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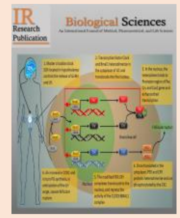

Biotech meets Artificial Intelligence to Enhance the Value of By-Products in Animal Nutrition

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ABSTRACT

The utilization of by-products from various industries in animal nutrition has been a common practice for many years. However, these by-products often have low nutrient availability and may contain anti-nutritional factors, limiting their use as animal feed. Biotechnology has provided various approaches to enhance the value of these by-products by improving their nutrient availability and safety for animal consumption. In this review, we discuss the biotechnological approaches used to enhance the value of by-products in animal nutrition, including the use of enzymes, fermentation, single-cell protein, and genetically modified crops. These biotechnological approaches can improve the digestibility and nutrient availability of by-products, increase the efficiency of animal production, and reduce waste. However, the safety of these biotechnological processes must be thoroughly evaluated to ensure that they do not have any negative impacts on animal or human health or the environment. This review highlights the potential of biotechnology to improve the utilization of by-products in animal nutrition and its future applications in the animal feed industry.

Introduction

Recent developments in livestock management have led to significant advancements in efficiency and productivity. These improvements include the implementation of automated feeding systems, milking robots, and advanced manure managements practices. In particular, the adoption of automatic milking systems (AMS) has grown significantly in the last two decades, with countries such as the Netherlands, France, and Scandinavia leading the way in Europe (De Koning, 2010. Suresh & Bas, 2021), to further optimize production efficiency, livestock managers are turning to advanced instrumentation, animal breeding techniques, genetic selection, and precision nutrition. These technologies can help improve animal health, increase yields, and reduce waste, ultimately leading to more sustainable and profitable operations. In terms of biotechnology, their use has revolutionized the market of animal nutrition and increased the potential feed utilization to meet up with a hike in global requirements of livestock products, which has reserved the role of animal nutritionist to set forth the optimize conditions which will increase feed efficiency to yield high livestock from less feed (Gupta B et al., 2022).

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The utilization of by-products from various industries in animal nutrition has been an effective strategy for reducing waste and increasing the efficiency of animal production. However, these by-products often have low nutrient availability and may contain anti-nutritional factors, limiting their use as animal feed. Food waste and by-products are good sources of protein, carbohydrates, vitamins, and minerals. However, the use of these products is limited in the food industry mainly due to the content of anti-nutritional factors (ANF) such as condensed tannins, saponins, trypsin inhibitors, phytates, isoflavonoids, among others (Ee and Yates, 2013; Tresina et al., 2017). Due to the adverse effects that the consumption of these anti-nutritional compounds can bring, several studies have been conducted in the last few years to develop methods to decrease the level of ANFs to permissible levels. These treatments are divided into three groups: physical (husking, soaking), thermal (extrusion, cooking, toasting, frying), and biological (germination, enzymatic treatment, fermentation) (Etoa et al., 2005; Khattab & Arntfield, 2009; Djoulde Darman et al., 2011; Nidhina & Muthukumar, 2015; Rathod & Annapure, 2016; Torres-León et al., 2018).

As predicted by researchers, the livestock industry has become a significant economic driver worldwide, with biotechnology playing a crucial role in its growth. Madan (2005), has previously reported that developing countries were not adequately prepared for the technological and economic change that lay ahead, including the opportunities, challenges, and risks associated with livestock production. However, these predictions have now become a reality. Today, livestock production is growing at a faster rate than any other sector globally, and it was predicted also to become the most important agricultural industry in terms of value addition (Nigatu, 2018). The increasing role of biotechnologies in livestock production has driven this growth and will continue to shape the industry's economic returns.

In this regard, different researchers demonstrate that the use of biotechnology will lead to drastic economic drift and improve livestock with sustainable living, with the fact that livestock has become progressively important for the growth of the agriculture sector in developing countries (Getabalew & Alemneh 2019, Gupta B et al., 2022). With the fact, to the increase in the global population, and the increase in the proportion of animal proteins in human diets, demands for valuable proteins are also increasing. Consequently, global aquaculture is facing continuing growth, followed by growth in global aqua feed production, which is expected to grow up to 73.15 million tons by 2025 (Tacon, 2020). Most food of animal origin consumed in developing countries is currently supplied by small-scale, often mixed crop-livestock family farms or by pastoral livestock keepers (John & Maria, 2001).

In terms of animal nutrition, biotechnology can improve the plane of nutrition through the protection of protein, amino acids (Yadav & Chaudhary, 2010), and fat (Shelke et al., 2011), However, those options are no longer sustainable for production, consequently, new intensive techniques including biotechnology are now required to augment productivity. Furthermore, it was suggested that biotechnological approaches can be employed for improving the productivity, economy, and physicochemical and nutritional attributes of a wide range of livestock products (Gupta & Savalia, 2012).

Regarding reducing factors, By-products and waste generation are having an impact on environmental, economic, and social sectors. To the environment, these contribute to Green House Gas (GHG) emissions (Girotto et al., 2015).

Modern biotechnology has the potential to provide new opportunities for achieving enhanced livestock productivity in a way that alleviates poverty, improves food security and nutrition, and promotes sustainable use of natural resources (Leng, 1991). Some scientific research has been conducted recently based on Artificial Intelligence (AI) to solve animal welfare and health-related problems (Bao & Xie, 2022). It was shown also by this author that most scientific research in animal farming driven by sensors and AI models was focused on data collection, processing, assessment, and analysis in the areas of animal behavior detection, disease monitoring, growth estimation, and environment monitoring at the experimental stage; there will be some issues in the ability for applying AI by all farmers in terms of costs and economical capacities. The integration of biotechnology in animal nutrition with artificial intelligence (AI) can lead to significant advancements in the field of animal agriculture. AI technologies, such as machine learning, can be used to analyze large amounts of data from various sources, including genetics, animal behavior, and nutrition, to develop more accurate and personalized animal diets.

On the one hand, facing the different applications of AI in recent days, using AI in biotechnology for animal nutrition is in precision feeding. By using sensors and machine learning algorithms, farmers and producers can monitor individual animals and adjust their diets in real time to meet their specific nutritional needs. This can help improve animal health and performance while reducing waste and the environmental impact of animal agriculture. On the other hand, biotechnology has provided various approaches to enhance the value of by-products by improving their nutrient availability and safety for animal consumption. Based on showing the principal process in biotechnology in animal nutrition and the idea of applying Intelligence Artificial to formulate new feeds based on the most beneficial components, this approach is to enhance the nutritious problem. This work discusses the principles of biotechnology in animal nutrition and the idea of how AI can be applied to enhance the nutrient value of by-products. The integration of biotechnological approaches with AI can help create more nutritious animal feeds, ultimately improving animal health and production while minimizing environmental impacts. create more nutritious animal feeds, ultimately improving animal health and production while minimizing environmental impacts.

Exploring the fundamental processes of Biotechnology in Animal Nutrition

Enzyme technology

The use of enzymes in animal nutrition has an important role in current farming systems (Choct, 2006). Currently, feed enzymes available commercially by catalytic types are 3-phytase, 6-phytase, subtilisin, α-galactosidase, glucanase, xylanase, α-amylase and polygalacturonase, and most for the swine and poultry segment (Selle & Ravindran, 2007).

Enzyme technology has been widely used to improve the digestibility of complex carbohydrates and proteins in by-products. The addition of exogenous enzymes such as phytase, xylanase, and cellulase to feed-containing by-products can improve nutrient availability by breaking down complex carbohydrates and proteins into simpler forms that can be more easily absorbed by animals. For example, the use of cellulases and xylanases has the added advantage of increasing the digestibility, thereby reducing the amount of manure and possibly methane emissions from ruminants. However, the response to the addition of enzymes in ruminants appears to be variable (Rode et al., 2001), the addition of phytase to animal feed containing soybean meal can increase the availability of phosphorus, an essential nutrient, and reduce the excretion of phosphorus in animal waste. With the aid of biotechnology, more effective enzyme preparations, can now be produced in large amounts at less cost (Mc Donald et al., 2010)

The animal feed enzyme sector grew at a rate of 4 percent per year between 2004 and 2009 and it is expected to grow annually by 6 percent from 2007 to 2012 (Thakore, 2008). But the use of enzymes as feed additives is restricted in most countries by local regulatory authorities (Pariza & Cook, 2010).

Fermentation Technology

Fermentation technology has also been used to improve the value of by-products in animal nutrition (Aro 2008). Fermentation can convert complex organic compounds into simpler compounds such as organic acids and enzymes, which can be used to enhance the digestibility of animal feed (Njokweni et al., 2021). For example, the fermentation of molasses can produce organic acids such as lactic acid, which can improve the nutrient availability of animal feed. Additionally, the use of fermentation can reduce the levels of anti-nutritional factors in by-products, making them safer for animal consumption (Suhag et al., 2021).

Among the biological treatments, fermentation has been identified as one of the processes with greater

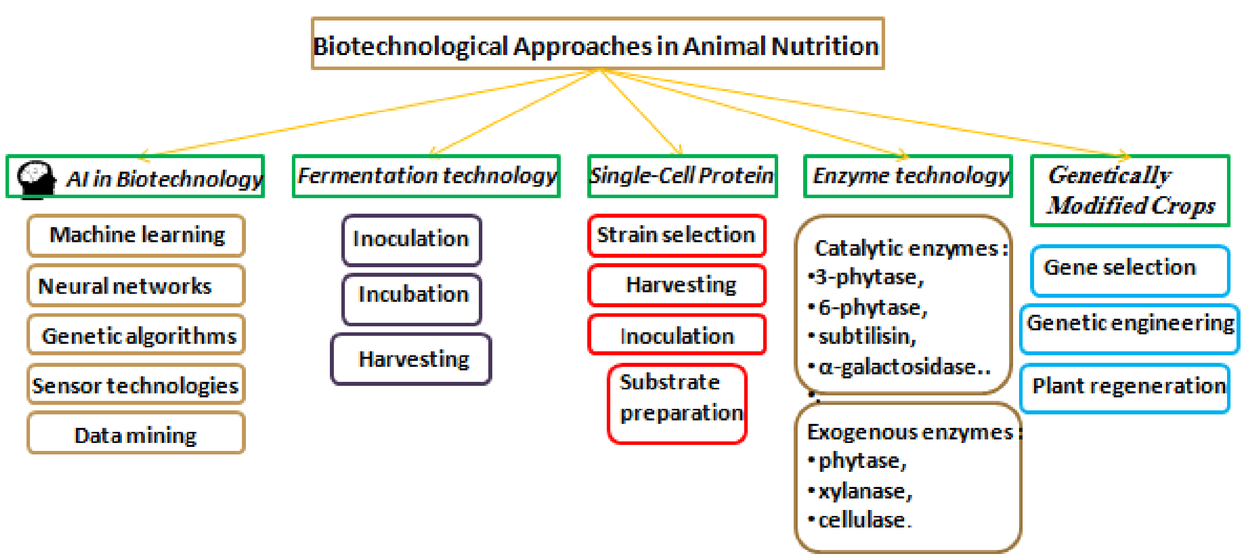

Fig 1. General scheme for biotechnology approaches and AI in animal nutrition.

efficiency because the ANF has been reduced and the digestibility of the protein has been increased substantially by this process. Microorganisms most used here are lactic acid bacteria (LAB) and filamentous fungi of the genus Aspergillus and Rhizopus. One of the special characteristics of these microorganisms is that they are recognized as safe (GRAS) since they are not producers of mycotoxins (Bangar et al., 2021).

Fermentation technology can be used to improve the value of by-products in animal nutrition by increasing the availability of nutrients and reducing the presence of anti-nutritional factors. The fermentation process involves the use of microorganisms to convert carbohydrates and proteins in the by-products into more digestible forms (Dawood & Koshio, 2020; Tanasković et al., 2021).

The resulting fermented products can be used as feed ingredients for livestock, improving their health and productivity.

Methods

Inoculation: The by-products are inoculated with specific strains of microorganisms, such as bacteria or fungi that can break down the carbohydrates and proteins in the material (Hasan et al., 2014).

Incubation: The inoculated by-products are incubated at a specific temperature and pH to allow the microorganisms to grow and produce enzymes that break down the carbohydrates and proteins (Schwan & Wheals, 2004).

Harvesting: Once the fermentation process is complete, the fermented product is harvested, dried, and milled into a form suitable for use as animal feed (Igbadul et al., 2014).

Those techniques including biotechnology are required to augment productivity, modernity, food security, and nutrition and promote sustainable use of natural resources (Asmare, 2014). For example, the fermentation of corn stover, a by-product of corn production (Lu et al., 2010, has been shown to increase the availability of nutrients such as protein, fiber, and minerals while reducing the presence of anti-nutritional factors such as lignin and phytic acid. Fermentation of soybean meal, a by-product of soybean processing (Pettersson & Pontoppidan, 2013), has been shown to increase the availability of amino acids and reduce the presence of trypsin inhibitors, which can interfere with protein digestion in animals.

Principles of Use

Selecting appropriate microorganisms: The choice of microorganisms used for fermentation should be based on their ability to break down specific components of the by-product and produce beneficial metabolites (Bych et al,, 2019) Optimizing fermentation conditions: The temperature, pH, and incubation time should be optimized for the specific microorganisms used to ensure optimal fermentation and maximum nutrient availability (Lakshmi et al., 2009).

Ensuring safety: The fermented product should be evaluated for safety and quality before use in animal feed to ensure that it does not contain harmful substances or contaminants (Nout & Motarjemi, 1997).

We should note that fermentation technology is a promising strategy for improving the value of by-products in animal nutrition. By optimizing fermentation conditions and selecting appropriate microorganisms, we can create high-quality fermented products that can improve the health and productivity of livestock.

Single-Cell Protein

Single-cell protein (SCP) is a potential alternative protein source for animal feed. SCP can be produced from various sources such as algae, yeast, and bacteria. SCP has high protein content and can be used to replace traditional protein sources such as fishmeal and soybean meal in animal feed. SCP production can also be an effective way to reduce waste by utilizing organic residues from various industries.

From the 1970s to the 1990s extensive research was conducted on single-cell proteins. Except for some algae, however, they are not being incorporated into livestock diets in either developing or developed countries. Algae such as Azolla and Lemna are used to a limited extent as feed for pigs by small-scale farmers. (Tema, 2015). Many microalgae are important sources of polyunsaturated fatty acids (PUFA), mainly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Barta et al., 2021; Sharma et al., 2020). This PUFA is poorly synthesized by animals, so it should be included in their diet. In addition, they are a rich source of almost all of the important minerals as well as vitamins. Additionally, some microalgae generally have a high protein content and a high digestibility (Hashemian et al., 2019).

In this context, microalgae already available on the market, become an alternative replacing conventional ingredients. To our knowledge, the use of small amounts of microalgae biomass in the feed can benefit the physiology of the animals, improving the immune response, resistance to diseases, antiviral and antibacterial action, intestinal function, and stimulation of probiotic colonization (Raja al., 2008). In general, the addition of these compounds to the diets of animals enhances their overall health and immune status, productivity, and the quality and stability of the resulting animal products. (Souza C & Dos Santo, 2021). Although the use of microalgae is increasingly directed towards many types of animals: cats, dogs, ornamental fish, horses, poultry, swine, sheep, and cow, studies still need to be explored.

Single-cell protein (SCP) is a potential alternative protein source for animal feed that can be produced using microorganisms such as bacteria, yeast, and fungi (Bratosin et al., 2021). SCP production involves the growth of these microorganisms on various substrates, such as waste products, to produce protein-rich biomass that can be used as animal feed (Suman et al., 2015).

Methods

Strain selection: The appropriate microorganism is selected based on its ability to grow on the chosen substrate and produce a high protein yield (Nasseri et al., 2021). Substrate preparation: The substrate is prepared to provide the necessary nutrients for the growth of the microorganism. This may involve sterilization, pH adjustment, and the addition of minerals and vitamins (Sharif et al., 2021).

Inoculation: The microorganism is inoculated into the substrate and allowed to grow under specific environmental conditions such as temperature, pH, and aeration (Md, 2012).

Harvesting, drying, and milling: Once the microorganism has grown and produced a sufficient amount of biomass, it is harvested and separated from the substrate (Nasseri et al., 2014).. The harvested biomass is dried and milled into a powder or pellet form suitable for use as animal feed (Nunes et al., 2014).

SCP production has been shown to be a promising alternative protein source for animal feed. Studies have shown that SCP produced using bacteria or fungi can have a protein content of up to 70-80%, comparable to traditional protein sources such as soybean meal or fishmeal. SCP can also be produced using a range of substrates, including agricultural waste products and industrial by-products, reducing the environmental impact of animal feed production (Bratosin et al., 2021).

Application Process from A to Z.

- Market research: Research the market demand and potential for SCP as an alternative protein source for animal feed.
- Infrastructure setup: Establish a production facility and equipment for SCP production, including fermentation tanks, drying and milling equipment, and quality control systems.
- Strain selection: Select an appropriate microorganism strain for SCP production based on the chosen substrate and protein yield.
- Substrate preparation: Prepare the substrate for optimal growth and protein production of the selected microorganism strain.
- Inoculation and fermentation: Inoculate the microorganism into the substrate and grow it under optimal environmental conditions for protein production.
- Harvesting and separation: Harvest the SCP biomass and separate it from the substrate using filtration or centrifugation.
- Drying and milling: Dry and mill the SCP biomass into a suitable form for animal feed.
- Quality control: Conduct quality control tests to ensure that the SCP biomass meets safety and nutritional requirements for animal feed.

Distribution and marketing: Distribute and market the SCP biomass to animal feed manufacturers and farmers as an alternative protein source for animal feed (Halmemies-Beauchet-Filleau et al., 2018).

The SCP is a potential alternative protein source for animal feed that can be produced using microorganisms and various substrates. The SCP production process involves strain selection, substrate preparation, inoculation, fermentation, harvesting and separation, drying and milling, and quality control. By optimizing the SCP production process, we can create a sustainable and environmentally friendly protein source for animal feed.

Genetically Modified Crops

The use of genetically modified (GM) crops has been a significant development in animal nutrition (Domino & Bordonaba, 2011). GM crops can be engineered to produce specific nutrients that are lacking in traditional feed sources. For example, GM corn can be engineered to produce high levels of lysine, an essential amino acid, which is often deficient in animal feed (Houmard et al, 2007). Additionally, GM crops can be engineered to produce fewer anti-nutritional factors, making them safer for animal consumption.

The use of genetically modified (GM) crops in animal nutrition has been a significant development that has revolutionized the animal feed industry. GM crops are developed by introducing genes into plant genomes to produce specific traits (Rommens, 2004) such as resistance to pests, herbicides, or drought. These traits can improve the nutritional value, safety, and sustainability of animal feed.

This area where can be integrated with AI for their development. With the help of AI, scientists can more efficiently identify the genetic traits that are most beneficial for improving animal nutrition and health. This can lead to the development of GMOs that are better suited for animal feed and that can help reduce the need for synthetic additives and antibiotics in animal diets.

Process

- Gene selection: A gene or set of genes is selected based on its potential to improve the nutritional value, safety, or sustainability of animal feed (Zhang et al., 2008).
- Genetic engineering: The selected gene is inserted into the plant genome using various genetic engineering techniques such as agrobacterium-mediated transformation or gene gun bombardment (Altieri, 2004).
- Plant regeneration: Genetically modified plant cells are regenerated into whole plants through tissue culture techniques (Evans et al., 2020).
- Field trials: Genetically modified plants are tested in field trials to assess their performance, including yield, pest resistance, and nutritional value (Chen., Shelton., & Ye, 2011).
- Regulatory approval: GM crops are evaluated by regulatory agencies to assess their safety for animal and human consumption, as well as their impact on the environment (Waters et al., 2021).

The genetic engineering of crops can be used to improve their nutritional value for animal feed by enhancing the levels of certain nutrients, such as amino acids, vitamins, or minerals. For example, GM soybeans have been developed to produce higher levels of essential amino acids such as lysine and methionine, which are important components of animal feed. GM maize has been engineered to produce phytase, an enzyme that improves the availability of phosphorus in animal feed.

GM crops can also be used to reduce the presence of anti-nutritional factors in animal feed, such as trypsin inhibitors or lectins. These factors can reduce the digestibility of feed and affect animal growth and health. GM soybeans have been developed to reduce the levels of trypsin inhibitors, improving the digestibility of soybean meal in animal feed.

Application

The use of GM crops in animal nutrition has become widespread, particularly in the poultry and livestock industries. GM soybean and maize varieties are widely used as ingredients in animal feed, particularly in the United States, Brazil, and Argentina. GM cottonseed meal is also used in animal feed in India, China, and Pakistan (Henseler et al., 2013). Studies have shown that GM crops can improve the nutritional value and safety of animal feed, leading to better animal health and growth. For example, GM soybeans with improved amino acid content have been shown to increase growth rates and feed conversion efficiency in poultry and pigs (Krishnan & Jez, 2018) GM maize with increased phytase activity has been shown to improve phosphorus availability and reduce the need for supplementary phosphorus in animal feed.

In conclusion, the use of GM crops in animal nutrition has been a significant development that has improved the nutritional value, safety, and sustainability of animal feed. The process of developing GM crops involves gene selection, genetic engineering, plant regeneration, field trials, and regulatory approval. The application of GM crops in animal feed has become widespread, particularly in the poultry and livestock industries, and studies have shown their positive effects on animal health and growth.

The Use of AI in Biotechnology for animal nutrition Purposes

This review provides an innovative idea for collecting big data on farm animal nutrition, which can be used to create personalized diets for individual animals based on their specific nutritional needs. By collecting data on an animal's age, weight, breed, and other factors, train artificial intelligence models to classify, quantify and predict. AI algorithms can recommend precise amounts of protein, carbohydrates, and other nutrients to optimize their health and productivity. Deep learning models can be trained to classify these affective states using sensor-collected data (Kolias et al., 2019; Zhang et al., 2017).

The use of AI in biotechnology for animal nutrition purposes has the potential to improve animal health and productivity, reduce environmental impact, and enhance food security. AI can be used to analyze large amounts of data and develop predictive models to optimize animal nutrition.

AI can also be used to develop new feed formulations that are more efficient and sustainable. By analyzing data on the nutritional content and availability of different feed ingredients, AI can identify the optimal combination of ingredients for a particular animal species or production system. This can help reduce the environmental impact of animal agriculture by reducing the amount of feed needed to produce a given amount of meat, milk, or eggs. AI can be used to monitor animal health and detect signs of disease or nutritional deficiencies (Rodriguez-Martinez et al al., 2008). By analyzing data from sensors or other monitoring devices, AI can identify patterns or anomalies that indicate a problem and alert farmers or veterinarians to take action.

Overall, the use of AI in biotechnology for animal nutrition purposes has the potential to transform animal agriculture by improving animal health and productivity, reducing environmental impact, and enhancing food security.

There are several methods that can be used to apply AI in biotechnology for animal nutrition purposes. Here are some of the most common methods:

Machine learning

This involves training algorithms to learn from large datasets of animal nutrition data and use that knowledge to make predictions and optimize animal diets. Machine learning algorithms can be trained on data from feed trials, animal performance records, and other sources to identify patterns and optimize feed formulations. Since Advanced statistical analyses were applied to the annotated data set using supervised AI and ML methods, namely the Latent Growth Curve Modelling, Random Forest, and Support Vector Machine models (Zhang et al., 2020; Elhaj et al., 2018).

Neural networks

This is a subset of machine learning that involves creating algorithms that simulate the way the human brain works (Ghosh & Adeli, 2009; Bishop, 1994) Neural networks can be trained on large amounts of data to recognize patterns and make predictions about animal nutrition needs.

Genetic algorithms

This is a type of optimization algorithm that mimics the process of natural selection to find the best solution to a problem (Kramer, 2017). Genetic algorithms can be used to optimize feed formulations by evaluating different combinations of ingredients and identifying the ones that produce the best results.

Data mining

This involves extracting useful information from large datasets of animal nutrition data (Silwattananusarn & Tuamsuk, 2012). Data mining techniques can be used to identify patterns and trends in animal performance data, feed ingredient data, and other sources of animal nutrition data.

Predictive modelling

This involves using data to create mathematical models that can be used to make predictions about animal nutrition needs (Zeng et al., 2015). Predictive modeling can be used to optimize feed formulations, predict animal performance, and detect health problems before they become serious.

Sensor technologies

This involves using sensors and other monitoring devices to collect data on animal behavior, feed intake, and other factors that affect animal nutrition. The data collected by these sensors can be used to optimize animal diets and detect health problems early.

These methods can be used individually or in combination to optimize animal nutrition and improve animal health and productivity.

Example of training algorithms

One example of training algorithms for animal nutrition purposes involves using machine learning to develop predictive models for optimizing animal diets. This can be done by collecting data on animal performance, such as weight gain, feed intake, and feed conversion ratio, and using that data to train a machine-learning algorithm (Oliveira et al., 2021).

The first step in this process is to collect and prepare the data. This involves collecting data from animal performance records, feed trials, and other sources, and organizing it into a format that can be used for machine learning. The data should be cleaned and pre-processed to remove any errors or inconsistencies and to ensure that it is suitable for analysis.

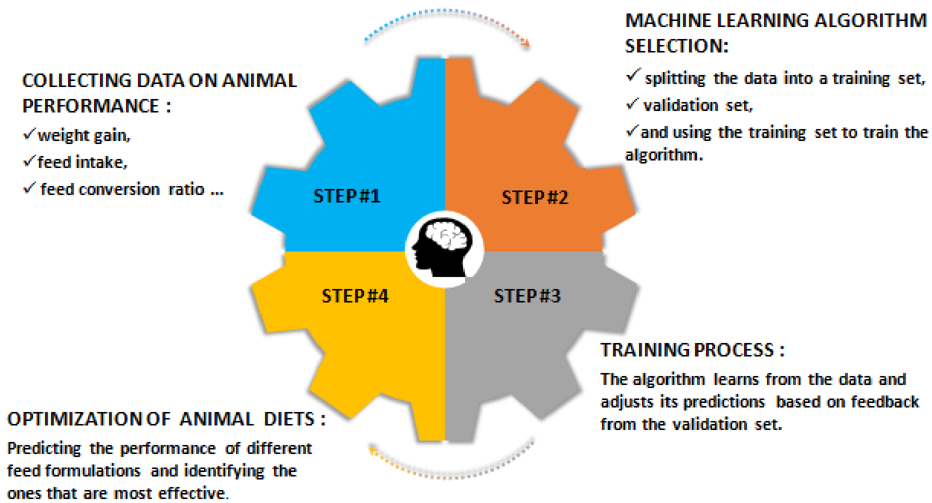

Fig 2. Training algorithms examples for animal nutrition.

Once the data has been prepared, the next step is to select a machine learning algorithm and train it on the data. This involves splitting the data into a training set and a validation set, and using the training set to train the algorithm to make predictions about animal performance based on different feed formulations.

During the training process, the algorithm learns from the data and adjusts its predictions based on feedback from the validation set. This process continues until the algorithm can make accurate predictions about animal performance based on different feed formulations.

Once the algorithm has been trained, it can be used to optimize animal diets by predicting the performance of different feed formulations and identifying the most effective ones. The algorithm can also be used to identify factors that affect animal performance, such as nutrient requirements, and to develop personalized diets for individual animals based on their specific needs. Overall, training algorithms using machine learning is a powerful tool for optimizing animal diets and improving animal health and productivity.

Expected Results

As the figure 3 shows; the use of AI in biotechnology for animal nutrition purposes has already yielded promising results:

- Personalized diets: By using AI algorithms to analyze individual animal data, it is possible to create personalized diets that meet the specific nutritional needs of each animal. This has been shown to improve animal health and productivity and reduce feed waste.
- Efficient feed formulations: AI can be used to optimize feed formulations by identifying the most efficient combination of feed ingredients for a particular animal species or production system. This can help reduce the environmental impact of animal agriculture by reducing the amount of feed needed to produce a given amount of meat, milk, or eggs.
- Health monitoring: AI can be used to monitor animal health and detect signs of disease or nutritional deficiencies. By analyzing data from sensors or other monitoring devices, AI can identify patterns or anomalies that indicate a problem and alert farmers or veterinarians to take action.
- Improved production: By optimizing animal diets and improving animal health, AI can help increase production and reduce costs for farmers. This can help make animal agriculture more sustainable and profitable in the long term.
- Overall, the use of AI in biotechnology for animal nutrition purposes has the potential to transform animal agriculture by improving animal health and productivity, reducing environmental impact, and enhancing food security. With continued research and development, we can expect to see even more significant results in the years to come.

Conclusion

The integration of biotechnology with artificial intelligence (AI) in animal nutrition will open up new opportunities for precision feeding, improved animal health and production, and reduced environmental impacts on animal livestock. The use of sensors and machine learning algorithms allows farmers and producers to monitor individual animals and adjust their diets in real time, meeting their specific nutritional needs. Otherwise, biotechnology is introducing innovative approaches to enhance the value of by-products in animal nutrition, with those processes AFN will be eliminated and make safe food for animal and human purposes. Further improving animal health and production. The application of AI in these biotechnological approaches can lead to the more efficient formulation of nutritious feeds. By exploring the fundamental processes of

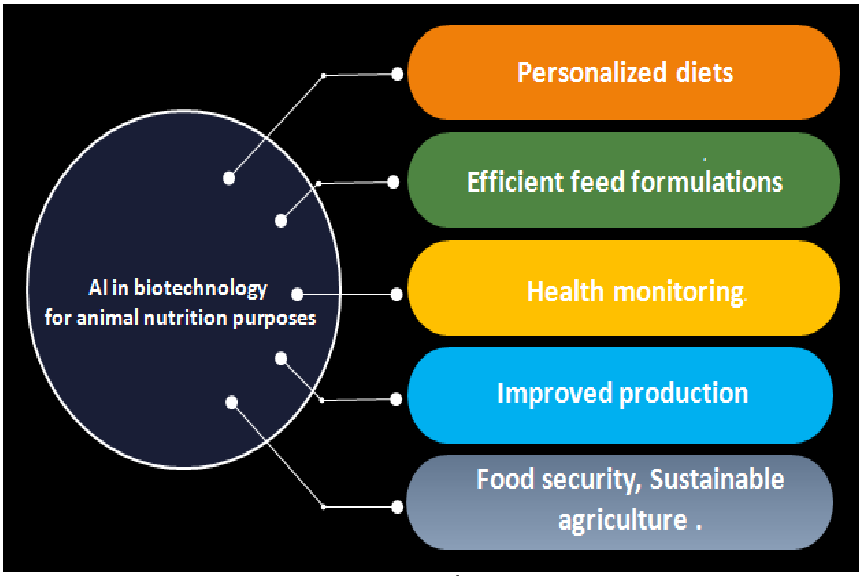

Fig 3. AI in biotechnology of animal nutrition results.

biotechnology in animal nutrition and integrating AI, the industry can continue to progress towards more sustainable and efficient livestock.

Contribution of authors

Oussama S and Chaima B, contributed to the conception and design of the study, data collection, interpretation, drafting and critical revision of the manuscript, and final approval of the version to be published.

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Conflict of interest

The authors declare no conflicts of interest exist in the submission of this manuscript.

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