



Feed Additives Used in Nutrition and Improve Poultry Performance and Health: A review

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A B S T R A C T

An approach to increase the efficiency of the poultry industry is to supplement the feed additives in diets to enhance growth rates, optimize egg production, mitigate disease prevalence, and improve feed utilization. This review specifically concentrates on different types of feed additives that could be added to poultry diets to improve performance and health. Primary constituents of poultry diets incorporate cereal grains, predominantly corn, along with wheat, barley, sorghum, and other grains. Additionally, a predominant protein source, e.g. soybean meal, is utilized, although alternative protein sources, both of animal and plant origin, exist. Beyond these components, the feed nutritional quality is influenced by factors such as method of feed, microbial contamination, the presence of antinutritional substances, digestibility, palatability, and intestinal health. A variety of feed additives are available to address these considerations. Particularly, the commercialization of feed additives requires approval through rigorous scientific evaluation, ensuring their lack of adverse effects on human and animal health, as well as the environment. Several feed ingredients formulated in poultry diets show antinutritional properties, limiting their applicability. To fulfil energy requirements and enhance poultry health, it is necessary to develop commercially viable alternatives to existing feed resources, emphasizing safety and cost-effectiveness. The use of feed additives in poultry can be valuable because they allow maximizing overall performance and an improvement in digestibility, the health of poultry.

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INTRODUCTION

Poultry meat has a higher nutritional value than other meats, which is demonstrated by the fact that it is regarded as a basic food for humans, contains vitamins and proteins, and plays a significant role in national economies (1). The poultry manufactured feeds are homogeneous mixtures of raw materials with some mineral salts and some materials may be added to them, such as vitamins, antibiotics, anti-oxidants, and other additives (2). Feed additives are a variety of product classes that are added as

small amounts to the basic diet to enhance feed quality, animal performance, and overall health. By influencing physiological processes like immunological function and stress tolerance, they also encourage animal ingestion, absorption, nutrient assimilation, and growth (3). According to reports, broiler performance might be improved and mortality rates decreased by using feed additives instead of antibiotics, all without endangering the environment or the health of consumers (4). Numerous factors, including diet, stress, antibiotics, and contemporary breeding techniques, have an impact on the health and

growth of animals. The preventive use of antibiotics plays a crucial role in preserving and stabilizes the health of poultry (5). Historically, antibiotics have been incorporated into poultry feeds due to their important role in enhancing intestinal health and eliminating harmful microbes. However, the increasing prevalence of bacterial strains resistant to these antibiotics as well as their potential harm to human health, the use of these antibiotics has become a subject of intense debate in recent years (6). The feeding quality, the dietary composition balance, and the availability of required and physiologically active components all have a direct impact on poultry products and farm animals, as well as the other qualities of animal products (7). It has become increasingly common to improve the quality of poultry products without using additives that may accumulate in poultry goods and subsequently be transferred to the final consumer (8). Consequently, researchers have actively sought safe and natural food additives, with organic acids, probiotics, enzymes, and other food additives being among the most important (9, 10). Additionally, as a substitute for antibiotics in animal production, phytogenic feed additives, also known as photobiotic, are currently employed (11). The European Feed Standard Agency (EFSA) classifies feed additives into five categories: sensory (flavors), nutritional (vitamins and amino acids), technological (organic acids, Anti-oxidants, pellet binders, etc.), biotechnology (enzymes, probiotics, prebiotics, and some phytogenics), and coccidiostats while the application of probiotics, phytogenics, and enzymes in poultry nutrition has increased, one way to increase the effectiveness of poultry feeding is to utilize feed additives to increase growth and egg production efficiency, avoid disease, and enhance feed consumption (12). This review specifically concentrates on different types of feed additives that could be added to poultry diets to improve performance and health.

ANTIBIOTIC ADDITIVES

The German doctor and researcher Paul Ehrlich is credited with pioneering modern chemotherapy. After years of arduous labor, Ehrlich finally created Salvarsan, also known as compound 606, in 1909 after discovering it while doing animal tests (13). In poultry production, antimicrobial agents play a vital role in both preventing and treating illnesses (14). Antibiotics have been widely used in poultry to prevent infections, improve health, and reduce mortality rates (15). Antibiotics are capable of either destroying or inhibiting the growth of microorganisms, Antibiotics are mostly used in animals for prevention of illness and treatment (16). The danger of incurable infections has increased as a result of the inappropriate use of antibiotics in both human and animal, widespread usage of antibiotics has resulted in the rise of antimicrobial resistance, which is a major global concern (17). In addition to causing treatment ineffectiveness and monetary losses, antimicrobial resistance in poultry diseases also makes it easier for resistant genes or bacteria to spread to people (18). Therefore, the use of antibiotic-fortified growth promoter diets (AGPs) has been banned in the European

Union (EU) since 2006, spurred research into alternative additives for maintaining gut health and optimizing production efficiency in poultry (19).

Antibiotic As Growth Inducing Agents

Antibiotics are chemotherapeutic medications used to treat infectious diseases in people, plants, and animals. However, a significant number of the antibiotics are used for non-therapeutic purposes to promote growth rather than for treatment (20). Antibiotics have contributed significantly to the development and success of the poultry industry since their discovery in the 1920s, and for almost 60 years, sub-therapeutic doses of antibiotics have been added to animal feed to promote growth and feed conversion efficiency as well as to ward off infections (21). AGPs are one method used by animal producers to lower or control the intestinal bacterial burden and hence enhance growth performance, Significant effects on the intestinal health of intensively grown broiler chickens result from the European Union's ban on AGPs usage and the United States' tighter limitations and discouragement of its use (22). Antibiotics are employed as growth promoters at both therapeutic and preventive levels, serving the dual purpose of treating ailments, managing infections, and enhancing growth performance (23). When it was discovered that birds fed streptomycin showed increased growth responses, the use of in-feed antibiotics quickly became widespread and established, as animal production intensified, it was determined that adding antibiotics to the diets produced a positive response 72% of the time, and that the overall effect of using in-feed antibiotics in the poultry was a 3-5% increase in growth and feed conversion efficiency (21).

The EU has implemented a ban on the use of antibiotics in feed used to animals feed due to prolonged use of antibiotics for medicinal and growth-promoting purposes which lead to the development of antimicrobial resistance among gram-negative bacteria (24). Concerns are raising regarding the consequences of the overuse antibiotic growth promoters in the livestock industry. Substances such as tetracyclines, macrolides, streptogramins, and fluoroquinolones are among the substances used in animal feeds (25). Several nations employ sub-therapeutic amounts of antibiotics in animal diets to promote growth and safeguard against harmful microorganisms. The historical addition of antibiotics to animal feed resulted in animals developing resistance to dangerous microorganisms (26). Persistent use of antibiotics as growth promoters and/or medical treatments in farm animals is expected to foster the proliferation of antibiotic-resistant bacteria. This poses an increased risk of chronic illnesses and bacterial infections, both antibiotic-resistant and non-resistant, throughout the food chain when human consumption involves animal products treated with antibiotics. To enhance the immunity of farm animals and their growth performance, it is imperative to develop new commercial alternatives based on their efficacy, safety, and cost-effectiveness (27). Nearly all antibiotics that used for feeding of nonruminants contain nitrogen and some of

them are aminoglycosides. the presence of nitrogen atoms in antibiotics alter the electronic configuration of the

compounds and enhance their antimicrobial activity (28). Table 1 includes the common antibiotics used in poultry.

Table 1. The common antibiotics used in the poultry industry

Antibiotics	The description	Mechanism	Source
Levamisole	Despite the lack of documented withdrawal data for levamisole in poultry, it mimics the hormone thymopoietin, which influences several immune system components.	It is used to treat capillaria infections in poultry currently. This substance is effective against lungworms and gastrointestinal nematodes.	(29)
Beta-Lactam	Among the semi-synthetic derivatives of beta-lactam antibiotics with a free amino group at the α -position at R on the penicillin nucleus are aminopenicillins, the amoxicillin.	Bactericidal (inhibits transpeptidase, damages the integrity of the bacterial cell wall, stops the production of new bacteria).	(30)
Tetracyclines	Escherichia coli tetracycline (also known as TetR), that were discovered in 1947 and works by attaching to the 30S ribosomal subunit. Because of their broad range of effectiveness, tetracyclines were quickly embraced in the clinic.	Inhibiting protein synthesis, antibacterial and bacteriostatic, are used to treat infectious diseases, and are now frequently employed in animal husbandry.	(31-35)
Nitrofurantoin	Semicarbazide the EU banned its usage in 1995, is a nitrofurantoin metabolite and food contaminant. Because of worries about the carcinogenicity of semicarbazide's residues in edible tissue.	Employed for the treatment of bacterial diseases in animals.	(36)
Quinolones/ Fluoroquinolones	A new and exciting age in antimicrobial treatment has been ushered in by the introduction of fluoroquinolones. These are a synthetic heterogeneous collection of molecules. The accidental discovery of the quinolone prototype in 1962 marked the start of the era of quinolone antibiotics.	One of the most valuable and widely used classes of antibacterial medicines in the world is the fluoroquinolone. The last century has seen a decrease in morbidity and death rates due in part to the discovery, development, and practical application of fluoroquinolone antibiotics.	(37)
Aminocyclitol	Aminoglycosides are natural or semisynthetic antibiotics derived from Actinomycetes.	In the early days of antimicrobial chemotherapy, they were frequently utilized as first-line medications and were among the first antibiotics to be used in routine clinical practice.	(38)
Sulfonamides	Sulfonamides are commonly used in poultry. They are quickly absorbed and dispersed throughout the chicken's body, collect in different tissues, and then transferred into its products. It is feared that residues in meat and eggs may be harmful to human health.	In poultry, sulfonamides are frequently used to treat coccidiosis, pullorum disease, infectious coryza, and fowl typhoid.	(39)
Macrolide	Macrolides function as antibiotics by attaching to the bacterial 50S ribosomal subunit. The macrolides are widely distributed throughout tissues and are well-known for accumulating inside phagocytes.	Macrolide antibiotics work by inhibiting the ribosome of bacteria to stop the synthesis of new proteins. They partially impede the peptide escape channel by attaching themselves to it. Thus, macrolides are considered as "tunnel plugs" that block the synthesis of all proteins.	(40-42)
Aminoglycosides	Actinomycetes are the natural or semisynthetic source of aminoglycoside antibiotics. is a phylum of Gram-positive bacteria, and its members are divided into six classes: Rubrobacteria, Coriobacteria, Acidimicrobiia, Actinobacteria, and Nitriliruptoria. Numerous industrial and agricultural biotechnology applications demonstrate their significant value.	Actinobacteria have recently been discovered to be used in chicken husbandry to produce bioactive substances including short-chain fatty acids (SCFA).	(43, 44)
Cocciostats	cocciostats can be either synthetic or naturally occurring polyether ionophores such as halofuginone, robenidine, diclazuril, and nicarbazin. Examples of naturally occurring cocciostats include monensin, narasin, lasalocid, salinomycin, and maduramicin According to Dubreil-Cheneau, Bessiral, Roudaut, Verdon.	Cocciostats are used to treat several animals that provide food by controlling protozoan infections. In order to preserve animal health and occasionally improve feed conversion, they are most frequently utilized as feed supplements in species that are raised under intense conditions, such as poultry.	(45, 46)
Amphenicols	Amphenicols are a series of highly effective antibiotics with broad-spectrum antimicrobial activity. Primarily comprising chloramphenicol (CAP), thiamphenicol (TAP), and florfenicol (FF).	They are extensively utilized in the breeding and production of cattle and poultry, but they should be used extremely cautiously in birds because they may have detrimental effects on human health as well. They are also known to suppress bone marrow and have been observed to cause liver damage, which results in abnormal liver functions and jaundice.	(47-49)

Animal Feed Containing Antibiotics and Human Health

Antibiotics play a crucial role in treating and preventing various animal illnesses (50). However, using antibiotics for animals can have direct or indirect effect on human

health either by the presence of antibiotic residues in animal products such as milk, meat and eggs that consumed by human or due to separate of antibiotic resistance bacteria to various component of ecosystem for example soil and water (51). According to Gassner and Wuethrich (52) metabolites of chloramphenicol present in animal

products have the potential to induce aplastic anemia in humans. The main cause of the rise of antibiotic resistance among bacterial species, including *Salmonella typhi*, the causative agent of the typhoid virus, is the misuse of antibiotics possessing chloramphenicol-like characteristics in animal feeds. Some significant bacteria have been commonly associated with resistance as a result of the ongoing use of growth promoters (53). Among the bacteria prone to frequent transmission from animals to humans and cause a zoonotic disease include *Salmonella*, *Campylobacter*, *E. coli*, and *E. enterococci*, as described below.

Salmonella spp.

Salmonella is a rod-shaped, gram-negative, facultative anaerobe belonging to the Enterobacteriaceae family of bacteria (54). Due to the high costs associated with disease surveillance, prevention, and treatment, *Salmonella* infection continues to be a major public health concern on a global scale (55). Gastroenteritis is the most typical symptom of a *Salmonella* infection, followed by bacteremia and enteric fever (56). Utilizing the traditional Kauffman-White approach, approximately 2600 serotypes of *Salmonella* have been identified, with the majority of these serotypes capable of adapting to various animal hosts, including humans (57). *Salmonella* and *Campylobacter*, the most often identified foodborne pathogens, are regularly discovered in poultry, eggs, and dairy products (58).

Campylobacter spp.

The most common bacterial causes of food poisoning are *Campylobacter*, specifically *Campylobacter coli* and *Campylobacter jejuni*. These microbes inhabit animal intestines without causing harm to their hosts. Prolonged quinolone use in food animals has led to the emergence of *Campylobacter* isolates resistant to both macrolides (59). Additionally, the regular use of fluoroquinolones to treat respiratory ailments in poultry has resulted in the development of fluoroquinolone-resistant *Campylobacter* within the gastrointestinal tracts of treated poultry (60).

Escherichia coli

Escherichia coli (*E. coli*) is a common commensal of humans and animals that provide food, which has evolved into harmful strains, *E. coli* strains are divided into pathotypes of extraintestinal pathogenic *E. coli* (ExPEC) or zoonotic intestinal pathogenic *E. coli* (IPEC) according to the kind of virulence factor present and the clinical signs of the host (61). According to Allocati et al. (62) *Escherichia coli* continues to be one of the most frequent causes of a number of prevalent bacterial infections in both humans and animals. According to a recent systematic review, a significant portion of human extra-intestinal infections caused by extended-spectrum cephalosporin-resistant *E. coli* can be traced back to food animals (63).

Enterococci

For over 30 years, it has been standard practice to add antimicrobial drugs to animal feed in order to boost growth,

and it is believed that this accounts for more than half of all antimicrobial use globally. The use of the glycopeptide avoparcin as a growth promoter appears to have produced a significant reservoir of *Enterococcus faecium* in food animals, which possesses the high-level glycopeptide resistance determinant vanA located on the Tn1546 transposon. Additionally, strains resistant to glycopeptides can be shared between humans and animals (64). Many of the drugs employed as growth promoters, being Gram-positive, and exhibit toxicity to enterococci. Among various farm animals, *E. faecalis*, *E. cecorum*, and *E. hirae* are the species most frequently found in the intestines. The persistent use of the antibiotic avoparcin as a growth promoter has led to the emergence of vancomycin-resistant enterococci was brought on by the ongoing use of the antibiotic avoparcin as a general practitioner (65).

Current Approaches to Antibiotics

Termination of inappropriate and unnecessary antibiotics use in animals is becoming more popular. In EU member states, the usage of antibiotics to fight disease and foster growth has decreased. The United Kingdom originally restricted the permission of many antimicrobials, including tetracycline and penicillin, in early 1969 on the recommendation of the committee led by Professor Michael Swann (66). Sweden phased out the use of antimicrobials as growth promoters in 1986, Norway in 1995, and Denmark in late 1998 or early 1999. Responding to concerns about the widespread emergence of antibiotic resistance in human diseases (67), the EU implemented a ban on antibiotics in 2006 (68).

SENSORY (FLAVORS) ADDITIVES FLAVORS

Any material that enhances or modifies the organoleptic qualities of the feed and/or the visual attributes of animal-based food is considered a sensory addition. These functional groupings include: (1) colorants: (a) substances that add or restore color to feeding materials; (b) substances that, when fed to animals, add color to animal-derived food; and (c) substances that positively affect the color of ornamental fish or birds; and (2) flavoring compounds: substances that, when added to feed materials, improve feed palatability or smell (69). According to Faugeron and Oguey (70) flavors are essential elements for enhancing meals. When used judiciously, flavors can serve various purposes:

Cover or a Replacement

Despite their good nutritional value, certain feed ingredients can have unpleasant odors (i.e. soapy, butyric, rancid, etc.) which may reduce the amount of feed consumed by an animal. Additionally, certain added ingredients (e.g. molasses) exhibit significant variability in both prices and quality, prompting interest in their partial or complete replacement. Substituting an expensive substance with a flavor possessing a comparable aromatic profile, combined with a sweetener, allows for the preservation of the same aroma while reducing costs. Achieving the optimal balance between cost savings and

sensory perception requires adjustments in dosages. The use of flavors benefits both the animal and the farmer by ensuring a consistent olfactory character in the feed or premix.

Attract and Energize

One of the main purposes of flavoring is to increase feed attractiveness. Incorporating a flavor into the feed will draw the animal feed intake, promote consumption, and exploratory behavior. The choice of flavor may depend on a general understanding of an animal's preferences as animals tend to be responsive and selective about their feed. They can be sensitive to even subtle changes, which might lead to resistance. However, feed formulation is continually evolving based on the availability, quality, and cost of raw materials. The introduction of a flavor helps to mitigate batch-to-batch differences, reducing fluctuations and providing formulators with more flexibility. This ensures greater feed acceptance by farm animals.

Materials that Give Feeds Color

The EU legal situation "Regulation (EC) No 1831/2003" (2003) establishes guidelines for the authorization, marketing, and labeling of feed additives and regulates the use of additives in animal nutrition, Colorants are classified as "sensory additives," which include substances that alter or enhance the organoleptic qualities of the feed or the visual attributes of the food derived from animals that consumed the feed (71). Xanthophylls are added to feed to give the egg yolk its golden hue and to color the skin of broilers in order to create goods that satisfy customer demands. There is a growing demand for xanthophylls on the global market due to their many new uses in human diet (71, 72).

The presence of xanthophylls in the human food chain may also be beneficial to human health, given that animal feed is at the first of the food chain, Astaxanthin and canthaxanthin are examples of naturally occurring carotenoid pigments that can be added to animal feed to make the final food products more palatable to consumers. Although it is arguable that these pigments have esthetic value, both astaxanthin and canthaxanthin have been shown to improve the health and welfare of animals. There is evidence that these pigments may also be advantageous to human health if they make their way into the human food chain (73).

NUTRITIONAL ADDITIVES

The regular biological function and metabolic processes of broiler poultry s must be supported by nutrient modification through the provision of immediate nutrients and additives. The most popular additions for reducing heat stress and boosting output are vitamins and Amino acids (74, 75).

Vitamins

To support the antioxidant status of animals, it is crucial to enhance the density of dietary vitamins such as vitamins A, E, and C beyond the minimal requirement (76, 77).

Vitamins are divided into water-soluble (vitamins B complex and C) and fat-soluble (vitamins A, D, E, and K) groups. All vitamins, except for vitamin C, must be consumed through food. Since poultry can synthesize vitamin C, it is typically not considered an essential nutrient. However, dietary vitamin C supplements may be helpful in challenging situations like heat stress, compared to other nutrients, vitamins have more intricate metabolic functions. Vitamins act as players or mediators in all biochemical pathways in the body, not only basic building components or energy sources (78).

Organic and Amino Acids and Role in Broiler Growth and Health

In today's broiler production, feed additives like organic acids and salts are critical because they support healthy growth and help mitigate the negative effects of stressors. They also enhance the small intestinal ecology and morphology, which results in the production of faster, higher-quality, and healthier broilers (79). The use of antibiotics has been outlawed as a result of the rise in antibiotic resistance. Alternative growth promoters such probiotics, prebiotics, enzymes, and organic acids are used to maintain the best possible level of health and productivity in broiler, organic acids only partially dissociate and are weak acids chemically. They are regarded as secure, Organic acids are now known to have antimicrobial, immune-boosting, and growth-promoting properties in broilers (80).

It is well known that dietary crude protein (CP) leads to higher heat production, which can jeopardize the broilers hyperthermic condition. AA supplementation is crucial to offset dietary CP intake (81, 82). Although natural feedstuffs provide chickens with nutrition, synthetic supplements are frequently supplied for some critical amino acids (lysine, methionine, threonine, and tryptophan), vitamins, and minerals (78). It may be possible to improve the overall balance of amino acids and reduce the amount of crude protein in the poultry feed by carefully adding synthetic amino acids (83). According to Corzo et al. (84); Rehman et al. (85), the broiler performance maximum requires a diet that includes ten essential amino acids: lysine, methionine, tryptophan, threonine, arginine, isoleucine, leucine, histidine, phenylalanine, and valine. Since sufficient dietary levels of methionine, lysine, and threonine are required to support optimal growth and carcass yield of fast-growing commercial broilers, the National Research Council's suggested values are used by several poultry nutritionists (77, 86). For poultry, sufficient intakes of dietary AAs are necessary for the maximum efficiency of production (87). Reported a recent amino acid composition of optimal protein for broilers, which is displayed in Table 2.

Table 2. Ideal ratios of digestible amino acids (g/kg of lysine) in broiler diets (88, 89)

Components	Chronological broiler age	
	0-21 days	21-42 days
Amino acid		
Arginine	1050	1080
Cysteine	320	330

Clycine	1760	1760
Histidine	350	350
Isoleucine	670	690
Leucine	1090	1090
Lysine	1000	1000
Methionine	400	420
Phenylalanine	600	600
Serine	690	690
Threonine	670	700
Tryptophan	160	170
Valine	770	800

Protein

Poultry contributes significantly to global food security by offering high-quality, reasonably priced protein in the form of eggs and meat (90). The protein is the most fundamental component of human and animal tissues, is essential for optimal growth, and health (81). Dietary protein serves as a source of Amino acid (AA) of the poultry for bone health, muscle development, and the production of egg protein (78). Synthetic AA and enzyme supplements are frequently used in poultry s to balance the diet and increase nutrient components' ability to be digested, crystalline amino acid supplementation and the use of plant sources nutritional content help traditional fowl optimize their nitrogen levels, a potent method for producing plant proteins with improved and increased nitrogen content in poultry diets (82).

Soybean meal serves as the primary ingredient in poultry feed Because of its excellent protein level, amino acid composition, and accessibility (91). It gives animals the essential amino acids (AAs) they need to grow quickly (92). To ensure the long-term sustainability of poultry production, an alternative protein source with a similar nutritional content is desperately needed, as feed is the primary source of expenses in the poultry production (93). The heterosporous aquatic fern known as azolla (*Azolla pinnata*) is extensively spread and can be utilized as a source of protein for animal feed and chicken (94). Microalgae have attracted a lot of interest as a sustainable alternative to traditional poultry feed ingredients. These tiny organisms are high in protein and retain a significant amount of essential fatty acids, vitamins, minerals, and Anti-oxidants. As a result, they can improve the nutritional value of poultry diets. They provide an exceptional source of protein that contains a significant amount of bioactive complexes, omega-3 fatty acids, and the essential amino acids (lysine and methionine), which are essential for healthy growth and development (90).

A study by Van Harn et al. (95) showed that CP concentration in grower and finisher diets might be reduced by 2.2-2.3% units without having an adverse effect on broiler growth performance in terms of minimizing N excretion from poultry manure. Improving the welfare of the poultry, lowering the CP concentration of broiler diets bears the risk of affecting growth performance when (semi-) necessary AA becomes scarce (96). However, it must be remembered that while lowering CP levels in poultry feed, the balance between adequate nutritional levels and production performance must be taken into account, if

growth performance and slaughter output are not negatively impacted (97). Grossmann and Weiss (98) reported a recent alternative protein source for poultry, which is displayed in Table 3.

Table 3. Alternative protein sources for poultry (98)

Type	Components
Cereals and pseudo-cereals	Prolamins and/or glutelin, which are water-insoluble proteins, make up the majority of the proteins in wheat, maize, and rice. Albumins and/or globulins make up the proteins of amaranth, quinoa, and oats.
Legumes and pulses	Globulins and albumins are the main storage proteins found in beans and pulses, with globulins often accounting for more than half of the total storage proteins. Other albumins are plant metabolic proteins that can function as lectins and enzyme inhibitors, which are antinutritive substances in legumes.
Oilseed proteins	11S globulins and albumins are the two main protein groups found in oilseeds like sunflower and rapeseed. A significant glutelin percentage may also be present in pumpkin seeds. However, different species of pumpkins have varied concentrations of each portion. For instance, albumins make up the majority of <i>Cucurbita maxima</i> .
Potato proteins	The glycoprotein patatin, which is found in potatoes as an 88-kDa dimer, and many protease inhibitors with lesser molecular weights between 5 and 25 kDa make up the majority of the protein in potatoes.
Insect proteins	Insect proteins include myofibrillar proteins, which are soluble in salt, sarcoplasmic proteins, which are soluble in water, and connective tissue proteins, which can be insoluble or soluble in acid or alkali. Albumins are equivalent to sarcoplasmic proteins, globulins to myofibrillar proteins, and glutelins to connective tissue proteins, according to the evidence that has been published. Therefore, a significant portion of myofibrillar and connective tissue proteins are found in insects.

TECHNOLOGICAL ADDITIVES

Anti-oxidants

Despite significant advancements in poultry production, encompassing meat and eggs produced, as well as improvements in growth rate and feed conversion rate, over the past three decades on a global scale (99). However, it has been established that the production of commercial poultry is linked to a number of pressures, including those related to the environment, technology, nutrition, and internal and biological processes (100, 101). Overproduction of free radicals and oxidative stress are consequently very prevalent issues in industrial poultry production because it is nearly impossible to prevent pressures. Therefore, the incorporation of natural Anti-oxidants into poultry diet must be considered (102). Recognizing and addressing indicators of stress is essential for reducing output loss and enhancing the health and well-being of poultry s. Nutritional management of oxidative stress in poultry s has been achieved through the use of dietary Anti-oxidants. Anti-oxidants play crucial roles in maintaining the health and production of laying hens by protecting the host from the damaging effects of free radicals and toxic consequences of lipid peroxidation. Various Anti-oxidants, both natural and synthetic, have

been demonstrated to mitigate or delay oxidative stress effects during production (99, 103).

Oxidative stress is unavoidable in poultry production and impacts the physiological, behavioral, and biochemical status of growing chickens, ultimately deteriorating meat quality. The poultry industry can overcome oxidative stress by using innovative processing techniques and poultry feed supplemented with antioxidants (104). Regularly added Anti-oxidants helps protect poultry feed from degradation during storage. Numerous studies have demonstrated that providing poultry with antioxidant compounds mixed into antioxidant-rich meals will increase the oxidative stability of animal products. Since poultry meat is particularly vulnerable to oxidative deterioration due to its high amount of polyunsaturated fatty acids, this approach could ultimately increase the value of poultry products (105). Oxidative stress is caused by a number of etiological conditions, such as high humidity, sunlight, wind speed, and ambient temperature. In addition to its carcinogenic qualities, oxidative stress impairs and manifests a variety of chronic inflammatory and cardiovascular, animal feed contains proteins, fats, and other organic materials that, when exposed to free radicals, turn rancid, lose their nutritional value, and release toxins that harm the health and productivity of the animals. Antioxidants have the ability to reduce oxidative damage that can result from diet and neutralize oxidants from metabolism. Ascorbic acid, alpha-tocopherol, trace minerals (copper, zinc, selenium, etc.), and different plant-derived substances including flavonoids and carotenoids are the most common antioxidants found in animal feed (106).

Pelletizing Additives

The most common thermal processing technique used to produce poultry feeds is pelletizing, and the commercial poultry industry has long recognized the advantages of feeding pelleted diets rather than mash diets (107), due to the benefits that come from handling these pellets commercially during production, transportation, and presentation for poultry (108). It became necessary to look for ways to lower production costs by reducing feed waste or loss due to the rising costs associated with manufacturing poultry feed. It has been shown that using pellets to minimize animal feed loss is a useful practice (109). The feed physical form (Mash and Pellet) is one of the most important factors that can affect the improvement of productive performance of broiler (110).

The impact of various factors on feed formulation, with solubles, dicalcium phosphate, and mixer-added fat specially, according to feed pellet quality factor, the physical quality of the pellets was negatively impacted by the mixer-added vegetable oils (111, 112). Nutritionists have reduced the quantity of fat included in poultry diets due to the adverse effect of mixer-added fat on pellet durability. However, by coating the feed particle, lubricating the die, and lowering the electrical energy of the pelleting process, an increase in the amount of fat supplied to the mixer may lower the overall cost of producing broilers (113).

Binders

Binders are firming or binding agents that create strong interparticle bonds by forming solid bridges through chemical reactions (114). In addition to reducing nutrient leaching and preventing fragmentation and abrasion of pellets during handling, shipping, and storage, they are used to reinforce pellets and enhance their integrity, durability, and stability (115, 116). By filling in the pore spaces between particles, binder materials such as lignosulfonate, bentonite, and sepiolite increase the strength and durability of pellets. By altering the composition of the feed mix following heat, moisture, and heat treatment during the pelleting process, binder materials like protein and starch increase the strength and durability of pellets through a chemical reaction. Certain binders can improve the physical characteristics of pellets as well as the growth and digestion of animals (117).

The ability to binding properties has led to the selection of numerous compounds. Many natural binders, including wheat gluten or starches, have been used to create hard pellets offer nutritional value for the animals, while some of these binders are inert raw materials with no nutritional value. However, synthetic binders, such as urea formaldehyde, sodium bentonite, or calcium bentonite, are manufactured artificially and may not always increase the nutritional content of feed. Polymers such as carboxymethylcellulose (CMC), alginate, agar, carrageenan, guar gum (galactomannan), gelatin, pectin, and lignosulfonate are examples of modified binders (114, 118). Animal feed with modified binder, such as gelatin, has nutritional value Table 4 includes a number of materials used as pellet binders.

BIOTECHNOLOGY ADDITIVES

External Enzymes

Dietary enzymes have been utilized over the previous ten years as a means of enhancing nutrient utilization in poultry diets (122). External enzymes are currently widely used as a type of feed additives in poultry diet formulations to mitigate the effects of antinutritional factors, enhance animal performance, and promote digestion of dietary components, future changes in animal production around the world are predicted to enhance the usage of feed enzymes in poultry feed formulations (123). Protease, phytase, alpha-amylase, xylanases, beta-glucanases, xyloglucanases, galactomannanases, pectinases, arabinofuranosidases, and ferulic acid esterases are a few common enzymes that are involved in the production of animal feed. Hydrolytic enzymes improve feed digestibility in the animal's intestines by eliminating antinutritional elements from feed ingredients (124). Feed enzymes help to lessen the adverse environmental effects of animal production by reduce the amount of nutrients excreted in the animal waste, especially nitrogen and phosphorus, Feed enzymes work to make nutrients (starch, protein, amino acids, minerals, etc.) available from the feed ingredients, and these feed enzymes are proteins that are eventually

digested or expelled by the animal, leaving no residues in meat or eggs (125, 126).

Table 4. Materials that are used as pellet binders

Materials	Source
Found that adding 2.4% moisture to feed that was conditioned at 60 °C boosted pellet durability from 56.5% to 67.2 %.	(119)
The calcium lignosulfonate binder was effective in improving pellet integrity, but feed consumption and weight gain of broilers were not affected.	(120)
1. By filling in the pore spaces between particles, binder materials such as lignosulfonate, bentonite, and sepiolite increase the strength and durability of pellets.	(117)
2. By altering the composition of the feed mix following moisture and heat treatment during the pelleting process, binder materials like protein and starch increase the strength and durability of pellets through a chemical reaction.	
The addition of lignosulfonates enhanced nutrient digestibility, broiler performance, and pellet quality when employed at a level of 1-3 %, and was effective as a binder in poultry diets.	(121)
1. Revealed there were notable variations in the physical pellet quality across the diets that contained 1.5% calcium fat powder.	(112)
2. Demonstrated the addition of 0.5% calcium lignosulfonate to diets containing 3% soybean oil greatly improved the pellets' length, hardness, and durability.	

Protease addition in poultry diets

Over the past ten years, there has been an increase in the usage of exogenous protease addition in poultry diets. In order to increase the energy and protein digestibility of diets based on grains and oilseeds, The protease by itself improved nutrient utilization and increased solubilization of the non-starch polysaccharides (NSP) components, at the lower dose, a growing trend in animal nutrition is exogenous protease supplementation, which has positive impacts on growth performance, nutritional digestibility, and endogenous enzyme secretion (127). Furthermore, the addition proteases may enhance the quality of ingredients by lowering item variability and reducing the detrimental impacts of lectins or heat-stable trypsin inhibitors (128).

Phytase

Phytases have been utilized as animal feed additives in poultry and fish diets since the first commercial phytase products were released in 1991 (129). Due to the absence of endogenous phytase, the majority of the phosphorus (P) in feed materials is found as phytate, which is not readily absorbed in the digestive tracts of several chicken species. Through the hydrolysis of phytate, phytase supplementation enhances P consumption, potentially lowering environmental P excretion. Phytase may also enhance feed utilization, weight increase, egg production and characteristics, energy availability, nutritional digestibility, and the retention of vital minerals in bones and blood. Therefore, the impact of phytase on performance and the absorption of calcium and phosphorus in layer chickens fed diets based on maize and soybeans has been well acknowledged (130).

Alpha-amylase

To enhance starch digestibility and optimize energy utilization to maximize the performance of broiler, the inclusion of alpha-amylase has emerged as an effective strategy, this enzyme catalyzes the hydrolysis of complex starch molecules into smaller units, such as glucose, maltose, and dextrins, thereby facilitating their absorption

in the gastrointestinal tract (131, 132, 133). Alpha-amylase supplementation in diets with lower metabolizable energy (ME) is a practical way to maximize broiler performance. Alpha-amylase also enhances the digestion of carbohydrates, boosting the amount of accessible energy (134).

Xylanase

In chicken diets made with cereals, xylanase supplementation has become essential for maximizing nutrient uptake and minimizing animal waste issues. It allows for comparable growth rates without reducing feed efficiency (135). The poultry xylanases function in a number of ways, including first, by breaking down the soluble arabinoxylans to lower digesta viscosity; second, by directly acting on the feedstuffs' cell walls and causing an increase in endogenous enzyme activity; and third, by releasing oligosaccharides as a result of xylan degradation in the distal portions of the gastrointestinal tract (GIT), which serve as a prebiotic (136).

Prebiotics in Poultry Diets

Prebiotics are substances that have undergone selective fermentation, which modifies the gut microbiota's makeup or activity, thereby benefiting host health, one the of alternatives antibiotic for growth promoter that is receiving a lot of interest is dietary fiber with prebiotic characteristics according to Roberfroid et al. (137). For instance, prebiotics like mannanoligosaccharide (MOS) may lessen the detrimental effects of cyclic heat stress on small intestine morphology, yeast fermentation (YF) metabolites have been demonstrated to lower stress measures in poultry exposed to heat stress, Additionally, it has been demonstrated that taking YF supplements before heat stress reduces gut barrier dysfunction measures (138).

Types of prebiotics

The prebiotics are oligosaccharide carbohydrates, primarily galacto-oligosaccharides (GOS), lactulose, inulin, and their derivative fructose-oligosaccharides (FOS) as well as xylooligosaccharides (XOS) (139). According to recent

research, prebiotics also contain various non-carbohydrates that satisfy the prebiotic requirements, like polyphenols that have been extracted from fruits like blueberries and black raspberries (140, 141). Are constantly being developed, mainly polypeptide polymers, polysaccharides, and polyphenols (139).

Mechanisms of action of prebiotic in poultry

Prebiotics may alter the gastrointestinal tract's biological processes in poultry to enhance health and performance by boosting growth, lowering mortality, and enhancing feed efficiency, prebiotics may have an impact on the breakdown of indigestible food ingredients, the production of vitamins and nitrogen, and the ease of eliminating unwanted foods from the diet, they may also cause positive changes in the gut microbiota and have an impact on host metabolism and immune function (142). A potential strategy is to incorporate prebiotics into the diets of poultry. Non-digestible carbohydrates known as prebiotics have been shown to favorably alter the composition and fermentation patterns of the gastrointestinal microbiota, favoring species that are advantageous to the host (143). For a substance to qualify as a prebiotic, it must meet specific criteria: (a) it should not be hydrolyzed or absorbed in the upper gastrointestinal tract; (b) it must serve as a selective nutrition source for beneficial microbial populations in the gastrointestinal tract; and (c) it must induce physiological reactions that are advantageous to the host. Short-chain fatty acids (SCFA), a product of prebiotic fermentation comprising lactic acid and volatile acids, serve as a crucial energy source for poultry. They also lower gastrointestinal pH, preventing the growth of pathogenic bacteria sensitive to acidity (144, 145).

Probiotics in Poultry Diets

Probiotics are feed additives containing live microorganisms that improve the intestinal microbial composition of the host and have a positive effect on the host. Numerous relevant studies have shown that adding probiotics to animal feed can effectively change the gut microbiota, which can improve gut immunity, disease resistance, and general health while also reducing pathogen shedding and illness signs (146).

Types of Probiotics

In poultry were among the regularly utilized probiotics, *Lactobacillus* species (*L. bulgaricus*, *L. plantarum*, *L. acidophilus*, *L. helveticus*, *L. lactis*, *L. salivarius*, *L. casei*, *L. reuteri*), *Enterococcus faecium* and *E. faecalis*, *Streptococcus thermophilus*, and *Bacillus subtilis*, reviewed by Khan and Naz (147).

Mechanisms of action of probiotic in poultry

By maintaining the balance of gut microbes, probiotics in feed help the host's health. They do this by preventing harmful bacteria from colonizing the gut through competitive exclusion. Probiotics naturally produce volatile fatty and organic acids, aid in digestion by breaking down

insoluble fibers, improve nutrient absorption and metabolism, and lower the pH of the gut to levels that affect pathogenic bacteria like *Salmonella* spp. and *E. coli*. Numerous studies have demonstrated that probiotics boost the immune system, linking their administration to increased humoral and cellular immune responses by boosting the production of T cells, CD+, B cells, and anti-inflammatory cytokines (148).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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إضافات الأعلاف المستخدمة في التغذية وتحسين أداء وصحة الدواجن: مراجعة

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الخلاصة

إن أحد الأساليب المستعملة لزيادة كفاءة صناعة الدواجن هو تجهيز الإضافات إلى الأعلاف لتعزيز معدلات النمو وتحسين إنتاج البيض وتخفيف انتشار الأمراض وتحسين استعمال الأعلاف، وتركز هذه المراجعة بشكل خاص على أنواع مختلفة من الإضافات الأعلاف التي تُضاف إلى اعلاف الدواجن لتحسين الأداء والصحة. تتضمن المكونات الأساسية لأعلاف الدواجن الحبوب، وخاصة الذرة الصفراء، إلى جانب القمح والشعير والذرة البيضاء والحبوب الأخرى. وايضا، يتم استعمال مصدر بروتيني رئيسي مثل دقيق فول الصويا، بالرغم من وجود مصادر بروتينية بديلة، سواء من أصل حيواني أو نباتي، وبخلاف هذه المكونات تتأثر جودة التغذية في العلف بعوامل مثل طريقة التغذية والتلوث الميكروبي ووجود مواد مضادة للتغذية وقابلية الهضم والطعم والصحة المعوية، وتتوفر مجموعة متنوعة من الإضافات الأعلاف لمعالجة هذه الاعتبارات. وعليه يتطلب تسويق هذا النوع من الأعلاف الموافقة عبر التقييم العلمي الدقيق، الذي يضمن عدم وجود آثار ضارة لها على صحة الإنسان والحيوان، فضلاً عن البيئة، وتُظهر العديد من مكونات الأعلاف المصنعة في اعلاف الدواجن خصائص مضادة للتغذية، الذي يحد من إمكانية تطبيقها لتلبية متطلبات الطاقة وتعزيز صحة الدواجن، ويعد من الضرورة تطوير بدائل جادة تجارياً لموارد الأعلاف الحالية، مع التركيز على السلامة والفعالية من حيث التكلفة. وعليه يكون استعمال إضافات الأعلاف في الدواجن مفيداً لكونها تسمح بتعظيم الأداء العام وتحسين قابلية الهضم حفاظاً على صحة الدواجن.

الكلمات المفاحية: المضادات الحيوية، إضافات الأعلاف، تغذية الدواجن، البريبيوتكس، صحة الدواجن.