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A biotechnology perspective of livestock nutrition on feed additives: a mini review

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Abstract

Biotechnology applications in livestock nutrition has significance in view of shortage of natural resources with associated conflicts, growing demand of animal products, by-products versus human population pressure necessitate needs for feed additives in livestock diets for better utilization of feeds and food materials which evolved from conventional, unconventional to novel alternative feed sources. The probiotic microorganisms, applications, mechanisms of action; advantages and safety of probiotics were explored. Prebiotics, their leading types, applications, safety of prebiotics and salient features of prebiotics as well as synbiotics, their impacts on livestock products (milk, meat, wool and eggs) quality as well as by-products. These microbes are involved in genetic manipulation of microbes in ruminants and monogastrics gastro-intestinal tracts (GIT's) which are monumentally beneficial in the form of protection of protein microbes/requirements, amino acids and fats digestion, especially those from fibre in ruminants, and the reestablishment of natural and genetically modified microbes in the rumen. Genetically modified grains for nutritional improvements and anti–nutritional factors could include low phytate corn, high oil corn, and low oligosaccharide soybean. Growth promoters of phytochemicals and/or phytobiotic herbs are health boosters, in-feed enzymes, organic acids, digestive boosters, antimicrobial peptides, antibacterial and useful alternatives to antibiotics and hormones. Feed additives that also promote growth in heat stress conditions are electrolytes, betaine, amino acids, leaf extracts and trace minerals. Other additives for growth and better carcass quality products are in form of antioxidants as ractopamine, L-carnitine, amino acids, nucleotides in broiler diet, corn oil or fish oil. Organic acids (formic and propionic acids) serve as feed preservatives and are particularly effective. Others are lactic, citric, fumaric and sorbic acids plus their salts (such as calcium formate and calcium propionate). Mycotoxins are reduced through absorption and bioavailability by using numerous mycotoxin binders. Pre-mixtures are vitamins, minerals, carotenoids, acids, preservatives, needed in small amounts. Modern biotechnology holds promising diverse beneficial applications and solutions in different ways like environment protection, gut microbes' manipulations, production of food (feeds, feed additives) for normal growth, better health, metabolic activities in a balanced diet, better welfare and well-being of our livestock and other emerging enterprises.

Key words: Biotechnology, livestock nutrition, feed additives, mini review

Une perspective biotechnologique de la nutrition du bétail sur les additifs alimentaires : une mini critique

Résumé

Les applications de la biotechnologie dans la nutrition du bétail ont une importance compte tenu de la pénurie de ressources naturelles avec les conflits associés, la demande croissante de produits animaux, les sous-produits par rapport à la pression de la population humaine nécessitent des besoins en additifs alimentaires dans les régimes alimentaires du bétail pour une meilleure utilisation des aliments et des matières alimentaires qui ont évolué à partir de *conventionnelles, non conventionnelles à de nouvelles sources d'alimentation alternatives. Les micro-organismes probiotiques, applications, mécanismes d'action ; les avantages et la sécurité des probiotiques ont été explorés. Les prébiotiques, leurs principaux types, leurs applications, la sécurité des prébiotiques et les principales caractéristiques des prébiotiques ainsi que des synbiotiques, leurs impacts sur la qualité des produits d'élevage (lait, viande, laine et œufs) ainsi que sur les sous-produits. Ces microbes sont impliqués dans la manipulation génétique des microbes chez les ruminants et les tractus gastro-intestinaux monogastriques (GIT) qui sont extrêmement bénéfiques sous la forme de protection des microbes/exigences protéiques, de la digestion des acides aminés et des graisses, en particulier celles des fibres chez les ruminants, et du rétablissement des microbes naturels et génétiquement modifiés dans le rumen. Les céréales génétiquement modifiées pour des améliorations nutritionnelles et des facteurs anti-nutritionnels pourraient inclure le maïs à faible teneur en phytates, le maïs à haute teneur en huile et le soja à faible teneur en oligosaccharides. Les promoteurs de croissance des phytochimiques et/ou des herbes phytobiotiques sont des boosters de santé, des enzymes alimentaires, des acides organiques, des boosters digestifs, des peptides antimicrobiens, des alternatives antibactériennes et utiles aux antibiotiques et aux hormones. Les additifs alimentaires qui favorisent également la croissance dans des conditions de stress thermique sont les électrolytes, la bétaïne, les acides aminés, les extraits de feuilles et les oligo-éléments. D'autres additifs pour la croissance et une meilleure qualité de carcasse se présentent sous forme d'antioxydants comme la ractopamine, la L-carnitine, les acides aminés, les nucléotides dans l'alimentation des poulets de chair, l'huile de maïs ou l'huile de poisson. Les acides organiques (acides formique et propionique) servent de conservateurs alimentaires et sont particulièrement efficaces. D'autres sont les acides lactique, citrique, fumarique et sorbique ainsi que leurs sels (tels que le formiate de calcium et le propionate de calcium). Les mycotoxines sont réduites par absorption et biodisponibilité en utilisant de nombreux liants de mycotoxines. Les pré-mélanges sont des vitamines, des minéraux, des caroténoïdes, des acides, des conservateurs, nécessaires en petites quantités. La biotechnologie moderne recèle diverses applications et solutions bénéfiques prometteuses de différentes manières, telles que la protection de l'environnement, les manipulations des microbes intestinaux, la production d'aliments (aliments pour animaux, additifs alimentaires) pour une croissance normale, une meilleure santé, des activités métaboliques dans une alimentation équilibrée, un meilleur bien-être et un meilleur bien-être de notre bétail et d'autres entreprises émergentes.*

Mots-clés : Biotechnologie, nutrition du bétail, additifs alimentaires, mini critique

Introduction

The current era of one world-one health concept, which emphasizes promotion of organic systems of production and/or with less dependence on bulk synthetic feed sources, call care to be taken regarding feeding good nutritional elements and balanced food, which play crucial role in maintaining growth and sound health of animals (poultry) as well as of humans (Dhama *et al*., 2013, 2014). Kiran and Deswal (2020) defined feed additives as ingredients or combination of ingredients used in micro quantity in animal nutrition; though not nutrients parse and cannot be considered as dietary essential to the animals. However, they have been reported to improve the efficiency of feed acceptance, nutrient utilization, growth and health of the animals. On the other hand, OJEU (2003) and Pluske (2013) defined feed additives as substances, micro-organisms or preparations, other than feed materials and pre-mixtures, which are intentionally added to feed or water in order to perform particularly, at least any of the following functions: favourably affect the characteristics of feed, animal products, colour of organisms (fish and birds), which satisfies the nutritional needs of animals, the environmental consequences of animal production, affect animal production, performance or welfare, mainly by affecting the gastro-intestinal flora or digestibility of feedstuffs, or have a coccidiostatic or histomonostatic effects. Lende (2021) reported non-feed additives as feed binders, carotenoid supplements, therapeutants and non-specific immune stimulants, probiotics, enzyme supplements, hormones, antioxidants, fiber, water, flavourings and palatability enhancers. Incidentally, bulk of the source of these feed additives are naturally occurring and hence can be easily manipulated as a replacement of animal growth promoters (AGPs) and utilized as probiotics, prebiotics, synbiotics, organic acids, essential oils, vitamins and minerals. Wen and He (2012) listed other growth promoting factors to include antimicrobial peptide (cecropin), organic acids, enzymes and mushrooms (*Lentinus edodes* and *Tremella fuciformis*) have also been tried with success.

This review purposefully attempts to point out the benefits, contributions and opportunities entrenched in biotechnology standpoints to livestock nutrition, feed additives in monogastrics (poultry, pigs), ruminants and other emerging livestock enterprises.

Probiotics: These are microorganisms that exert beneficial effects on the host through different ways by competing with pathogenic bacteria for energy sources and nutrients. Therefore, reducing their proliferation/antagonizing them in the gastro-intestinal tract (GIT) through the production of antibacterial compounds such as cytokines, bacteriocins and hydrogen peroxide inhibit the growth of pathogenic microorganisms. Lactic acid-producing probiotics (*Lactobacillus* species and *Bifidobacterium* species) may exert an antimicrobial effect on pathogens by reducing the confined pH of the gut lumen (Brown, 2011; Mizock, 2015). Mizock (2015) further reported that among *Lactobacillus* species, *L. plantarum* is most often associated with bacteriocin production. Several types of bacteriocins have been isolated from various *L. plantarum* strains. Some probiotics produce nutrients and growth factors which are stimulatory and beneficial to microorganisms of the gut microbiota. Probiotics have anti-inflammatory properties (Brown, 2011) and exert antitoxin effects (Mizock, 2015), which are saccharolytic bacteria that are able to ferment carbohydrates to lactic acid that inhibits growth of pathogens. Such metabolites produced from fermentation can be used by many kinds of anaerobic bacteria to produce beneficial short-chain-fatty acids (S.C.F.A.) (Mizock, 2015). The genera *Lactobacillus* and *Bifidobacterium* are the most widely used probiotics and include a large number of species and strains characterized by important properties in an applied context (Felis and Dellaglio, 2015). Genetic manipulation of useful microbes in the rumen has been altered genetically to increase their cellulolytic ability and reduction in methanogenesis to improve the overall utilization; elimination of the anti-nutritional factors in feeds and also increase the essential amino acids, especially limiting amino acids synthesized by rumen microbes. Depolarization of lignin by lignase enzyme which is produced by the soft-rot fungus (*Phanerochaetechrys osporium*) can be useful for the animals (Roland, 2013). Efficiency and stability of lignase gene has been modified by Recombinant DNA technology (Mahima *et al*., 2012a). Protein and digestibility reduce as forage crops mature (Roland, 2013). The author also reported that ruminants are able to utilize roughage efficiently due to rumen microorganisms which produce enzymes to digest plant cell wall contents (cellulose and hemicelluloses). Hence, the breakdown and digestion of plant cell walls in the rumen can have a marked effect on animal productivity (Ghazanfar *et al.,* 2011); aided techniques as inoculants of native and recombinant rumen microorganisms, natural adaptation and microbial feed enzymes have proved useful (Roland, 2013).

Mahima *et al*. (2012b) reported that the use of bacteria such as *Lactobacillus plantarum*, *L. buchneri, L. acidophilus, Streptococcus bovis*, *Pediococcus pentosaceus*, *P. acidilacti*, and *Enterococcus faecium* and yeasts such as *Saccharomyces cerevisiae*alone or their mixtures, and the use of enzymes (cellulases, hemicellulase, amylase) alone or as a mix with microbial inoculants in silage production is restricted to few intensively managed commercial dairy and beef production farms in developing countries. However, the extent of their use in developed countries is higher (Mahima *et al*., 2012b; Andualem, 2015).

Prebiotics: There are several types of prebiotics such as peptides, proteins and lipids that has been in use. Oligosaccharides are the most important because they can be hydrolyzed and fermented by gut bacteria. The microbes occur naturally in foods such as leeks, asparagus, chicory, Jerusalem artichokes, garlic, onions, wheat, oats, and soybeans (Lee *et al*., 2014). Currently, candidate prebiotic compounds encompass several non-digestible oligosaccharides (NDO) including, among others, fructo-oligosaccharides (FOS), oligofructose, insulin, lactulose, galacto-oligosaccharides (GOS) and trans-galacto-oligosaccharides (TOS). Legumes are also a good source of oligosaccharides known as α-galactosides or the raffinose family of oligosaccharides (RFO), which are utilized by bifidobacteria (Lee *et al*., 2014). The authors further reported that β-glucans are another important group of prebiotics, which are polysaccharides mainly found in oat and barley bran.

Synbiotics: These are nutritional supplements combining probiotics and prebiotics in a synergistic form to survive well in the digestive system. Without the necessary source of nutrients for the probiotic, it will have a more important intolerance for oxygen, low pH, and temperature (Alloui *et al*., 2013). However, results on *in vivo* trials are promising, showing a synergistic effect coupling probiotics and prebiotics in the reduction of food-borne pathogenic bacteria populations (Mucci, 2019). The author further reported that in broilers; probiotic and FOS each reduced intestinal *Salmonella enteritidis* colonization when used singly, but their combination was more effective. A considerable increase in the bifidobacteria, lactobacilli and total anaerobes populations has been shown when feeding a diet containing a combination of GOS and *Bifidobacterium lactis* but no incremental effect on body weight, feed intake and feed conversion ratio was observed (Mucci, 2019). In another study, the author reported that in a dietary treatment with a synbiotic product (a combination of *E. faecium*, a prebiotic derived from chicory, and immune modulating substances derived from sea algae) on broiler chickens, body weight, average daily weight gain, carcass yield percentage, and feed conversion rate were significantly increased compared with the control, whereas no increase in organ weight was found, with exception for the small intestine; a significant increase in the villus height in both duodenum and ileum was also observed. The same author reported that the use of synbiotics represented important and synergistic strategy to improve gut health of chickens from the first day of life and control pathogen release in the environment, decreasing the risk of food-borne infections in humans.

Roland (2013) reported that some of the restrictions which nutritionists face during feed formulation like the presence of anti-nutritive factors were solved through the use of low phytate phosphorus corn cultivars which contained approximately 35 % phytate phosphorus and 65 % of non-phytate phosphorus, which was reversed in the use of commercial corn. Feeding studies with high oil corn on broilers showed that there was a significant ($p<0.05$) enhancement in body weight and feed conversions (Nciszek *et al*., 2013). Yan *et al.* (1987) reported that hens fed on high oil corn diet had a better feed to egg ratio. The egg yolks when analyzed contained increased levels of linoleic acid and oleic acid. Companies like Dupont have already developed heritably modified soybeans with low oligosaccharides. These cultivars gave an increase of 3 % in amino acid digestibility and 5 % increase in dry matter digestibility (Raksasiri *et al*., 2018). The authors reported that soybeans with high lysine were developed to increase the lysine content from 3 % to 4.5 % and this would reduce the supplemental addition of lysine in diets and the same could be done with corn.

In-feed enzymes: These help the animals break down and digest plant materials such as cellulose or pectin, which they otherwise cannot utilize effectively (Huyghebaert and Thacker, 2013). In fact, certain enzymes (xylanases and beta-glucanases) are already commonly added to commercial feed for broiler chickens. The mechanism behind the effectiveness of in-feed enzymes as growth promoters is not fully understood but may include changes to the gut microbiota, prevention of damage caused by undigested plant parts rubbing against the inner lining of the intestine, breakdown of larger molecules into compounds with prebiotic activity, or impacts on the composition of the intestinal content and its digestibility (Huyghebaert and Mohsen, 2015). In-feed enzymes are also promising interventions for preventing certain diseases such as necrotic enteritis in chickens. In-feed enzymes are not a promising alternative for ruminating animals such as cattle because the rumen inactivates any enzymes before they reach the intestine (Amlan, 2010). Recently, genes encoding for different enzymes, including phytases, ß-glucanases, and xylanases, have been cloned and expressed in different commercial systems (microorganisms and plants). Amlan, (2010) reported that it is possible to produce large amounts of cheap enzymes by continually selecting favourable microbes, growing them in advanced fermentation systems (as silage additives) and by streamlining the extraction and purification of the enzymes. Same author reported that microorganisms generally involved in production of enzymes are; Bacteria (*Bacillus subtilis, Bacillus lentus, Bacillus amyloliquifaciens* and *Bacillus stearothermophils*), Fungus (*Triochoderma longibrachiatum, Asperigillus oryzae* and *Asperigillus niger*) and Yeast (*S. cerevisiae*).

Organic acids*:* Organic acids such as formic, propionic, sorbic, phosphoric, citric or acetic acids are also promising alternatives for growth promotion and disease prevention (Hashemia *et al*., 2011). The authors further reported that it is possible that an organic acid's ability to kill bacteria (minimize proliferation of pathogenic bacteria by destroying their cell membrane) by lowering pH, at which activity of proteases and beneficial bacteria is optimized contributes to its growth promotion property. In addition, organic acids affect gut microflora by favouring the growth of certain acid-loving beneficial bacteria, and improve feed utilization as well as metabolism and minimization of various stresses, has antioxidant properties (physiological functions) of the stomach by increasing its acidity levels (Hashemia and Davoodi, 2011). Formic and propionic acids are effective against *E. coli* and *Salmonella* species, while lactic and butyric acids favour lactobacilli in the gut microflora (Cooper, 2017). In swine, a meta-analysis concluded that organic acids have demonstrated some, albeit variable, efficacy as growth promoters and that organic acids have positive impacts on disease prevention, measured for instance in the form of reduction in gastro-intestinal illness and diarrhea in piglets (Partanen and Zdzislaw, 2015). Lückstädt and Mellor (2011) reported that organic acids also demonstrated a positive effect in cattle by enhancing performance and preventing certain digestive diseases such as rumen acidosis, but more information is needed.

Feed acidifiers: These are organic acids considered to be any carboxylic acid (fatty acid and amino acid), weak and do not disassociate completely in water. The short-chain fatty acids (SCFA) (C1–C7) are found to be associated with antimicrobial activity (Beulah *et al*., 2020). They are either simple mono-carboxylic acids such as formic, acetic, propionic and butyric acids or carboxylic acids with the hydroxyl group such as lactic, malic, tartaric and citric acids or short-chain carboxylic acids containing double bonds like fumaric and sorbic acids (Shahidi *et al*., 2014). Generally, organic acids with antimicrobial activities have a pKa value in the range of 3 and 5. Tripathi (2017) reported that organic acid treatments composed of individual acids and blends of several acids had been found to perform antimicrobial activities similar to those of antibiotics. The use of organic acids and their salts in poultry production are generally considered safe (Adil *et al*., 2010). It has been in use mostly as feed preservative, for which formic and propionic acids are particularly effective (Lückstädt, 2014). Lactic, citric, fumaric and sorbic acids and their salts (calcium formate, calcium propionate) are used under the classification 'feed preservative' (Lückstädt and Mellor, 2011). Acidifiers are sprayed as a liquid directly on to feedstuff/compound feed, are added directly in powdered forms or via premix and liquid form via drinking water (Tripathi, 2017). Acidifier (Pro GIT SF3) was provided by KemiraOyj (Asia Pacific, Shanghai, China) and contained 34 % calcium formate, 16 % calcium lactate, 7 % citric acid and 13 % moderate-chain fatty acids-MCFA (Lauric acid based) (Ding *et al*., 2017). Tripathi (2017) reported that the performance of poultry was enhanced by the addition of organic acids in diet as these organic acids decrease the pathogenic bacteria (*Salmonella, Clostridia, Enterococcus, Campylobacter* and *Escherichia coli*). Organic acids supposedly lowered the pH of the chyme and thereby enhanced the protein digestibility. Supplementation of the mixture of organic acid in the broiler birds diet may led to an increase in overall digestibility and availability of nutrients (such as calcium and phosphorus) due to developing beneficial microflora (*Lactobacillus* species) of the digestive tract (Tripathi, 2017).

Fascina *et al*. (2012) reported that the use of an organic acids mixture (comprising 30.0 % lactic acid, 25.5 % benzoic acid, 7 % formic acid, 8 % citric acid and 6.5 % acetic acid) in broiler diets improved its performance as compared to the control diet at 42 days of age and organic acids provided better carcass characteristics. Supplementation of organic acids in feed is found to improve the production parameters like body weight and feed conversion ratio (FCR) in broiler chicken (Ding *et al*., 2017). Khodambashiemami *et al*. (2013) and Vitor *et al*. (2012) reported that single acidifiers and their salts have been found to increase activity of proteolytic enzymes and gastric retention time. Most studies showed that dietary addition of acidifiers gained a positive effect on growth performance (Hashemia *et al*., 2012; Ding *et al*., 2017). These positive effects induced by supplementation of acidifier during animal production are highly associated with the modification of digesta pH, gut microflora (Hashemia *et al*., 2012; Ding *et al*., 2017), and intestinal growth (Ding *et al*., 2017). Perhaps significant increases of the villus width, height and area of the duodenum, jejunum and ileum of broiler chicks is the intrinsic factor to the guts health and efficiency (Tripathi, 2017). The author further reported that broilers fed diets containing formic acid had the longest villi (1273 µm and 1250 µm for 0.5 % and 1.0 % formic acid, respectively) compared with control (1088 µm). Tripathi (2017) reported that crypts of jejunum were deeper in birds fed the formic acid diet (1.0 %) than birds fed the antibiotic diets (266 µm vs. 186 µm, respectively; $p<0.05$) in the same experiment, thus formic acid supplementation increased both the villus height and crypt depth.

Cooper (2017) reported that water and organic acids act as acidifiers, as organic acids reduce the pH of water in-conjunction with sanitizers like chlorine at optimum pH of 5.5. Organic acids have triple benefits (help sanitize the water, break down lime scale and promote gut health) alone it may reduce pH down to between 3.8 and 4.2, to eliminate pathogenic bacteria from the water; as "birds do prefer acidic water and are quite tolerant to it, but pH close to 3.5 will damage the gut lining". It could therefore be right to state that acidifying water is a key to eliminating pathogenic bacteria, promoting healthy gut microflora and ultimately boosting health. Cooper (2017) warned that it is vital to get the right balanced or clean water of reliable hygiene and safety with a high pH (optimum between 5 – 6) which will not tamper with efficacy of antibiotics and vaccines (or promote biofilms that may proliferate other opportunistic pathogens). It is recommended that borehole water be analyzed every 6 – 12 months for pH.

Phytochemicals (phytonutrients): These are plant-derived compounds, such as essential oils or tannins that may have anti-bacterial and growth promoting effects (HA dietary feeding of essential oil extracted from herbs improved the secretion of digestive enzymes, consequently improved the digestibility of the feeds and enhance the growth performance of broilers. The authors further reported that ginger enhances nutrient digestion and absorption because of its positive effect on the gastric secretion, enterokinase and digestive enzyme activities. Khan *et al*. (2012a, b) corroborated the presence of active agents in the herbs to have strong capability for scavenging superoxide radicals, hydrogen peroxide and nitric oxide from activated macrophages, reducing iron complex and inhibiting lipid peroxidation. Yirga (2015) reported that Herbs phenolic components like carvacrol and thymol are responsible for their antioxidant activity. For instance, in thyme leaves are such components as caffeic acid, p-cymene-2, 3-diol and biphenylic. Flavonoid compounds in herbs have also been found to exhibit antioxidant activity. Zhang *et al*. (2011) reported that supplementation of ginger at the rate of 5 g kg^{-1} significantly increased activities of SOD and GSHPx and reduced MDA in broilers at the age of 21 and 42 days.

Lara and Rostango (2013) reported that the comfort of broiler birds and other livestock species is affected badly by heat stresses, thereby causing suppression of production efficiency. Lara and Rostango (2013) and Norain *et al*. (2013) had reported reduction in growth performance due to heat stress (or related stresses) in broiler birds. The authors further reported that dietary manipulations like increasing the supplemental levels of vitamins and minerals along with the altered dietary energy and protein contents were tried to compensate the reduced feed intake in this climatic conditions. This action prevented loss of electrolytes by dietary cations and anions, balancing the dietary cation/anion difference (DCAD); which the supplementation of electrolytes (sodium bicarbonate ($NaHCO_3$), potassium chloride (KCl), calcium chloride ($CaC1_2$) and ammonium chloride (NH_4C1) achieved either through feed or water. The authors further reported that intake of sodium salts (NaCl, $NaHCO_3$) through diet had resulted in better body weight gain, feed intake and feed to gain ratio, and also increased water intake. Toghyani *et al*. (2012) reported that betaine supplementation helped in maintaining the osmolytic protective property of livestock, especially in heat stressed birds; promotes higher water retention in the cells thus resulting in more carcass yield and improved meat quality. This is achieved by positively affecting the lipid metabolism resulting in increased fatty acids catabolism via carnithine synthesis pathway and thus reduced carcass fat deposition (Toghyani *et al*., 2012). Al-Fataftah and Abdelqader (2013) reported that leaf extracts can be used as an alternative in nature for replacement of the synthetic acetylsalicylic acid, thereby controlling temperature of the body of broiler birds which are heat stressed. Moeini *et al*. (2011) and Toghyani *et al*. (2012) showed that when chromium nicotinate (an organic source of chromium) was used as a supplement, it proved to be beneficial to broiler chickens under conditions of stress caused by hot weather inspite of lowering feed consumption.

***Toxins binders*:** The methods for reducing exposure to mycotoxins mainly are to reduce their absorption and bioavailability by using various mycotoxin binders (adsorbing and biotransforming agents). The most widely known of these are aluminosilicates [Astra Ben 20® (sodium bentonite); Red Crown® (calcium bentonite); Flow Guard® (sodium bentonite); Microsorb® (sodium bentonite); Volclay FD-181 (sodium bentonite)] like clay, bentonite [Sodium bentonite, ATOX® (Natural combination of smectite and sepiolite (E-558 and E-562) of high purity); Sodium calcium montmorillonite; Organophil modified montmorillonite, Montmorillonite], montmorillonite [Modified montmorillonite nanocomposite, Milbond-TX®: inert montmorillonite clay-based adsorbing agent, Swy-2: wyoming sodium montmorillonite], zeolite [Octadecyldimethylbenzy ammonium exchanged-clinoptilolite-heulandite tuff, Clinoptilolite, Calcium/potassium/sodium hydrated aluminosilicate], aqueous sodium calcium aluminosilicate (HSCAS) [NovaSil™ and Myco-Ad® Zeolex®] and active carbons [Activated carbon, Filtrasorb 400, Aquacarb™ 207EA, GCN 1240, Nuchar® SA-20, Darco KB-B, Superactivated charcoal, SORBOPOR MV 125] (Ipcak and Alcicek, 2015). Another method is the degradation of mycotoxins into non-toxic metabolites by using indigestable complex Carbonhydrates (bacteria- *Lactobacillus rhamnosus* strain GG *Lactobacillus helveticus*46 and 72 *Lactobacillus jugurti* 63 *Lactobacillus lactis* 170 *Lactobacillus casei* spp. Casei C3 *Streptococcus thermophilus* NG40Z and C5 *Lactobacillus paraplantarum*, *Lactobacillus rhamno sus* strain GG *Lactobacillus rhamnosus* strain LC-705, *B. longum*, *L. acidophilus*, *S. typhimurium*; others are: *Nocardia asteroides Mycobacterium fluoranthenivorans* species, nov. *Rhodococcusery thropolis*, Mixed culture (*Alcaligenes*, *Bacillus*, *Achromobacter*, *Flavobacterium*, *Pseudomonas* and *Curtobacterium* spp. strain 114-2; and yeast cell walls- Yeast cell wall, MTB-100®, Mycosorb™, Esterified glucomannan, EX16, BETA, LEC), micronized fibers-ADFIMAX®, enzymes [Protease A, Pancreatin, Epoxidase from *Eubacterium* BBSH 797, Aflatoxin-detoxifizyme (ADTZ), Lactonohydrolase], fungi [*Aspergillus niger*, *Eurotium herbariorum*, *Rhizopus* spp., and non-aflatoxin (A F)-producing *A. flavus*, *A. parasiticus* NRRL 2999 and NRRL 3000], yeast [*Trichosporon mycotoxinivorans*, *Phaffiar hodozyma* and *Xanthophyllomyces dendrorhous* isolates, Mycotox®, Mycofix® Plus], bacteria + yeast [Combination of *Eubacterium* BBSH 797 and *Trichosporon mycotoxinivorans*], vitamin, amino-acid and synthetic polymers like [cholestralamine, AntitoxVana (Polyvinyl polypyrrodilone), polivinil-polipirrolidon polymers (PVPP)] (CFP/EFSA/FEEDAP, 2009; Ipcak and Alcicek, 2015). Lende (2021) reported that in fish nutrition, some bentonites also bind aflatoxin and carry it through the gut without harming the fish.

Vitamins and minerals: Vitamins are a group of organic compounds required in small quantities by poultry only, but they are essential for normal body functions, growth, and reproduction (Verma, 2014; Pandit, 2015). A deficiency of one or more vitamins can lead to a number of diseases or syndromes. Vitamins are divided into two categories: fat-soluble and water-soluble. The fat-soluble vitamins are A, D, E, and K. The water-soluble vitamins include vitamin C and the B vitamins. Vitamin C supplementation is useful when birds are in stress (Verma, 2014; Pandit, 2015). Vitamin A is required for normal growth, reproduction and maintenance of epithelial cells in good condition. Fish liver oil and greens are rich sources of vitamin A. Vitamin D_3 is required for proper absorption and utilization of calcium and phosphorous, which are required for normal growth, bone development, and egg shell formation. Vitamin D can be produced when sunlight hits the bird's skin. Fish liver oils are rich sources of vitamin D. Vitamin E is a powerful antioxidant and important for normal neurological functions. Vitamin K is essential for synthesis of prothrombin, thus it plays an important role in clotting mechanisms and also has a protective effect against coccidiosis. Wheat germ oil, fish liver oil, alfalfa meal, greens, germinated pulses, soybean oil, grains and fish meals are rich source of Vitamin A, D_3, E and K (Verma, 2014, Pandit, 2015).

Pandit (2015) reported that B vitamins include thiamin, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folic acid, and cyanocobalamin. The B vitamins are involved in many metabolic functions, including energy metabolism. A vitamin premix is typically used to compensate for the fluctuating levels of vitamins found naturally in food and to assure adequate levels of all vitamins. Thiamine (Vitamin B_1) is necessary for proper carbohydrate metabolism. It is found in abundance in rice polish, wheat bran and cereal grains. Riboflavin (Vitamin B_2) is part of enzyme systems so plays a vital role in metabolism. Grasses and brewer's yeast are rich source of this vitamin. Pyridoxine (Vitamin B_6) is necessary for proper metabolism of amino acids (Verma, 2014; Pandit, 2015). Cereal grains, yeast and alfalfa meal are rich sources of this vitamin. Cyanocobalamin (Vitamin B_{12}) is involved in nucleic acid synthesis, carbohydrate and fat metabolism and methyl synthesis:

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