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Review Article

Feed Sustainability and Efficiency

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ABSTRACT

As the world population approaches the projected 10 billion thresholds in 2050, it is anticipated that global food demand, particularly for protein, would increase dramatically in the ensuing decades. In terms of absolute and relative growth rates, poultry has outpaced the other major meat types produced globally over the past 50 years. Poultry production is expected to continue to be a significant and expanding sector of meat production due to escalating global demand. Scientists need to rethink their approaches considering the rapidly increasing demand for poultry meat coming from both developed and developing countries worldwide. Several problems impede the chicken industry's value chain. Several challenges impede the poultry industry's value chain. Production must be both socially and environmentally responsible in addition to being economically viable. Nutritional improvements for chickens will aid in addressing these problems. It is evident how crucial it is to use a holistic strategy to properly and sustainably transform feed into high quality poultry protein. Regardless of the time of year, these high-yielding animals need to be able to consistently consume, digest, absorb, and convert enough nutrients to meet their genetic potential. To attain high consistency output with acceptable risk, this task will require improving the usage of existing technology, developing new technology, and expanding our knowledge and information network.

Keywords: Poultry; Feed efficiency; Sustainability; Nutrition; Balanced diet; Technology

INTRODUCTION

The demand for poultry meat and other associated products has skyrocketed over the past few years. In 2020, there were 137 million tons of chicken meat produced globally, making it the most popular meat worldwide. Consequently, the chicken industry makes a significant contribution to the consumption of animal proteins, human nutrition, and global food security [1]. The world has seen a tremendous increase in the demand for poultry meat and other poultry feed with the advent of time. The trend of this growing demand will continue over time. It is not exaggerated to say that with the increase in demand, the production of poultry meat and egg has also increased both in developed and developing countries. In the next 20 years, it is predicted that a rapid increase in poultry production will take place in developing countries too because of rapid urbanization and the higher increase in animal protein demand. Globally, the poultry industry has grown quickly due to several factors, including improved knowledge of poultry feeding, genetic selection, and disease management. The main factor in improving egg and meet quality and quantity has been feed formulation [2]. For instance, the time it takes for a 2 kg meat chicken to reach the market has significantly decreased from 63 days to 35 days between 1976-2009, because of the efficient conversion of feed into poultry products. The need for feed and raw materials is significantly being impacted by this increase in poultry production. The key input for poultry production is feed, hence low cost, high quality feeds must be readily available if poultry production is to remain competitive and expand to meet consumer demand for animal protein.

LITERATURE REVIEW

Feed system and poultry production

The poultry sector, historically, has passed through a system of evolution with three distinct phases:

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- Traditional system of poultry production at home to meet the domestic need.
- Semi-commercial poultry production system.
- Industrial scale production.

Every system operates within a basic technological framework. The factors that set one production system apart from another are bird selection, husbandry, and feed systems. Depending on the approach implemented, different amounts of food, nutrition, and resources are needed to grow poultry.

Strategies in traditional systems: Most developing countries still raise poultry using traditional methods. The local birds raised in this system might be fed on household wastes, environmental materials (arthropods, mollusks, greens, seeds, etc.) agricultural residues, feedstuffs, and aquatic plants, as well as by-products from nearby small industrial units. The struggle for feed resources in villages determines the survival and expansion of extensive poultry systems.

Feeding strategies in semi-commercial system: Small to medium sized flocks of native or enhanced genotype birds and the purchase of at least half of the feed from industrial compounders define the semi-commercial poultry system. The feeding methods utilized in this approach include dilution of purchased feed with local feed, total mixing of local feed with commercial feed, and complete ration mixing on the farm.

Feeding strategies in the commercial system: Commercial production is dominated by developed nations, and it has recently become more prevalent in developing nations as well. This system makes use of vertically integrated production units and birds that have undergone genetic analysis. Feed is the core element of such a system, accounting for more than 60% of the costs of production. Productivity in such a system is reliant on the availability of a highly effective feeding system and the usage of nutritionally balanced and designed feed to meet the needs of the birds.

Feeding poultry with a balanced diet

Since most poultry species are omnivores, it is possible to combine several feeds to create the most useful final feedstuff. Except for a few geese and ostriches, which have well-developed digestive systems, most birds are sensitive to food because of their digestive systems. Most birds have substantially shorter digestive systems than other animals. Food passes from the mouth through the cloaca in less than three hours in chickens with rapid growth. High performing birds require nutrient rich diets that are considerably easier to digest to compensate for their short digestive systems and quick digestion times. Nutrient balance is crucial under these circumstances [3].

Because genetic modifications have also altered the physiology of the birds, genetic selection cannot function alone. By altering dietary needs and nutritional management, the genetic potential of the new strain can only be met. The high genetic potential of the newly selected birds can only be achieved with the help of properly formulated energy and nutrient dense feed. Poultry, especially growing birds, is exceptional in that any change in the composition of the diet has an immediate and noticeable impact on the performance of the birds. The poultry industry has successfully taken advantage of this phenomenon (Table 1) [4].

Table 1: Minimum nutrient recommendations for laying hens and meat chickens expressed as percentages or units per kg of food.

		Meat chickens			Lying hens
Nutrient	**Unit**	**0 week-3 weeks**	**3 weeks-6 weeks**	**6 weeks-8 weeks**	
Metabolizable energy	kcal/kg	3200	3200	3200	2900
	MJ/kg	13.38	13.38	13.38	12.13
Crude protein	%	23	20	18	15
Amino acids					
Arginine	%	1.25	1.1	1	0.7
Glycin+serine	%	1.25	1.14	0.97	-
Histidine	%	0.35	0.32	0.27	0.17
Isoleucine	%	0.8	0.73	0.62	0.65
Leucine	%	1.2	1.09	0.93	0.82
Lysine	%	1.1	1.1	0.85	0.69
Methionine	%	0.5	0.38	0.32	0.3

Methionine+cysteine	%	0.9	0.72	0.6	0.58
Phenylalanine	%	0.72	0.65	0.56	0.47
Phenylalanine+tyrosine	%	1.34	1.22	1.04	0.83
Threonine	%	0.8	0.74	0.68	0.47
Tryptophan	%	0.2	0.18	0.16	0.16
Valine	%	0.9	0.82	0.7	0.7
Fatty acid					
Linoleic acid	%	1	1	1	1
Major minerals					
Calcium	%	1	0.9	0.8	3.25
Chlorine	%	0.2	0.15	0.12	0.13
Non-phytate phosphorus	%	0.45	0.35	0.3	0.25
Potassium	%	0.3	0.3	0.3	0.15
Sodium	%	0.2	0.15	0.12	0.15
Trace minerals					
Copper	mg	8	8	8	-
Iodine	mg	0.35	0.35	0.35	0.04
Iron	mg	80	80	80	45
Manganese	mg	60	60	60	20
Selenium	mg	0.15	0.15	0.15	0.06
Zinc	mg	40	40	40	35

Recent advancements in poultry nutrition

The biggest single cost connected with raising poultry is feed. Therefore, nutritional research in chickens has focused on problems relating to finding impediments to optimal nutrient digestion and usage, as well as on methods for enhancing feed utilization. The knowledge of experts in other biological sciences, such as molecular biology, immunology, microbiology, histology, and microanalysis, is increasingly being blended with that of specialists in poultry nutrition. It is seen that most of the feed is not converted into animal products and most of the feed goes as undigested waste. In most cases in broilers, though they are efficient in food digestion, 30% of the ingested feed goes undigested. This reveals that the effectiveness of feed utilization for animal products has improved [5].

Recent advancements in poultry nutrition have mostly focused on three domains:

- Gaining knowledge of the needs and metabolism of nutrients.
- Determining the number of nutrients and their availability in feed ingredients.
- Designing diets at the lowest possible cost that successfully balance nutritional supply and demand.

Precision feeding is the overarching goal to reduce expenses and increase economic gains. When there was uncertainty regarding the supply of essential nutrients, such as phosphorus and amino acids, or when dietary requirements were unclear, there was a historical inclination to over-formulate diets. This method is no longer permitted since it is wasteful and because excess nutrients excreted in the manure eventually become a source of pollution. Optimizing the efficiency of nutrient use involves fine tuning meals to better meet the needs of the birds [6].

Nutrient requirement: Nutrient requirements are difficult to define since they are always changing and affected by a wide

range of variables. Two main categories of variables determine nutrient requirements: Those that are unique to birds, such as their genetic make-up, sex, form, and stage of development, and those that are present in their environment. Precision in defining criteria depends on accuracy in both areas. The characterization of nutrient requirements for various classes of chicken has significantly advanced owing to the improved uniformity of genotypes, housing, and husbandry practices across the poultry industry. It has made it possible to make significant advancements in the definition of nutrient requirements for various classes of chickens.

Identifying the nutrient profile and ingredient quality: Producers of poultry are constantly looking for ways to increase the types and quantities of feed additives they can use in feed formulations. The prevalence of these possibilities is raising because of improvements in feed evaluation and nutritional analysis methods. The main purpose of the feed ingredients is to provide the nutrients that the bird consumes and uses for vital processes. Data on the ability of raw materials to delivering key nutrients are currently in abundance. However, the inherent heterogeneity of each raw material puts strain on the precise feed formulations. Data on variation (or matrices) for the main feed ingredients are available and used in feed formulation systems to increase precision. It is an important advance that quick diagnostics, such as near infrared reflectance analysis, are now available to determine gross nutritional content and continually track changes in ingredient supply.

It is established that not all nutrients in foods are available for use in production and that some nutrients in foods are either excreted undigested or are not utilized. As feed evaluation techniques advance, data on the availability of nutrients for chicken, particularly phosphorus and amino acids, have been growing. The greater use of digestible amino acid concentrations in feed formulations rather than total amino acid concentrations, for instance, is a new trend. The use of digestible amino acid content is especially important in developing countries where highly digestible conventional products are not easily accessible and diet formulations may include components with low digestibility.

By developing diets based on digestible amino acids, it is possible to increase the product categories that may be used and the proportions of alternative items that can be used in poultry diets. This assures more constant performance from the birds and improves formulation accuracy, which may also result in lower feed costs.

Feed formulation: Once the nutritional requirements have been determined, the following step is to blend products and supplements to meet those requirements. A balanced diet offering the proper amounts of nutrients that are biologically available is the aim of the formulation. Commercial food producers also strive to provide a healthy diet for the cheapest price possible. The production of a least cost feed necessitates numerous mathematical calculations due to the variety of available feedstuffs and nutritional requirements. Over time, feed formulation has changed from the straightforward balancing of a few feed ingredients for a small number of nutrients to a computer assisted linear programming system. With commercially available formulation software, stochastic non-linear programming systems are currently becoming more and more common. The next stage is to combine products and supplements to meet the nutritional demands after they have been identified. Since the variation in ingredient composition is non-linear, stochastic programs are the most efficient way to combat this issue.

Nonconventional feed resources in poultry

Over the years, there has been a massive rise in the consumption of chicken products, particularly poultry meat, and this trend is likely to continue. The developing world will account for a large portion of the rise in worldwide demand for chicken products [7]. The poultry industry's explosive growth has a substantial impact on the need for feed and raw materials. The demand for the four elements that make up conventional feed maize, soybean meal, fishmeal, and meat meal cannot be met, even with optimistic estimates. It is crucial to look into the use of locally available, alternative feedstuffs in feed compositions because it is predicted that the gap between local supply and demand for these traditional components will widen over the coming decades [8].

A wide range of alternative feedstuffs is available to all three poultry production systems. The semi-commercial system and traditional family poultry systems (scavenging and backyard) hold the best possibility of properly utilizing these feeds. Only a portion of the feed requirement is met by commercial compounders, hence the semi-commercial technique allows for the mixing or dilution of purchased feeds with locally available, alternative feedstuffs. In local, low-input family poultry systems, alternative feeds can be used to supplement the feed foundation [9].

Non-conventional feed sources: The term "Non-Conventional Feed Resources" (NCFR) refers to all feeds that are either not typically utilized in commercially manufactured livestock rations or have not historically been used in animal feeding. NCFR generally includes a range of feeds derived from perennial crops as well as feeds with both animal and industrial origins [10]. Single cell proteins, feed material made from agro industrial byproducts of plant and animal origin, palm press fiber (an oil palm byproduct), pallet oil mill effluent, and other innovative sources of feedstuffs have all been referred to be NCFR. Stubbles, haulms, vines, as well as other agro industrial byproducts including those from the production of sugar, cereal grains, citrus fruits, and vegetables from the farm, as well as weeds growing on sea shores [11].

Advantages of the non-conventional feedstuff

Non-conventional feed resources offer the following common advantages to poultry:

- These are unutilized tangible resources from production and consumption.
- They can take the shape of a solid, slurry, or liquid and are primarily organic. Their economic worth is frequently quite low.

- Fruit wastes that have sugars, such as pineapple pulp and banana rejects, are much more advantageous energetically.
- Some of the NCFRs are great sources of fermentable carbohydrates, such as cassava and sweet potatoes.
- The majority of feeds derived from crops are bulky, low-quality cellulosic roughages, suited for feeding to animals, with high crude fiber and proteins.

DISCUSSION

Factors affecting the use of non-conventional feed

Nutrition related aspects: Although alternative feeds are the most affordable option, using them has certain drawbacks as well. First, the quantity and quality of their nutrients are variable and irregular. Information on the availability of nutrients is scarce. Anti-nutritional elements may also be present in some of the feeds. They also require the addition of supplements while using them.

Technical factors: Technically, non-traditional feed ingredients are not always available throughout the year. Such feeds are widely dispersed over the seasons of the year, and storage is costly. They are bulky for use, storage, and transportation due to their physical nature. Before using them, they need to be processed. There is a dearth of knowledge regarding their use in poultry digestion.

Socioeconomic aspects: Several important considerations can cast doubt on alternative feeds, including competition for human consumption and farmers' lack of interest because these products are of lower quality than other crops. If they are processed for further use, they are not cost-effective.

Strategies to overcome the nutritional challenges posed by the alternative feed

The following are the major criteria to overcome the nutritional deficiencies posed by non-conventional feed.

Evaluation of feed: One of the main factors preventing poultry feed suppliers from contemplating the use of alternative ingredients is the difficulty in evaluating the nutritional value of an ingredient because of the unavailability of suitable facilities for research and analysis. Over the years, there has been a lot of interest in assessing alternate feed resources, particularly from developing nations. However, frequent feed evaluation and constant updating of matrix values are essential for the effective use of these substances because there are so few published data on the digestible AA and Apparent Metabolizable Energy (AME) of alternative feed ingredients.

Dietary planning using digestible amino acids: It is necessary to formulate feed based on metabolizable energy and digestible AA when fibrous and poorly digested components are being examined for usage. The amount of AA that can be digested varies depending on the component; some ingredients can be digested more easily than others. When diet formulas include a variety of alternative, poorly digested substances, the utilization of digestible AA is especially relevant.

Use of synthetic amino acids to compensate for amino acid specification: To increase the accuracy of feed formulations and fulfill the AA requirements, it is possible to effectively harness the differences in the AA digestibility of feeds. Nowadays, owing to the availability and utilization of feed grade essential AA in synthetic forms, nutritionists may accomplish this. There has been a lot of interest in using decreased protein diets supplemented with synthetic AA to increase feed efficiency, decrease nitrogen and ammonia emissions, and ensure sustainable poultry production.

Commercial exogenous enzyme augmentation: Over the past two decades, the commercial use of biotechnology and the acceptance of feed additives in poultry nutrition have created numerous opportunities to improve nutrient uptake, feed efficiency, and productivity. Exogenous feed enzymes are conceivably the most significant ingredient to enter the chicken feed industry. Since glycanases (xylanases and glucanases) have become more readily available in the 1990's, Non-Starch Polysaccharides (NSP) has no longer been able to inhibit the use of viscous grains like wheat and barley in poultry diets. Regarding substitute ingredients, feed enzymes can:

- Make it possible to utilize some ingredients (which might not be possible otherwise).
- Get rid of nutritional restrictions and allow for larger inclusion levels.
- Broaden the variety of ingredients used in feed formulations.

Feed sustainability and efficiency

Sustainability: The value chain of the poultry industry is hampered by several issues. In addition to being economically feasible, production must also be socially and environmentally responsible. Nutritional advancements for poultry will help to meet these issues. It is clear how vital it is to use a holistic approach to successfully convert feed into high quality poultry protein in a sustainable manner. These high yielding animals must be able to regularly consume, digest, absorb, and convert enough nutrients to reach their genetic potential, regardless of the time of year. The effective completion of this task will necessitate the increasing use of current technology, the development of new technology, and the expansion of our knowledge and information network to achieve high consistency production with acceptable risk [12].

According to Pelletier N, feed production accounts for 70% of the cost of producing eggs, over 50% to 85% of all life cycle greenhouse gas emissions, 80% of energy use, and similarly significant proportions of other resource and environmental consequences [13]. A focus on enhancing the sustainability of poultry feeds is unquestionably necessary given the growing awareness of the role that animal production plays in several sustainability concerns and the ongoing expansion of the egg industry [14].

The impact of feeding

In the future decades, it is anticipated that global food demand, particularly for protein, would rise significantly as the world population approaches the estimated 10 billion mark in 2050

[15]. Among the primary meat varieties produced around the world over the past 50 years, poultry has seen the highest absolute and relative growth rate [16]. Poultry meat is expected to continue to be the key sector of overall meat production due to rising global demand (Figure 1).

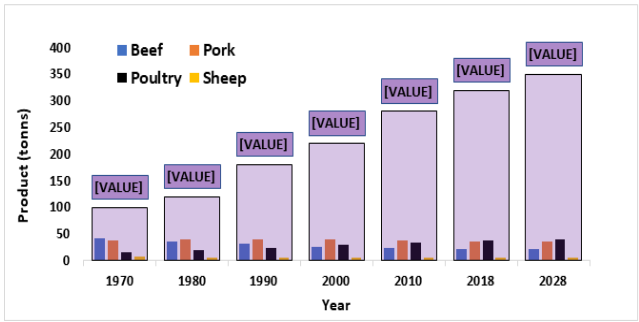

Figure 1: Global production of four main types of products (beef, pork, poultry, and sheep); evolution from 1970 to 2018 and projection from 2018 to 2028.

This tendency has been primarily fueled by the convenience, purported health benefits, and reduced price of chicken meat compared to red meat, in addition to concerns of culture and religion. [17]. The poultry sector will be critical in ensuring food security for a rising world population [18].

On the one hand, this gives a unique opportunity, but on the other, it also poses a significant challenge that must be overcome. Considering the growing public concerns about the pressure and competition for limited natural resources, loss of animal and vegetable biodiversity, the spread of antimicrobial resistance, as well as the environmental burden of livestock production, the concepts of "sustainable intensification" and "producing more with fewer resources" have been reinforced as refined strategies for feeding future generations [19].

Feed efficiency: The most popular technique to define Feed Efficiency (FE) in poultry is the Feed Conversion Ratio (FCR), which assesses the correlation between feed intake and body weight gain for a specific growth stage. FE can also be viewed from a different perspective as a homoeostatic process that determines the net result of "energy intake," which is determined by voluntary feed intake and the efficiency of digestive processes (*i.e.*, nutrient digestion and absorption), and "energy expenditure," which is determined by maintenance requirements, particular nutrient redistribution mechanisms, and the rate of metabolic processes and intermediary metabolism in tissues and organs.

Broad benefits of feed efficiency: Higher FE means that less feed is needed per unit of production output from a practical standpoint (*i.e.*, 1 kg of chicken meat).

Human food security: Any improvement in FE would promote food security for humans as feeding is a major production cost and would help the poultry industry remain economically viable.

Environmental impact: Advances in FE can reduce greenhouse gas emissions, which are mostly brought on by the production of feed crops, the transportation and processing of feed ingredients, and the conversion of natural ecosystems into farmed land.

Reduction of eutrophication: Furthermore, more productive hens have a higher ability to store dietary nitrogen and phosphorus, which reduces the excretion of nitrate and phosphate in manure and NH_3 emissions into the environment. Higher FE can thereby lessen the likelihood of eutrophication and acidification of poultry production.

Energy consumption, biodiversity conservation, and feed to feed competition: Improvements in FE can help with the conservation of animal and plant biodiversity, feed to food competitiveness, and energy utilization such as electricity and fossil fuels.

Impact on water utilization and climate change: Concerns about climate change and the pervasive effects of drought have made the impact of FE on water footprint more significant. M. M. Mekonnen MM, et al., estimate that the manufacturing of feed ingredients has the greatest impact on the industry's astonishing (Figure 2).

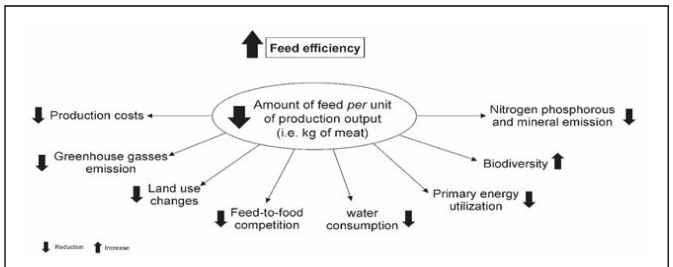

Figure 2: Feed efficiency relationship with biotic and abiotic environmental domains.

Water use (4.3 m^3 H_2O/ton of meat). Therefore, lowering the amount of feed needed per unit of output can lower the total amount of water used by the chicken meat supply chain, whether considering crop cultivation, the production of feed, or drinking water intake. How the increase in feed efficiency has led to improvements in other parameters is shown in Figure 2. Enhancing feed efficiency can help conserve both biological and non-biological environmental resources.

Additive based feed improvement and sustainable expansion: According to EU regulation 1831/2003, the field of feed additives has grown rapidly in recent years, giving rise to a wide variety of products with different specialties. The following feeds have been added to the formulas, which has improved the feed.

Precise amino acid addition: Dietary protein has always been a hot topic in chicken nutrition due to its value for bird performance and health, production costs, and environmental effects associated with nitrogen excretion. One of the most challenging goals of the contemporary poultry industry is to reduce dietary crude protein concentrations in contrast to current norms without impairing bird growth performance, FE, or health. Recent research has shown that such a reduction is possible, but to a different extent, provided the meal is kept at an appropriate level in terms of its amino acid profile to meet the demands of the bird.

Protease: By encouraging the activity of endogenous proteases, exogenous protease supplementation is a viable dietary method to increase dietary nitrogen absorption. Exogenous proteases have long been a component of enzyme combinations. On the other hand, interest in this field of research has increased since the discovery of mono component proteases ten years ago. Protease can enhance both growth performance and environmental impact indicators because it increases dietary nitrogen retention.

Phytase: The electronegative charge carried by the phosphate groups in phytic acid leads it to have an antinutritional effect when the surrounding pH is close to neutrality. When phytic acid chelates remarkably large amounts of minerals (forming phytic acid salts called phytates), proteins, and carbohydrates in this condition, which is easily found along the chicken's digestive tract, insoluble complexes that escape the digestive processes and are subsequently excreted with detrimental effects on animal performance and environment. However, the anti-nutritional effect of phytic acid can be limited by the enzymatic action of phosphatases, such as phytases, which rapidly hydrolyze the esters bonds that support the phosphate groups (Vieira).

Trace elements: The usage of Trace Minerals (TM) by the poultry industry, such as Copper (Cu), Manganese (Mn), and Zinc (Zn), has sparked controversy due to the possibility of ecological damage. Inorganic salts like carbonates, oxides, or sulfates are utilized to add these nutrients to broiler diets because most products used to manufacture chicken feed don't contain enough TM.

CONCLUSION

It is abundantly clear from the current broiler system, which is characterized by a scarcity of natural resources and growing public concern over environmental impact and animal welfare, that sustainable production intensification is the only pathway that the contemporary poultry industry can turn to satisfy the rising demand for poultry meat. Given the benefits of enhanced diet utilization for environmental and economic sustainability, raising FE in poultry is currently a major goal. To do this, deep insight into the nutritional requirements of modern fowl is required. By reducing dietary nitrogen, phosphorus, and trace mineral excretion, feed additives can be used to boost overall productivity while addressing substantial environmental concerns. Additional research on the challenges is encouraged to further improve resource utilization, animal productivity and health, and production costs while safeguarding the environment. Therefore, a multi-actor approach combining breeding businesses, researchers, as well as poultry nutritionists, and producers, is essential to promote the sustainable increase of chicken production and accomplish the cherished aim of feeding future generations effectively and responsibly.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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