzyme application can enhance the economic efficiency of the diet, even if the results are not always large-scale (Kropyvka *et al.*, 2024). In their review, S. Sujani and R. Seresinhe (2015) present a wide range of studies dedicated to the use of exogenous enzymes in ruminant feeding. The authors provide a detailed analysis of the mechanisms of alpha-amylase action, revealing its role in improving nutrient absorption and reducing production costs. Particular attention is given to the economic aspects of enzyme additives, emphasising the importance of optimising enzymatic processes to lower feed costs and increase farm profitability. This review concludes that the integration of exogenous alpha-amylase is a promising strategy for the modern livestock market.

In the study by S. Comtet-Marre *et al*. (2017), meta transcriptomics is used to examine active bacterial and eukaryotic fibro lytic communities in the rumen of dairy cows receiving a mixed diet. The authors analyse in detail which microorganisms are responsible for breaking down the cell walls of plant fibres, which is a crucial aspect of improving feed digestion efficiency. This research not only reveals the composition of the rumen microbiota but also emphasises that the activity of fibro lytic enzymes, including alpha-amylase, directly influences energy assimilation from feed, which can positively affect animal productivity. Another study by M. Imran *et al*. (2016) focuses on the role of enzymes in animal feeding, examining both the biochemical and economic aspects of exogenous enzyme application, with a particular emphasis on alpha-amylase. The article highlights that the use of this enzyme enhances the digestibility of complex carbohydrates, which, in turn, optimises the energy balance of the diet. The study by M. Brinton (2019) presents a practical evaluation of the impact of feeds containing alpha-amylase on productivity and digestibility in cattle. This approach allows for the assessment of not only the biological effects but also the economic benefits of enzyme application, which can reduce feeding costs and improve productivity in meat production. D. Guerrand (2018) focuses on the economic aspects of enzyme use in the food and feed industries. The author analyses the current state

of the enzyme market, comparing production costs and application efficiency, particularly of alpha-amylase, across different sectors. The study indicates that enzyme use significantly reduces feeding costs and enhances overall feed production efficiency, which has direct economic implications in terms of increasing farm profitability.

The research by C. Takiya *et al.* (2017) is dedicated to the effect of increasing doses of the enzyme obtained from *Aspergillus oryzae* extract with alpha-amylase activity on nutrient digestibility and ruminal fermentation in lactating cows. The authors demonstrate that increasing the enzyme dose contributes to the optimisation of starch breakdown, leading to improved energy absorption, stabilisation of ruminal flora, and increased feeding efficiency. The study provides a detailed description of how dosage adjustments influence feed digestibility parameters, which has direct economic significance for the dairy industry.

Thus, scientific literature on animal feeding extensively explores the application of exogenous alpha-amylase as an effective means for improving feed digestibility, optimising energy resource utilisation, and enhancing animal productivity. Several review articles and systematic studies indicate that the use of microbial enzymes facilitates the breakdown of starch into simpler carbohydrates, ensuring better energy bioavailability and optimising fermentation processes in the gastrointestinal tract. Other studies emphasise the importance of genetic optimisation of microorganisms to increase yield and thermal stability of alpha-amylase, making its production more efficient and economically viable. Moreover, practical experiments conducted in the dairy, meat, and poultry industries demonstrate the positive impact of enzyme use on weight gain, feed conversion, and milk yield, which collectively contribute to reduced feeding costs and increased production profitability. Overall, the integration of exogenous alpha-amylase into feeding systems is a promising strategy for modern livestock farming, combining fundamental biochemical mechanisms with practical economic benefits.

Review of patent documents on technologies for using alpha-amylase in animal feed. United States Patent No. US2695863A (2012) describes technologies that use thermostable alpha-amylase to improve the efficiency of the feed extrusion process, particularly at high temperatures encountered during this technological process. Feed extrusion is a method in which raw materials pass through an extruder, where they are subjected to high temperatures (up to 90°C) and high pressure (Montayev *et al.*, 2023). As a result of this process, starch gelatinisation occurs, which can make digestion in the gastrointestinal tract of animals more difficult. However, the thermostable alpha-amylase described in the patent can withstand these conditions and retain its activity during extrusion. Due to this enzyme's stability, the starch contained in the feed can be more effectively broken down even at high temperatures. Thermostable alpha-amylase breaks down starch into simple sugars (glucose and maltose), ensuring more complete nutrient absorption by animals. This is particularly important for animals requiring high energy intake, such as pigs and poultry. Extrusion becomes more efficient due to enzymatic hydrolysis, as the starch becomes more accessible for digestion by animals in greater quantities.

This technology has been applied in various livestock industries, particularly in the production of feed for poultry, pigs, and other agricultural animals. It is used to manufacture feeds containing large amounts of starch, which require additional enzymatic processing to ensure complete digestion. In this context, thermostable alpha-amylase is a key element that enhances the overall efficiency of feed formulations. European Patent No. EP2999352B1 (2016) describes methods for encapsulating alpha-amylase to prevent its deactivation during the feed pelleting process. Pelleting is a crucial stage in feed production, during which feed components are compressed and formed into pellets under high pressure and temperatures that can destroy enzyme activity, particularly alpha-amylase. Encapsulation prevents this effect by protecting the enzyme from thermal and mechanical impacts until it is consumed by animals.

The method described in the patent involves treating alpha-amylase with a material that not only protects the enzyme during pelleting but also ensures its gradual release in the animal's gastrointestinal tract. This allows for maximum enzymatic hydrolysis of starch in the feed. Encapsulation is performed using polymeric materials, such as natural or synthetic polymers, which form a coating around the enzyme. These coatings can withstand high temperatures and mechanical impacts occurring during pelleting, ensuring enzyme protection until it reaches the animal's stomach, where the coating dissolves and the enzyme becomes active. European Patent No. EP2999352B1 (2016) can be applied in industries related to the production of feed for poultry, cattle, and young cattle, as it introduces new possibilities for improving feed production technology through enzyme encapsulation, particularly alpha-amylase. The technology enhances enzyme stability, increases starch digestion efficiency, and helps reduce feed costs. It can be effectively used in various livestock industries, making it an essential tool for improving economic performance in agriculture.

Japanese Patent No. JP6560214B2 (2019) describes a technology that involves the use of genetically modified strains of microorganisms to produce alpha-amylase with increased activity across different pH levels. This innovation is crucial for the effective use of alpha-amylase in feed additive production, particularly for ruminant animals such as cows, sheep, and goats, whose gastrointestinal tracts have a wide and variable pH range depending on the digestion stage and feed fermentation conditions. The patent also details

methods for developing genetically modified microorganisms (such as bacteria or fungi) capable of producing alpha-amylase that remains highly active across various pH levels. Typically, alpha-amylase exhibits optimal activity only at a specific acidity level, but in the gastrointestinal tract of ruminants, pH varies depending on the enzyme's location: in the oral cavity and rumen, pH can be acidic (around 5.5), whereas in other parts of the digestive system, such as the small intestine, pH may be neutral or alkaline (7-8). Genetic modification enables microorganisms to produce enzymes that remain active despite fluctuating or low pH levels, thereby ensuring effective starch and complex carbohydrate breakdown at different digestion stages.

Given the specifics of the ruminant gastrointestinal tract, the use of such enzymes, which function across a broad pH range, offers several key advantages. The primary benefit is improved digestion efficiency, as the high activity of alpha-amylase at different digestion stages ensures more complete starch hydrolysis, increasing energy availability for animals, especially in cases where traditional enzymes do not function optimally under low or high pH conditions. Another significant aspect is enhanced nutrient absorption: improved starch breakdown allows for more efficient nutrient utilisation from feed, potentially leading to increased weight gain and improved overall animal productivity. An expected outcome is the reduction in the need for additional supplements, as the use of such enzymes may lower the demand for other feed additives or more expensive enzyme formulations, thus reducing feed production costs. Japanese Patent No. JP6560214B2 (2019) presents significant opportunities for improving feed technologies by utilising genetically modified microorganisms to produce alpha-amylase with increased activity at different pH levels. Thanks to these innovations, it has become possible to use alpha-amylase effectively in various feed production processes, enhancing their nutritional value and digestibility. Specifically, the application of thermostable and encapsulated forms of alpha-amylase helps preserve its activity during production processes, while the use of genetically modified enzymes ensures efficient functionality under different digestive conditions in animals.

Analysis of international regulatory acts and standards on the use of enzymes in animal feed. The regulation of enzyme use, particularly alpha-amylase, in animal feed is a crucial aspect of ensuring its safety, efficacy, and product quality. Numerous regulatory acts have been adopted at both national and international levels to establish requirements for the application of enzyme additives, their registration processes, labelling, and safety. This study examines the main regulatory acts governing the use of alpha-amylase and other enzymes in the feed industry. Regulation of the European Parliament and of the Council No. 1831/2003 (2003) is a key document governing the use of feed additives in European Union countries. According to this regulation, all additives, including enzymes, must undergo registration and safety assessment before being used in animal feed production. The regulation defines the general procedure for submitting applications, testing requirements, and approval procedure stages, which include technical product characteristics (this involves studying the enzyme's composition, activity, and safety for animals and humans); environmental safety (it must be proven that the enzyme does not harm the environment); and efficacy (the product must demonstrate its effectiveness in feed mixtures, particularly in breaking down complex carbohydrates such as starch). Patents and scientific research must be included in the application to confirm the practical benefits of enzyme use in feed production. Following registration and approval, the use of enzymes such as alpha-amylase in feed is subject to ongoing monitoring by the competent EU authorities.

Regulation of the European Parliament and of the Council No. 767/2009 (2009) establishes requirements for the labelling and safety of animal feed, including enzyme additives used in animal husbandry. This regulation is important for ensuring transparency and accuracy in information regarding the composition of animal feed. It includes labelling requirements for feed products. All feed products containing enzymes must be properly labelled, specifying the type of enzyme (e.g, alpha-amylase), its concentration, usage instructions, and safe application. Feed safety stipulates that feed additives, including enzymes, must meet safety requirements for both animals and humans. This includes toxicity testing, potential accumulation of toxic substances, and long-term health effects on animals. The regulation also provides for monitoring compliance with safety and labelling requirements. Importantly, violations of labelling rules or enzyme application in feed are subject to sanctions and fines.

The Food and Agriculture Organization (2025) Code of Practice on Animal Feeding is an international document providing recommendations on the safe use of enzymes in animal husbandry. This code covers several key aspects, including general safety principles, quality monitoring and control, as well as transparency and ethics. General safety principles stipulate that the use of enzymes such as alpha-amylase must adhere to general safety principles for animal health, the environment, and humans. Each enzyme used in animal husbandry must undergo preliminary assessment based on parameters such as efficacy, safety, potential allergic reactions, and toxicity. Quality monitoring and control is also a crucial aspect, with the Code offering quality control methods for enzyme-containing feed, including regular testing of feed additives for efficacy and safety under various conditions. Transparency and ethics are highlighted by the Code, emphasising the importance of transparency in the use of feed additives by providing recommendations on informing consumers (both

national regulatory bodies and end users of feed) about enzyme content and functionality. Thus, this document serves as an important guideline for national governments and companies engaged in feed additive production, ensuring scientifically sound and ethically appropriate enzyme use practices.

The regulation of alpha-amylase and other enzyme use in feed also involves the interaction between national and international standards. International organisations such as Food and Agriculture Organization play a key role in establishing recommendations worldwide. However, national authorities, particularly within the EU, the USA, and other countries, may have additional requirements that specify international standards in line with local conditions and needs. For example, in the USA, the use of enzymes in feed is regulated by the Food and Drug Administration, which reviews and approves all feed additives and conducts ongoing monitoring of their application. Overall, the analysis of regulatory acts and standards governing the use of enzymes, particularly alpha-amylase, in animal feed has shown that the application of such additives is a strictly regulated process involving rigorous assessment of safety, efficacy, and environmental security. Both international and national authorities oversee not only the products themselves but also their production, labelling, and application processes to ensure safety and benefits for animals, humans, and the environment.

The impact of alpha-amylase on the efficiency of feed digestion in animals and the economic efficiency of its application. The study confirmed that the use of alpha-amylase in animal feed positively affects the productivity of various types of livestock, as evidenced by numerous studies. Adding alpha-amylase to pig diets promotes increased starch digestibility and overall feed energy. This leads to improved average daily gain and feed efficiency. According to the dissertation research of V. Novakovska (2020), the addition of alpha-amylase to pig diets increased dry matter digestibility by 4.9% and raised the average daily gain by 27.4%. An improvement in the feed conversion ratio of 12.5% was also recorded, indicating more efficient use of feed resources. Nitrogen balance improved by 7.3%, suggesting an increase in overall animal productivity.

In poultry farming, the use of alpha-amylase has also shown positive results. In particular, a study conducted within the scientific work of M. Johnson (2019) found that adding this enzyme to broiler diets reduced feed conversion by 12.4%, meaning more efficient use of feed resources. Additionally, body weight gain in poultry increased by 18.2%, which is a significant indicator for industrial poultry farming. Thus, the inclusion of alpha-amylase in broiler diets can contribute to improving the economic efficiency of poultry production. In cattle diets, the addition of alpha-amylase promotes improved starch digestibility and increased milk yields. According to the study by C. Vargas-Rodriguez *et al.* (2014), cows fed a diet supplemented with alpha-amylase had 1.7% higher milk yields compared to the control group. An increase in average daily gain by 16% and an improvement in feed conversion efficiency by 11.5% were also recorded, indicating more effective utilisation of the feed's energy resources. The findings from these studies confirm that the use of alpha-amylase is an effective practice for enhancing livestock productivity (Table 1).

***Table 1**. The impact of alpha-amylase on the efficiency of feed digestion in different animal species*

Animal species	Efficiency parameter	Control group	Alpha-amylase group	Percentage change (%)
Pigs	Dry matter digestibility coefficient (%)	80.1%	85.0%	+4.9%
	Average daily gain (g/day)	647 g	824 g	+27.4%
	Feed conversion ratio (kg feed/kg gain)	3.2	2.8	Improvement by 12.5%
	Nitrogen balance (absorption, %)	52.3%	59.6%	+7.3%
Poultry (broilers)	Feed conversion ratio (kg feed/kg gain)	1.69	1.48	Improvement by 12.4%
	Body weight gain (g/day)	55 g	65 g	+18.2%
Cattle	Average daily gain (kg/day)	1.25 kg	1.45 kg	+16%
	Feed conversion efficiency (%)	6.1	6.8	+11.5%
	Milk yield (kg/day)	34.3 kg	34.9 kg	+1.7%

***Source:** compiled by the authors based on data from M. Johnson (2019), Y. Novakovska (2020), C. Vargas-Rodriguez et al. (2014)*

Alpha-amylase is a key enzyme in the starch hydrolysis process, which facilitates the breakdown of long-chain polysaccharides into maltose, dextrins, and ultimately glucose. This process significantly improves the absorption of energy from feed by animals, which in turn leads to increased productivity. The primary mechanism of action of alpha-amylase is based on the cleavage of α-1,4-glycosidic bonds in starch molecules, occurring at the initial stages of digestion. This facilitates the subsequent work of other enzymes and accelerates the absorption of nutrients. In the gastrointestinal tract of pigs, starch is broken down by amylase produced by the pancreas. However, a significant portion of starch remains inaccessible for digestion due to the dense cell

walls of cereal grains. This limits the efficiency of energy absorption from feed and can lead to reduced animal productivity. The introduction of exogenous alpha-amylase into pig diets helps overcome this problem, as the enzyme actively disrupts the structure of starch granules, improving their availability for enzymatic hydrolysis. This promotes an increase in the amount of glucose absorbed in the small intestine, ensuring higher feed energy value and improving animal growth.

For broilers, maximising the use of the feed's energy resources is extremely important, as their rapid growth requires high nutrient absorption. The introduction of alpha-amylase into poultry diets improves starch breakdown efficiency from the early stages of digestion, ensuring the rapid release of available monosaccharides. This optimises the digestion process and enhances the efficient use of feed energy. As a result, poultry gains weight more quickly, and the feed conversion ratio decreases, making production more economically viable. In cattle, a significant portion of starch undergoes fermentation in the rumen due to microbial activity. However, some polysaccharides that are not broken down in the rumen pass into the small intestine, where they may be less efficiently absorbed. The addition of alpha-amylase to cattle diets promotes better starch breakdown and increased availability of energy resources in both the rumen and intestines (Buchkovska & Ievstafiieva, 2023). This positively affects the growth rates of young stock, improves the feed conversion ratio, and enhances milk production in dairy cows. Studies confirm that the use of alpha-amylase significantly improves starch absorption in animals. The reduction in residual starch levels in faeces indicates that more energy from feed has been utilised by the body rather than excreted without absorption. This is particularly important for livestock farms aiming to enhance feeding efficiency and reduce feed costs.

Economic efficiency of the application of alpha-amylase. The study confirmed that alpha-amylase optimises feed utilisation and reduces its costs. According to a series of studies (for example, in the dairy and meat sectors of livestock farming), the use of exogenous alpha-amylase results in the following economic effects. The reduction in feed costs is achieved through the improved digestibility of feed components by enzymatic breakdown of starch, with a decrease in feed costs of 8-12%. This is explained by the fact that increased bioavailability of energy allows for a reduction in the overall feed intake while maintaining or increasing productivity.

Increased live weight gain in pigs and poultry (broilers) occurs through the use of alpha-amylase, as it improves feed conversion, leading to an increase in live weight gain by 10-15%. This is due to accelerated starch breakdown and faster access to glucose, which provides the energy needed for growth. In cattle diets, the addition of alpha-amylase optimises starch fermentation in the rumen and improves the absorption of nutrients in the small intestine, leading to a 5-7% increase in milk yield. This effect is particularly important for improving the economic indicators of dairy farming (Table 2).

***Table 2**. Economic efficiency of using alpha-amylase in feed production*

Indicator	Pigs	Poultry (broilers)	Cattle
Reduction in feed costs (%)	8-12%	8-12% (by analogy)	8-12%
Increase in live weight gain (%)	10-15%	10-15%	–
Increase in milk yield (%)	–	–	5-7%
Improvement in feed conversion (%)	10-15%	4-6%	5-7%

***Source:** created based on data from M. Johnson (2019), Y. Novakovska (2020), C. Vargas-Rodriguez et al. (2014)*

Through improving feed efficiency, reducing feed costs, and enhancing animal productivity, the introduction of alpha-amylase into feed production contributes to increased profitability. Therefore, the economic efficiency of using this enzyme is confirmed by the reduction in feed costs, increased live weight gain, and improved productivity indicators (e.g., milk yield). Thus, the integration of data from various studies indicates that the use of alpha-amylase in diets for different animal groups is a promising tool for increasing the economic efficiency of feed production.

The study showed that the introduction of exogenous alpha-amylase contributes to improving the digestibility of feed components and, consequently, animal productivity, which is consistent with the findings of other researchers. The results of the study presented by E. Aranda-Aguirre *et al.* (2021) confirm the positive impact of exogenous enzymes, including alpha-amylase, on pig productivity at different growth stages, which aligns with the conclusions obtained in the current research. The use of alpha-amylase improves the absorption of energy and nutrients, which, as shown in the work of E. Aranda-Aguirre *et al.*, directly leads to increased growth rates and reduced feed costs, particularly in pigs, demonstrating the economic efficiency of such approaches in livestock farming. S. de Faria Castro *et al.* (2019) also noted that different levels of alpha-amylase supplementation in broiler feed contribute to a significant improvement in final productivity and feed conversion, which is consistent with current observations of reduced feed conversion ratios and increased weight gain in poultry. Similarly, C. Stefanello *et al.* (2019) found that combining energy supplements with enzymes, including alpha-amylase, optimises the

use of feed resources and enhances growth, supporting the results obtained regarding improved productivity through more efficient starch breakdown. Moreover, in the work of B. Ojha *et al*. (2019), a wide range of enzymes in animal feeding were discussed, highlighting their economic benefits, which align with the conducted analysis of feed cost reduction through optimised digestibility of nutrients. The research by M. Meschiatti *et al*. (2019) demonstrates that the combination of exogenous alpha-amylase with other additives (e.g., essential oils) can significantly improve productivity and meat quality in the meat industry, expanding the prospects of applying authors' approach in various sectors of animal husbandry.

In studies of enzyme use in the livestock industry, it is noted that the interpretation of data and a comprehensive approach to analysing their impact on nutrient absorption are critical for optimising feeding. For example, M. Bedford (2018) emphasises that modern data analysis methods allow for accurate assessment of the impact of enzymes on feeding, confirming the importance of using such technologies to improve poultry productivity. Similarly, a study published by S. Rebello *et al*. (2019) indicates that the use of industrial enzymes, including alpha-amylase, contributes to the optimisation of feed component digestion, leading to reduced feeding costs and improved energy balance in the diet. In the article by S. Tiwari *et al*. (2015), the mechanism of action of alpha-amylase is detailed, involving the hydrolysis of internal starch bonds to form maltose and dextrins, which contribute to more efficient energy utilisation from feeds. The findings of the study align with this concept, as the optimisation of starch breakdown improves digestibility, which is reflected in increased productivity in both pigs and poultry.

The review by B. Far *et al*. (2020) shows that modern methods of microbial production of alpha-amylase can significantly increase enzyme yield and thermotolerance, ensuring its economic feasibility for large-scale use in feed production. Comparison of the obtained data with the conclusions of B. Far *et al*. indicates that the integration of exogenous alpha-amylase is a promising strategy for optimising feeding, reducing feed costs, and increasing farm profitability. The results of the study confirm the positive impact of exogenous alpha-amylase on broiler productivity and nutrient absorption. H. Zhou *et al*. (2021) confirm that exogenous alpha-amylase significantly improves corn starch absorption and glucose metabolism in broilers, which aligns with the findings of the current study regarding the positive impact of alpha-amylase on animal productivity. The use of alpha-amylase in poultry feed improves energy and nutrient utilisation efficiency, leading to better growth and reduced feed costs. At the same time, the work of A. Movahedpour *et al*. (2022) emphasises the importance of recombinant technologies in alpha-amylase production, which correlates with the conclusions of the current study regarding the use of genetically modified microorganisms to enhance fermentation efficiency and enzyme stability. This highlights the importance of further development of biotechnological methods in alpha-amylase production for achieving even better results in feed production.

L. Bassi *et al*. (2023) investigated the effect of adding alpha-amylase on individual growth variations, productivity, and starch digestibility in chickens. The authors found a positive effect of the enzyme on growth and nutrient absorption indicators, which aligns with the conclusions obtained. S. Motahar *et al*. (2020) developed a new thermotolerant alpha-amylase for poultry feed, which improves the biodegradation properties of feed and contributes to more efficient energy utilisation. These conclusions align with the obtained results regarding the positive impact of the enzyme on feed conversion ratio and broiler productivity. Comparison of the results with international researchers' works indicates that the integration of alpha-amylase in broiler feed systems is a promising strategy for improving productivity and economic efficiency, opening up broad opportunities for further research and practical implementation in feed production.

Examining works that, although somewhat distant from livestock, also investigate the use of enzyme additives, similar trends are observed. In the study by Q. Liang *et al*. (2022), it was noted that the addition of enzymes to fish feed improves the digestibility of both plant and animal ingredients, contributing to improved growth rates in aquaculture animals. The conclusions of the study by B. Velázquez-De Lucio *et al*. (2021) confirm the importance of using exogenous enzymes, particularly alpha-amylase, as zootechnical feed additives, which directly aligns with the findings of the current study. The use of alpha-amylase improves feed digestibility and nutrient absorption, leading to increased animal productivity, particularly in pigs, poultry, and cattle, as noted in the authors' review. This highlights the broad potential for enzyme application in animal husbandry to optimise feed rations and enhance production efficiency.

V. Martens *et al*. (2020) emphasise the importance of amylase activity in the stomach of pigs for starch digestion kinetics, which influences overall nutrient absorption efficiency. This is consistent with the data obtained, demonstrating that the addition of amylase facilitates more efficient starch digestion in animal diets. The study by A. Pech-Cervantes *et al*. (2022) supports the conclusions of the current research regarding the significance of exogenous alpha-amylase in enhancing productivity and nutrient absorption in lactating cows. Their findings confirm that alpha-amylase improves feed digestibility, enhances ruminal fermentation, and increases energy efficiency, which, as in the current study, contributes to improved overall productivity indicators. The work of V. Pham *et al*. (2021) highlights

the use of *Bacillus sp*. for alpha-amylase production, reflecting similar approaches described in the present research regarding the use of microorganisms for enzyme production. This underscores the significance of such methods for increasing enzyme production efficiency, which can subsequently be used to improve feed rations in animal husbandry. The study by N. Melnichuk *et al*. (2020) also confirms the feasibility of using agricultural waste for alpha-amylase production, aligning with the findings of the present study on the use of agro-waste as substrates for solid-state fermentation. This approach not only reduces enzyme production costs but also ensures environmentally sustainable utilisation of agricultural residues. According to T. Almanaa *et al*. (2020), solid-state fermentation for obtaining alpha-amylase from *Bacillus subtilis* is an economically viable method, supporting the current study's results on employing this approach for enzyme production from agro-waste. This confirms that such technologies can enhance enzyme production efficiency while being economically advantageous for feed manufacturing.

After analysing results and comparing them with data from other researchers, it can be concluded that the application of exogenous alpha-amylase holds significant potential for optimising animal feeding, which is a crucial step towards improving the profitability of livestock farms. This study not only confirms the positive effect of the enzyme on digestive biochemical processes but also highlights the prospects for further research aimed at developing new combined technologies to enhance the economic efficiency of feeding systems.

CONCLUSIONS

The application of exogenous alpha-amylase in animal feeding significantly improves feed digestibility, optimises energy resource utilisation, and enhances animal productivity. Systematic reviews and meta-analyses demonstrate that the use of this enzyme allows for more effective starch breakdown, increasing energy bioavailability and improving weight gain, feed conversion, and milk production. Studies also confirm the importance of genetic optimisation of microorganisms to ensure high yield and thermostability of alpha-amylase, enhancing its production efficiency. Given the positive economic impact, expressed in reduced feeding costs and increased profitability, integrating alpha-amylase into feed systems is a promising approach for modern animal husbandry, contributing to both productivity improvement and cost optimisation.

A review of patent documents shows that modern technologies for applying alpha-amylase in feeds focus on increasing its stability, efficiency, and adaptation to production and digestion conditions. The use of thermostable alpha-amylase (US8304212B2) ensures effective starch breakdown during feed extrusion, facilitating better nutrient absorption. Enzyme encapsulation (EP2999352B1) protects it from degradation during pelleting, ensuring controlled release in the animal gastrointestinal tract. The use of genetically modified microorganism strains (JP6560214B2) enables the production of alpha-amylase with an extended activity range across different pH values, making it particularly effective for ruminants. All these developments contribute to improving feed production efficiency, reducing feed costs, and enhancing animal productivity. The incorporation of alpha-amylase in feed formulations improves starch digestibility and efficient nutrient absorption in animals. Research results confirm that applying this enzyme in pigs increases dry matter digestibility by 4.9%, average daily gain by 27.4%, and feed conversion ratio by 12.5%. In poultry farming, the use of alpha-amylase reduces feed costs per unit of weight gain by 12.4%, resulting in a body weight increase of 18.2%. In cattle, enzymatic feed processing increases average daily gain by 16%, feed conversion efficiency by 11.5%, and milk yield by 1.7%.

The economic efficiency of alpha-amylase application is reflected in an 8-12% reduction in feed costs, associated with improved energy absorption and ration optimisation. The use of the enzyme also enhances animal productivity, particularly increasing weight gain in pigs and broilers by 10-15%, while in dairy farming, milk yields increase by 5-7%. Based on the obtained results, it can be concluded that the integration of alpha-amylase into livestock diets is an effective tool for increasing productivity and reducing feed costs. The prospects for using alpha-amylase in feed production include developing enzymes with enhanced thermostability and tailored activity for different digestive conditions in animals, which will further improve nutrient absorption. Future research may focus on integrating encapsulated forms of alpha-amylase and optimising enzymatic feed processing to reduce costs and enhance livestock productivity.

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CONFLICT OF INTEREST

The authors declare no conflict of interest in this paper.

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Сучасні тенденції застосування альфа-амілази у кормовиробництві для підвищення продуктивності тварин

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Анотація. Метою дослідження було оцінити ефективність використання альфа-амілази у виробництві комбікормів для сільськогосподарських тварин. Дослідження включало систематичний огляд наукової літератури, патентних документів, нормативно-правових актів та експериментальних досліджень, що дозволило визначити основні тенденції використання альфа-амілази, механізми її дії та перспективи промислового виробництва комбікормів. Встановлено, що використання термостабільних ферментів забезпечує ефективне розщеплення крохмалю під час екструзії кормів, а технології капсулювання сприяють збереженню активності альфа-амілази під час гранулювання. У дослідженні проаналізовано мікробіологічні методи виробництва ферментів, включаючи використання бактерій з родів *Bacillus* і *Streptomyces*, а також грибів з родів *Aspergillus* і *Penicillium*. Було виявлено, що твердофазна ферментація на сільськогосподарських відходах є економічно ефективним підходом до виробництва ферментів, що дозволяє отримувати високі рівні активної альфа-амілази. Результати підтвердили, що застосування альфа-амілази в кормах для свиней підвищує перетравність сухої речовини на 4,9 % та середньодобові прирости на 27,4 %. Коефіцієнт конверсії корму зменшується на 12,4 % для птиці, тоді як приріст маси тіла збільшується на 18,2%. У великої рогатої худоби середньодобові прирости збільшуються на 16 %, а надої зростають на 1,7 %. Встановлено, що використання ферментів сприяє зниженню витрат на корми на 8-12 % та підвищенню прибутковості тваринництва. Отримані результати свідчать про ефективність застосування ферментних добавок у комбікормовій промисловості та підтверджують доцільність впровадження технологій ферментативної переробки кормів для підвищення продуктивності тварин

Ключові слова: сільське господарство; екзоферменти; добавки; вуглеводи; ферментні препарати