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The Application of Unconventional Protein Sources in Animal Feed

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ABSTRACT
With the growth of the global population, the livestock industry has developed rapidly and has broad prospects. As a major livestock country, although China's conventional protein feed resources can ensure sufficient energy supply, the protein content is relatively low, which has led to a high dependence on imports for high-quality animal protein feed raw materials. Due to various international factors, the economic benefits of China's livestock industry have been impacted to some extent, and the shortage of protein feed resources has become increasingly prominent. This paper systematically reviews the classification, application effects and industrialization status of unconventional protein sources, with a focus on analyzing the application potential of insect protein (such as black soldier fly, mealworm), single-cell protein (such as yeast), plant by-products (such as rapeseed meal, cottonseed meal) and animal by-products (such as feather meal) in feed for livestock and ruminants, Summarize the effects on animal growth performance, intestinal health and economic benefits.

KEYWORDS
Unconventional protein sources; Animal feed; Insect protein; Single-cell protein; Sustainable development

1 Introduction

Livestock farming is increasingly becoming a core industry for meeting global demand for meat, eggs and milk, with feed costs accounting for 60% to 70% of total farming costs, with protein feed being a key component. Soybean meal, fish meal, etc. are the main sources of protein in feed. They are imported in large quantities and are vulnerable to international influence, with large price fluctuations. Therefore, choosing to develop and utilize unconventional protein feed can provide alternative options for conventional protein feed by taking advantage of more diverse protein sources, effectively alleviating the consumption and import volume of soybean meal, fish meal, etc. Unconventional protein sources are partly derived from the conversion of by-products in agriculture, food and other fields, and their application can effectively promote the recycling of resources. Research on unconventional protein feed is of great significance for optimizing feed formulations, reducing production costs and promoting sustainable development of animal husbandry in the context of the rapid development of animal husbandry intensification.

The Food and Agriculture Organization of the United Nations (FAO) advocated insect protein as an alternative to traditional feed as early as 2013, and the European Union gradually approved the use of insect protein in aquatic and livestock feed from 2017 to 2021. By the end of 2024, China's Ministry of Agriculture and Rural Affairs included black soldier flies and mealworms in the Feed Ingredient List, marking the beginning of the development of unconventional protein sources. At present, the development and application of unconventional protein sources in China is slower than in foreign countries. This paper analyzes and sorts out the types and characteristics of unconventional protein sources, systematically analyzes their application effects in animal growth and development, and discusses the feasibility of unconventional protein sources in animal feed, aiming to provide a comprehensive reference for related research.

2 Classification and Characteristics of Unconventional Protein Sources

Unconventional protein sources can be classified as follows:

2.1 Insect Proteins

There are a wide variety of insect species and a large number of the same species, which have great potential for development. Insects are rich in protein, which can meet the growth and development needs of livestock and can be used as an alternative to conventional protein sources. Insect protein resources have the following advantages: high protein content, balanced amino acid composition; It contains special bioactive substances; Short life cycle, high yield; Use livestock manure, to reduce environmental pollution [1].

2.1.1 Black Soldier Fly Larvae

The black soldier fly is a saprophytic insect of the soldier fly family. It feeds on livestock manure and domestic garbage to produce high-value animal protein feed, which is rich in nutrients. Among them, the larvae and pupae are good feed ingredients. With a short growth cycle, high bioconversion rate and low cost, organic waste can be resourcefully converted into high-quality insect protein, oil and other products [2].

2.1.2 Mealworms

Also known as breadworms, noodle worms, etc. It is a rich source of protein, with its larvae, pupae and adults having 51%, 57% and 61% respectively of protein and, 30% [1] of fat. According to experiments, using 3% to 6% fresh mealworms instead of the same amount of domestic fish meal to feed meat chickens increases weight gain, improves feed conversion rate, and is the ideal high-quality high-protein live feed [3] for carnivorous and omnivorous animals such as fish, frogs, turtles, ornamental animals, medicinal animals, rare livestock and precious fur animals in special animal husbandry.

2.1.3 Drosophila Blackbellied

Drosophila blackbellied is one of the most thoroughly studied organisms by humans. Its strong reproductive capacity and short growth cycle make it possible [4] to obtain a large amount of experimental materials in a short time for protein feed production.

2.2 Single-cell protein

Single-cell protein refers to protein-rich microorganisms that grow in petroleum or agricultural and industrial organic waste, while unconventional protein sources refer to algae and many crops[5] whose potential has not been fully exploited at present.

2.2.1 Fermented Proteins

Fermented proteins use microbial fermentation to reduce the anti-nutritional and toxicity of protein raw materials. Microorganisms act like an efficient biological factory, breaking down anti-nutritional factors and macromolecular substances (such as proteins, polysaccharides) in the raw materials into small peptides, organic acids, and other easily absorbable small molecules, and synthesizing large amounts of single-cell proteins (microbial proteins). It can increase the utilization rate of feed raw materials and significantly reduce production costs. The reason why fermented feed can improve the digestibility of nutrients is that unconventional protein feed, after microbial fermentation, can significantly change the physicochemical properties of feed raw materials, reduce anti-nutritional factors, significantly reduce raw material toxicity, and degrade proteins, especially generating many small molecule peptides [6].

2.2.2 Algal Protein

The content of algal protein is as high as 60% to 73% [6]. In feed, using algae as a feed additive can enhance the digestion and utilization rate of feed protein, improve the immunity of animals, and reduce production costs [7].

2.3 Plant By-products

Here are several common plant by-products and their characteristics.

2.3.1 Rapeseed Meal

A by-product of extracting oil from rapeseed, with protein content up to 30%-45%, but rapeseed meal contains glucosinolates that need to be fermented and degraded[8] to improve palatability and facilitate digestion and absorption by livestock.

2.3.2 Cottonseed Meal

It is a by-product of cottonseed oil extraction, with crude protein content of about 41%-44%, but the free gossypol in cottonseed meal can harm animals and have a negative impact on their growth, development and reproduction. High-temperature treatment of cottonseed meal with methanol can effectively reduce its free gos [9] sypol content and improve its digestibility.

2.3.3 Palm Meal

The protein content of palm meal is lower than that of soybean meal, peanut meal, etc., approximately 14%-20%[10]. But it contains many amino acids that animals need, and its high content of the anti-nutritional factor cellulose hinders its efficient application [11] in animal feed. After microbial fermentation treatment [11], the quality of palm meal is improved and it has the potential to replace traditional protein raw materials such as fish meal and soybean meal.

2.4 Animal By-products

Here are several common animal by-products and their characteristics.

2.4.1 Feather Meal

Feather meal contains 80% to 85% crude protein, has the highest content of sulfur-containing amino acids, with cystine up to 4%, and also has high levels of valine, leucine, isoleucine, and a variety of essential amino [12] acids needed by animals. It is feasible to use feather meal as a feed additive in animal feed after processing.

2.4.2 Blood Meal

Blood meal is a product[13] made from animal blood through special processing techniques and is rich in protein. The protein content of blood meal is 80%-86% [13]. It also needs to be fermented to reach its maximum value.

3 The Effects of Unconventional Protein Sources in Different Animal Feeds

3.1 Livestock and Poultry feed (Pigs, Chickens, Ducks)

In livestock farming, the focus of research is on the effects of unconventional protein sources on the growth performance and health of animals.

3.1.1 Growth Performance

Studies have shown that fermented protein significantly increases crude protein digestibility in broilers, and when the addition of fermented feed is 15%, it has a significant effect [6] on the average daily weight gain of broilers, which may have a positive effect on growth performance. In addition, experiments have shown that replacing 50% or less of fish meal with black soldier fly larva powder does not affect the growth performance of broilers and improves [14] the meat quality of broilers to some extent, while a substitution ratio of 75% or more significantly reduces the meat quality [14] of broilers. Therefore, it is necessary to find the optimal substitution ratio to balance the effect and cost. Studies have found that replacing soybean meal with 8% rapeseed meal in the diet has no effect on the growth performance of growing pigs and can reduce feed costs [15], while replacing soybean meal with 16% double-low rapeseed meal instead reduces the apparent dig [15]estibility of dry matter, organic matter, total energy and crude protein in piglets. This shows that the substitution ratio of unconventional protein sources is crucial to the growth performance of animals.

3.1.2 Health Status

Studies have shown that fermented cottonseed meal, fermented rapeseed meal, fermented peanut meal, rice protein powder, black soldier fly powder and fly maggot powder can all increase the standard ileal amino acid digestibility [16] of broilers, indicating that unconventional protein sources can have a beneficial effect on the intestines of livestock and poultry.

In general, unconventional protein sources, as feed additives, as substitutes for conventional protein source feeds such as soybean meal, may improve the growth performance of livestock and poultry. More importantly, it can reduce feed costs without altering growth performance and potentially improving health conditions. It is important to note that unconventional protein sources should be replaced in a reasonable proportion in the feed.

3.2 Aquatic Feed (Fish, Shrimp)

Among aquatic animals, especially carnivorous fish and shrimp, there is a high dependence on fish meal in feed. Therefore, the core of the application of unconventional protein sources in aquatic feed is the potential and feasibility of replacing fish meal.

Protein sources for aquatic feed usually include soybean meal and fish meal. However, these conventional resources are limited. For sustainable development and cost savings, unconventional protein sources have the potential to replace fish meal. Studies have shown that black soldier fly larvae powder replacing 25% and 100% of fish meal in feed can significantly increase the weight gain rate, specific growth rate, and protein efficiency of Jefu tilapia, with the best[17] effect in the treatment group replacing 100%, which well demonstrates that some high-quality unconventional protein sources have the potential to completely replace fish meal. But at the same time, experiments have found that when the ratio of defatted black soldier fly to replace fish meal in the vanna shrimp feed reaches 40%, 60%, 80%, and 100%, it will have different degrees of adverse effects [18] on the growth performance, muscle hardness, and muscle crude protein content of the shrimp. Similar cases are At higher substitution ratios (45%, 75%, and 100%), soybean meal levels in cottonseed concentrate protein substitutes can affect the growth and intestinal health [19]of Nile tilapia, so it is also necessary to pay attention to the upper limit of the proportion of unconventional protein sources replacing conventional protein sources.

3.3 Ruminant Feed

Rumen degradation rate to rumen protein ratio is a key indicator for evaluating the nutritional value of protein sources to ruminants. Ruminants have a more special digestive system compared to ordinary livestock and poultry, and further research is needed on the feasibility of using unconventional protein sources as feed additives in ruminant feed. Also, studies have shown that when using leguminous plants (acacia) as protein sources, it can enhance the protein synthesis capacity of rumen microorganisms in dairy goats, etc [20]., which also indicates that unconventional protein sources have the potential to replace soybean meal in ruminant feed.

As mentioned in the above three types of feed, the effects of unconventional protein sources in various animal feeds will vary depending on the species of the feed recipients and the physicochemical properties of the protein sources themselves. From the perspective of overall application prospects, these new protein resources show significant

application potential in enhancing the growth performance of animals, improving their health levels, and as an effective alternative to expensive traditional protein raw materials such as fish meal.

4 Challenges and Feasibility Analysis of Promoting Unconventional Protein Sources

Based on the classification and characteristics of unconventional protein sources and their application effects in animal production, it can be found that unconventional protein sources have the potential to replace conventional protein sources. Although they can be promoted, they still face challenges.

Economic benefits: Studies have found that when black soldier fly larvae powder is added in appropriate amounts, economic benefits [14] can be increased without affecting the growth performance of broilers, indicating that attention needs to be paid to the addition amount of unconventional protein sources in feed. Economic benefits are very important in animal feed. Unconventional protein sources can reduce the cost of feed production on the basis of improving animal growth performance and maintaining animal health, which is conducive to sustainable development.

Technical and data challenges: Research on unconventional protein sources is still scarce at present, industrialization technology is not mature enough, large-scale production urgently requires advanced breeding technology and processing equipment support [21], and also faces safety and health problems, such as the incomplete safety and nutritional value assessment system for insect protein feed, and the lack of unified standards and norms [21]. For plant by-product protein sources such as cottonseed meal, it is necessary to address the anti-nutritional factors (such as gossypol) or other restrictive components [9] contained in them in order to enhance their safety and nutritional value. So safety and health issues are also challenges for unconventional protein sources in the future.

However, unconventional protein sources still have great potential for development. The Ministry of Agriculture and Rural Affairs, in collaboration with the Ministry of Science and Technology, the Ministry of Education and other departments, has jointly increased support for the research and development and creation of new unconventional protein feed products, expanded the production scale and promotion and application of microbial protein raw materials, and provided strong support for ensuring feed grain supply and safeguarding national food security. Domestic regulations are constantly being improved, for example, black soldier fly and mealworm have been included in the Feed Raw Materials Catalogue.

5 Conclusions and Prospects

5.1 Conclusion

This study systematically sorted out the classification and characteristics of major unconventional protein sources such as insect protein, single-cell protein, plant by-products and animal by-products, and analyzed their application effects in the feed of livestock, poultry, aquatic products and ruminants. In general, unconventional protein sources have shown significant substitution potential and application value in animal production.

5.1.1 The Application Effect is Significant, But There are Species and Dose Differences

A large number of studies have shown that unconventional protein sources (such as black soldier fly larval powder, fermented protein, etc.) can not only maintain or improve the growth performance of animals (such as daily weight gain, feed conversion ratio), but also have positive effects on animal health (such as improving amino acid digestibility, improving intestinal health) at appropriate substitution ratios. However, there is an upper limit to the optimal substitution ratio, beyond which there may be negative effects (such as reduced meat quality and affected growth).

5.1.2 Dual Challenges of Economic and Ecological Benefits

The core driving force for the development and utilization of unconventional protein sources lies in their ability to reduce feed costs and decrease reliance on imports of traditional protein sources such as soybean meal and fish meal, thereby enhancing the security and stability of feed supply in our country. At the same time, many unconventional protein sources (such as insect protein) can realize the resource conversion of organic waste, in line with the requirements of circular economy and sustainable development.

5.1.3 Promotion Still Faces Core Challenges

At present, the industrial promotion of unconventional protein sources is still constrained by key bottlenecks such as economic benefits (the production cost of some protein sources, such as insect protein, is still higher than that of soybean meal), technological maturity (imperfect large-scale breeding and processing technology), and the lack of safety data (imperfect long-term feeding safety assessment system, anti-nutritional factors of some protein sources need further processing).

5.2 Research Prospects

Based on current research status and existing challenges, future research and development of unconventional protein

sources should focus on the following directions:

5.2.1 Precision Nutrition and Formulation Optimization

Future research needs to be more refined, establishing databases of optimal alternative ratios for unconventional protein sources for different animal species, breeds, and physiological stages. Focus on the combined use of multiple unconventional protein sources to achieve formula optimization and further cost reduction through nutritional complementarity effects.

5.2.2 Break through Key Technological Bottlenecks to Reduce Production Costs

Optimize large-scale insect farming, microbial fermentation efficiency, and detoxification and modification techniques for by-products (such as enzymatic hydrolysis, fermentation, physical extraction), and significantly reduce production costs through technological integration and innovation

Establish a complete database of unconventional protein source nutrients and anti-nutritional factors, and use modern technologies (such as bionic digestion, near-infrared spectroscopy) to rapidly assess their nutritional value and provide a basis for precise formulation.

5.2.3 Policy Guidance and Deep Integration of Industry, Academia And Research

Continue to strengthen collaborative support among government departments and increase investment in research and development. By deepening "industry-university-research" cooperation, we encourage research institutions and leading enterprises to work together to accelerate the transformation of laboratory results into market products, and jointly promote the maturation and growth of the unconventional protein source industry chain.

In conclusion, unconventional protein sources are the key path to ensuring future feed protein supply and promoting sustainable development of animal husbandry. Through multi-disciplinary and multi-field collaborative innovation, it is expected to overcome existing challenges and become an indispensable and important component of the feed industry.

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