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Review

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Recent Advances and Future Directions in Poultry Nutrition - A Review

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ABSTRACT

The poultry industry in India has made a remarkable growth and it is currently emerging as a sunrise sector with a growth rate of 8.51 and 7.52% in egg and broiler production, respectively. Also, the per capita consumption of eggs has gone up from 30 to 68 eggs per annum and demand for processed chicken meat has been growing by 15- 20% per annum. The worldwide consumption of poultry products such as meat plus eggs are currently high and it is growing continuously as compared to other livestock products. So, it is important to know what the recent advances that were made and what will be the future directions in poultry nutrition in a brief. Recent advances that have made includes defining nutrient requirements and nutrient composition, least cost feed formulations based on amino acid and energy, use of biotechnological products in poultry feeding as well as nano minerals supplementation. There are certain future directions like use of alternative raw material, use of phytogenic feed additives as alternative to antibiotic growth promoter, focus on gizzard development and gut health, use of next generation feed enzymes, split feeding and in ovo nutrition are of prime importance.

Key words: Antibiotic alternative, Feed additives, Gut health, Nutrition, Poultry, Supplements

INTRODUCTION

According to the 20th Livestock Census-2019, the total poultry population is 851.81 million and it is increased by 16.81% as compared to previous livestock census (Anonymous, 2019). The poultry industry in India has made a remarkable growth and it is currently emerging as a sunrise sector with a growth rate of 8.51 and 7.52% in egg and broiler production, respectively. India is the third largest egg and fourth largest broiler producing country in the world and it has an estimated production of 103.3 billion eggs and 4.1 million tons of broiler meat per annum. Broiler and layer segment constitutes about 65.3% and 34.7% with the monthly turnover of 400 million chicks and 8,400 million eggs, respectively (Kolluri *et al.*, 2020). Production standards of broilers and layers have continuously improved and the male broilers are currently reaching a live weight of 2.5 kg at 33 to 35 days of age, and white egg layers capable of producing 330 eggs in 52 weeks of lay. The body weight of broilers at 42 days has increased by 25 to 50 gram per year and the feed conversion ratio (FCR) to 2 kg body weight has improved 2 – 3 points annually (Ravindran and Abdollahi, 2017).

The global average of FCR in 2013 was around 2.0 for weight gain (live weight) and 2.8 for slaughtered meat (carcass weight). When slaughtered, the world average layer flock as of 2013 yields a carcass FCR of 4.2, still much better than the average backyard chicken flock (FCR 9.2 for eggs, 14.6 for carcass) (Macleod *et al.,* 2013). Since past poultry producers have been able to reduce their feed conversion ratios from producing a bird weighing 2 kilograms in 70 days with an FCR of 2.5 to a bird weighing the same in comparatively less number of days with an FCR of 1.5 today. The industry made this leap possible using genetic improvements most probably and rapid disseminations of improved chickens.

In India, the per capita consumption of eggs has also gone up from 30 to 68 eggs per annum and that of chicken from 400 gms to 2.5 kg per annum in the

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last five years. Demand for processed chicken meat has been growing by 15- 20% per annum in recent years. Poultry meat and eggs are cherished worldwide and are consumed in various forms. They are rich in proteins and a major source of essential micro-nutrients such as vitamin A, vitamin B12, riboflavin, calcium, iron and zinc. The Indian Council of Medical Research (ICMR) recommends the consumption of 180 eggs per capita per year. The primary objective of nutritional research include selection of the good quality ingredients for the healthy growth of birds and as a result of which there will be elimination of certain disease condition that is causing economic losses to farmers and ultimately it will be reducing the cost of production.

The poultry sector has advanced remarkably and poultry meat production had been the most successful than any other in the animal industry. So, the main purpose of this overview is to make researchers, young scientist and students know about the various recent advancements and future directions in the field of poultry industry. Thus, this overview will form a base of generalized knowledgeful information.

RECENT ADVANCES IN POULTRY NUTRITION

Defining nutrient requirements

Defining nutrient needs is bit of difficult because they are influenced by several factors. The factors influencing nutrient requirements are of two main types, the first one is bird related ones, such as genetics, sex, and type and stage of production; and the second are external ones, such as thermal environment, stress and husbandry conditions. One must be very much precise in both this areas for defining nutrient requirement accurately. Defining requirements for the ten essential amino acids has been made easier by acceptance of the ideal protein concept. The ideal protein concept generally uses lysine as the reference amino acid, and the requirements for other essential amino acids are set as percentages (or ratios) of the lysine requirement. This has now become accepted practice for setting the amino acid specifications in the poultry industry for feed formulations (Ravindran, 2013).

Nutritional requirements are not static but dynamic. Thus, with the change in genetic makeup, feeding system and feeding management there is a need for verification, updating and fine tunning of nutritional requirements on a continuous basis (Reddy, 2015). The latest feeding standards adopted are Indian council of agriculture research (2013) which includes nutrient requirements of broiler breeders and layer chicken including cockerels and breeder males, Bureau of Indian standards (2007), Nutrient requirement of poultry (1994) by NRC of National Academy of Sciences (USA). Historically, the industry has utilised the nutrient requirements recommended in the publication by National Research Council (NRC). Currently, the recommendations suggested by commercial breeding companies provide guidelines that more closely match the requirements of modern bird strains than those recommended by NRC (1994) (Ravindran and Abdollahi, 2017). However, NRC standards under Indian conditions may not be appropriate as the requirements differ due to several factors such as genetic makeup, environmental temperature, managemental practices, metabolic characteristics, feedstuff qualities and dietary variables. Substantial differences also exist in the estimates of nutritional requirements for chicken and other poultry species of tropical countries from that of temperate climate (Reddy, 2015).

Defining nutrient composition and ingredient quality

There is the availability of rapid tests, such as the near-infrared reflectance analysis, to predict gross nutrient composition and to access the variability in ingredient supplies (Ravindran, 2013).

(a) Near-infrared reflectance spectroscopy (NIRS)

Recent developments in near infrared spectroscopy (NIRS) are extremely cost-effective, near instant and provide on-site analysis. This is beneficial to animal nutritionist to formulate better diets. Currently the NIRS may be used as a tool to predict the digestible amino acid and likely the energy content of feedstuffs. Also, NIR has a potential to deliver bird's nutrient requirements with unfailing accuracy, without over or under supplying. Latest NIR technology software and hardware developments can help nutritionists better understand their feed ingredients. Emerging technologies such as centrally maintained on-line calibrations, pay-as-you-use calibrations, portable NIR and affordable in-line NIR installations are making NIR technology more accessible across the entire feed industry. Rapid sample analysis by NIR allows nutritionists to better understand the variation in raw materials. It will adjust ingredient safety margins.

Near infrared spectroscopy is a technology that uses the infrared region of the electromagnetic spectrum (from about 800 nm to 2500 nm) to study the physio-chemical properties of samples in a non-destructive way. The technique is rapid, non-destructive, precise, and cost-effective, compared with other laboratory techniques (Yakubu *et al.,* 2020). Calibration is the key for successfully using the NIRS technique. Accurate, robust calibration models are difficult to obtain as their construction requires the use of a large enough number of samples to include all variations of physical and/or chemical properties (Restaino *et al.,* 2008). So, calibration transfer between instruments is needed because usually calibration equations which are suitable for one kind of spectrophotometer are not working properly on spectra acquired by other instruments. Marchesini *et al.* (2017) concluded that the transfer of calibration curves is good enough to obtain accurate predictions about the composition of the chopped maize plant, using portable NIR instruments. Soto *et al.* (2013) concluded that feed formulation using NIRS as the source of information for amino acid content improved broiler body weight at 21 and 42 days without affecting FCR.

(b) Feed formulations based on amino acid

Dietary protein sources are often a high expense component of poultry diets. As animals require specific amino acids, formulations requiring specific amino acids often lead to crude protein (CP) levels that are overly costly and result in excess nitrogen being excreted as an environmental pollutant (Sigolo *et al.,* 2017). So, using low protein diets can be more economical. Harn *et al.* (2020) showed with their studies result that the crude protein content of grower and finisher diets can be reduced by 2.2-2.3% units without adverse effects on growth performance of broilers, while crude protein reduction seems promising to reduce nitrogen excretion from broiler houses, improve bird welfare, and reduces dependence on vegetable protein sources. Also, Kamely *et al.* (2020) concluded that moderate reductions in dietary crude protein in the starter phase of broilers did not significantly affect growth performance or relative organ weights in either the starter phase or beyond until 35 days of age.

Formulating diets based on digestible amino acids makes it possible to increase the range of ingredients that can be used and the inclusion levels of alternative ingredients in poultry diets. This improves the precision of formulation, may lower feed costs and ensures more predictable bird performance (Ravindran, 2013).

(c) Feed formulations on energy basis

Despite its limitations, apparent metabolisable energy (AME) has been the system of choice for describing available energy. Net energy (NE) system which is a refinement of the AME concept, has received attention from time to time. To be acceptable to the commercial industry, formulations based on NE values should demonstrate an economic advantage over the current system, which is yet to be proven (Ravindran and Abdollahi, 2017).

(d) Better feed formulations and processing

Once the nutritional needs are defined, the next step is to match these needs by using combinations of ingredients and supplements. The objective of feed formulation is to derive a balanced diet that will provide appropriate quantities of available nutrients at least cost. Over the previous years, feed formulation has evolved from a simple balancing of few feedstuffs for a limited number of nutrients to computer-aided linear programming systems. Currently, newer systems of stochastic non-linear programme are becoming popular with the commercial availability of this formulation software. Because variability in ingredient composition is non-linear, stochastic programmes address this issue in the most cost-effective manner possible. Newer approaches, which predict the most profit for a given ingredient combination are being increasingly used by the commercial industry (Ravindran and Abdollahi, 2017).

Kasturi feed formulation is simple and practical feed formulation software, is developed by K. Chandra Shekhar in the year 2002. It is meant for least cost feed formulation and generally users friendly. It comes with two functions: (1) Optimize: where it uses liner programming to optimize feed formulation at least cost, (2) Analyse: if one does not want least cost formulation but only want to know the nutrient values, this will calculate the nutrients values and the formula cost on entering the ingredients quantity and rate. It is mostly suitable for egg producers, broilers, hatcheries, feed manufacturers etc. Another software is WIN FEED, it is the cheapest least cost feed formulation software developed in the year 2012. It is equally useful for ruminants and non-ruminants such as poultry, cattle, sheep, horses, dogs, cats, fish and aqua culture etc. WinFeed works in two modes, Linear Mode: suitable for conventional feed formulation and Stochastic Mode: specifically for probability based least cost feed formulation. Eco-Mix is user friendly windows-based software which prepares any kind of balanced feed with least cost. This software can be used for poultry, cattle, horse, fish, pets, ruminants and non-ruminants etc (Patil *et al.,* 2017).

Growth models are used to simulate feed intake and production parameters under a given husbandry condition. Such models are effective tools to compare actual versus potential performance, which can indicate the extent of management or health problems in the flock and it will also provide economic analysis of alternative feeding regimens.

Modelling approach is possibly the best way to determine the optimum economic feeding program for broilers and laying hens and for predicting performance in the future (Sakomura *et al.,* 2015). The models are only as good as the datasets we use to develop them (Ravindran, 2012). Offering feed to poultry in pellet or crumbled form has improved the economics of production by bettering feed efficiency and growth performance. These improvements can be decreased feed wastage, higher nutrient density, reduced selective feeding, decreased time and energy which are spent for eating, destruction of pathogenic organisms and more importantly, increased feed consumption (Amerah *et al.,* 2007).

The requirements for energy and amino acids may also be affected by the feed form (pellet or mash). The foremost advantage of pellet feeding is facilitation of easy ingestion. Increasing the diet density through the pelleting process has been reported to markedly increase productive energy. Broilers fed with pellets have lower heat increment and utilise more of the feed energy for productive purposes than those fed with mash (Latshaw and Moritz, 2009). Lemons *et al.* (2021) concluded that broiler birds fed crumbles had the highest body weight and body weight gain/bird, regardless of crumble feed quality and birds fed intact pellets achieved increased weights when feed quality was highest similar to birds fed crumbles.

Use of Biotechnological Products in Poultry Feeding

The ultimate goal of using biotechnology in animal nutrition is to improve the nutritional plan by increasing the availability of nutrients from the feed and reducing the wastage of feed (Asmare, 2014). Some of these applications are already in use (for example, new feed ingredients like single-cell protein and yeast protein, designer ingredients like high-oil maize, high-methionine lupins and low-phytate maize, feed additives like antimicrobials and crystalline amino acids, feed enzymes like microbial phytases, gut ecosystem enhancers like probiotics (direct-fed microbials), prebiotics like mannan oligosaccharides and others whose potentialities are known but are yet to be commercially applied because of technical limitations and public concerns such as bioactive peptides: improved growth and efficiency (e.g. growth hormone-releasing peptides), improved gut function, immune-modulation and antibacterial properties, nucleotides: stimulation of intestinal development, tissue growth and better immune response, antimicrobial replacers: antimicrobial enzymes (e.g. lysozyme) and delivery of specific antibodies via spray-dried plasma and egg products, transgenesis: to modify nutrient metabolism and improve growth efficiency by transfer of genes (Ravindran and Abdollahi, 2017)

Phase Feeding

This is a feeding system in which dietary amino acid levels are reduced steadily over time in an attempt to reduce costs associated with excess dietary protein or amino acids (Ravindran and Abdollahi, 2017). The wider implementation of phase/precise feeding, however, is limited by several issues like information on metabolizable energy and digestible amino acid requirements for different classes of poultry is lacking, we do not have objective rapid tests, which the industry can use to estimate metabolizable energy/digestible amino acids as the raw materials are received at the feed mill, information is still needed on the comparative digestibility of amino acids for different classes of chickens - layers and broilers of different age groups (Ravindran, 2012).

Meremikwu and Obikaonu (2020) concluded that extending the growing period of the broiler using a high-low-high phase feeding led to the production of roasters (heavy broilers) that achieved identical body weights with the control group at 12 weeks of age and there was zero mortality noted. Also, the nutrient restricted birds had about 25% lower cost of feed per kilogram weight gain than the control group.

Split feeding

Split feeding is generally alternative system for feeding layer birds. It means to provide different morning and afternoon diets to the hens. This responds to their physiological feeding behaviour and nutrient intake according to the different requirements throughout the day. Benefits of split feeding includes: cost savings, greater profits and increased egg quality and number. Better sustainability is the result of improved nutrient efficiency. El-Razek *et al.* (2020) concluded that split feeding of Dandarawi layers at their late phase of egg laying cycle had led to decreasing feed consumption, improving feed conversion ratio, saving in feed cost and increasing egg number and egg mass.

Nano minerals

Nano-minerals are specially synthesized mineral particles with its particle size ranging from 1 to 100 nm. Like nanoparticles, nano-minerals possess higher physical activity and chemical neutrality, which may be the reason for efficient absorption in the animal system (Hassan *et al.,* 2020) and they are reported to be stable under high temperature and pressure as well.

Nano-minerals as feed supplement can increase the feed efficiency, diminish feed cost by reducing the supplemental doses, and simultaneously intensifying the yield and value of animal products by virtue of their superior bioavailability (Patra and Lalhriatpuii, 2019). Different beneficial biological effects of nano-minerals in poultry are, growth: improvement in the body weight gain and feed efficiency, immunity: improve the cell mediated and humoral immunity, meat production: improvement in meat quality and also improvement in meat keeping quality, egg production: improve egg production, egg weight, hatching percent, egg quality parameters, hematology and blood biochemistry: improves antioxidant enzymes hormones related to growth and reproduction, miscellaneous: reduce environment pollution, retained more efficiently, less excretion (Swain *et al.,* 2021). Data given in table 1 represents meta analysis of nano minerals supplementation.

Table 1. Meta analysis of nanominerals supplementation

Nano minerals	Experimental bird	Effects	References
Zinc oxide nanoparticles	Broiler bird	Improves antioxidatives capabilities, Improves growth performance	Zhao *et al.,* (2014)
Nano zinc	Layer bird	Improved average body weight and FCR	Mishra *et al.,* (2014)
Nano calcium carbonates	Laying hens	Stronger egg shell strength, promoted water intake to dissipate heat	Wang *et al.,* (2017)
Zinc oxide nanoparticles	Laying hens	Improve egg quality, bone parameters, antioxidative status	Abedini *et al.,* (2018)

Organic Minerals

Organic mineral is an organic compound in mineral form. Organic trace minerals have higher bioavailability than inorganic trace minerals. Hence, supplementation of organically complexed/chelated trace minerals could help avoid the use of higher dosages of inorganic trace minerals in poultry feed and prevent environmental contamination because they have lower inclusion rates and reduced excretion (Bao *et al.,* 2007; Bao and choct, 2009). In market there is availability of high quality supplement of chelated minerals product like chelated Asocal and mineral mixture like Sermin for better growth of birds.

Rao *et al.* (2016) concluded that chicks supplemented with chelated trace minerals had significant increase in body weight gain, deposition of minerals in the tissue and improved feed conversion ratio (FCR) compared with that among chicks supplemented with inorganic trace minerals at similar dose. Also, broiler birds fed with a diet supplemented with organic chromium (0.5 ppm) showed increased body weight gain compared with birds supplemented with inorganic chromium sources (Mohammed *et al.,* 2014).

FUTURE DIRECTIONS IN POULTRY NUTRITION

Sometime in the future, we should modify feed formulations that will accommodate science-based as well as the needs of the society. The impact of social issues (use of antibiotic growth promoters, environmental issues) will have direct impact on decision-making from farm level to retail distribution of poultry products.

Sustainability

Previously, when feeds were formulated, the main objective was how to supply the nutrients (nutrient input). Today, there is much more public concern about what comes out of the bird (nutrient output) (Ravindran, 2012). A major problem facing intensive poultry production in India is the disposal of litter (Bolan *et al.,* 2010). Poultry manure can also become a serious environmental pollutant and contributor to greenhouse gases. There are environmental and health issues linked to bio-aerosols (e.g. microbes, endotoxins and mycotoxins suspended in air) generated at production, manure storage facilities and during land spreading of poultry litter (Bolan *et al.,* 2010).

Central Pollution Control Board (CPCB) has updated the norms that apply to all types of poultry farms. Smaller poultry farms which is having over 5,000 birds at a single location will need an approval to establish and operate under the Water Act of 1974 and the Air Act of 1981 from the State Pollution Control Board (SPCB) or Pollution Control Committee (PCC). According to the CPCB, new poultry farms should be constructed 500 metres from residential zones to reduce stink and flies, and 100 metres from important watercourses such as rivers, lakes, canals, and drinking water sources to avoid pollution due to leaks and spillages. The updated standards also address environmental concerns raised by poultry farms, such as reducing smell and gaseous pollution through effective ventilation, managing solid waste and hatchery debris, collecting, storing, and composting manure. Poultry houses should be well ventilated to dissipate heat and prevent build up of gases. Excreta should be scratch once in two days and manure collected shall be stored for processing. Manure storage facilities shall be minimum 2 m above water table.

Results from various studies have shown increased phosphorous digestibility and its utilization, and reduced phosphorous excretion into the environment as a result of phytase addition (Applegate *et al.,* 2003; Penn *et al.,* 2004; Angel *et al.,* 2006; Leytem *et al.,* 2007). Supplementation of commercial enzymes can enhance the nutritional value of crops containing high contents of soluble non-starch polysaccharides (NSPs). The NSPs digestibility is very low in poultry and a large amount is voided via the excreta. The NSPs can also bind to large quantities of water and as a result, the fluid viscosity increases. Increasing viscosity may cause problems in the digestion of carbohydrate, protein and fat. Furthermore, high viscosity of intestinal content increases the sticky dropping amounts. These problems can be overcome by addition of enzymes to poultry diets. An increased use of exogenous enzymes is expected not only from the nutritional and economic aspects but also from the health and environmental point of view (Alagawany *et al.,* 2018).

Alternative raw materials

Poultry production costs have continually increased because of the fluctuation prices of high-quality raw materials such as soybean, corn, and others. Many attempts have been made to decrease the cost of feeding to the minimum levels. These attempts include replacing the expensive feedstuffs by cheaper and more abundant by-products to support the sustainability of poultry production (Aftab, 2009).The discovery of alternative protein sources for poultry feeding diet has become a particular focus in the current scenario to decrease dependence on soyabean meal as the main ingredient of protein in poultry feeds (Ashayerizadeh *et al.,* 2018). Dried distillers' grains with solubles (DDGS), sunflower meal (SFM), decorticated cotton seed meal (gossypol free) and rapseed meal are new feed ingredients and may be used as an alternative source of protein in animal and poultry diets. Body weight gain and nutrient digestibility significantly improved by 60% soyabean meal replacement with maggot meal during starter phase in broiler chicks (Khan *et al.,* 2018).

Antibiotic free nutrition and gut health

The use of antibiotics in poultry rations for the purpose of stimulating growth is useful in improving production and preventing infections but the excessive use of these antibiotics led to raise in bacterial resistance to diseases in addition to the accumulation of remnants of these drugs in animal products and therefore they were dispensed (Nisha, 2008).The main characteristic of a good antibiotic growth promoter (AGP) alternative is practicality; it must consistently improve animal performance (Huyghebaert *et al.,* 2011). Antibiotic alternatives may have some positive regulatory and antioxidant effects on intestinal flora in poultry and these compounds can also be considered as growth stimuli in poultry production. Meta analysis of combined or synergistic effect of additives is given in table 2.

Combination of other strategies including modifications in husbandry and nutritional management need to be considered to promote gut health and good gut flora and these may include: Use of highly digestible pre-starter diets, use of lower dietary protein levels and better balance of amino acids, use of coarse particle size or whole grain feeding to enhance gizzard development, maintenance of good litter quality and maintaining proper stocking density etc. When gut health is compromised, digestion and nutrient absorption are affected (Jha and Berrocoso, 2015), which in turn, may have a detrimental effect on feed efficiency and greater susceptibility to diseases leading to economic loss. Some important alternative to antibiotics are discussed below:

Probiotics are single or mixed culture of living microorganisms which when administrated in adequate numbers have health benefits for the host by improving the host intestinal microbial balance, enhancing of colonization resistance against pathogens and improving the immune responses (Das *et al.,* 2012). The species of microorganisms being used in probiotic preparations are varied and LAB, i.e., Lactobacillus bulgaricus, Lactobacillus acidophilus, Lactobacillus casei, Lactobacillus lactis, Lactobacillus salivarius, Lactobacillus plantarum, Streptococcus thermophilus, Enterococcus faecium, Enterococcus faecalis, Bifidobacterium spp., are the most common type of bacteria used as probiotics (Kabir, 2009).

Prebiotics are non digestible feed ingredients that beneficially affect the host by selectively altering the composition and metabolism of the gut microbiota. Prebiotics may provide energy for the growth of endogenous favorable bacteria in the gut, such as bifidobacteria and lactobacilli, thus improving the host microbial balance (Das *et al.,* 2012). The most often used prebiotics are fructo-oligosaccharides (FOS), inulin, galacto-oligosaccharides (GOS), xylo-oligosaccharides (XOS), pyrodextrins, and lactulose (Alloui *et al.,* 2013). When both probiotic and prebiotic are combined, they form symbiotic (Huyghebaert *et al.,* 2011). The functional benefits of symbiotic, are resistance to gastrointestinal bacterial infection, antimicrobial activity, and improvement of immune system are envisaged in the development of symbiotic products (Saminathan *et al.,* 2011).

Various exogenous enzymes including b-glucanase, xylanase, amylase, a-galactosidase, protease, lipase, phytase, etc. have been supplemented in poultry diets (Bedford and Cowieson, 2012). Preparing poultry diets with a mixture of glucanase and xylanase improved the feed conversion ratio and nutrient digestion in the ileum, so, adding two types of enzymes produces a synergistic effect than if only one type of enzyme was used (Cowieson *et al.,* 2010). Organic acids are commonly used as acidifiers in poultry nutrition. They act directly against bacteria that are present in the feed. Organic acids can also act indirectly by reducing the pH in the gut. Butyric acid is nowadays commonly used. Lactic acid is more effective against bacteria. Formic acid, propionic acid have broader antimicrobial activities and can be effective against bacteria and fungi, including yeast. Butyric acid is nowadays commonly used.

Phytogenics are a group of natural growth promoters (NGPs) or non-antibiotic growth promoters used as feed additives, derived from herbs, spices or other plants (e.g. garlic, oregano, thyme, rosemary, coriander and cinnamon) as well as to their respective plant extracts in the form of essential oils. They are commonly regarded as favourable alternative feed additives to antibiotic growth promoters (AGPs) in poultry nutrition (Windisch *et al.,* 2008). Phytogenic relieve the host animals from immune defense stress during critical situations and increase the intestinal availability of essential nutrients for absorption, thereby helping animals to grow better (Hashemi and Davoodi, 2010). Karangiya *et al.* (2016) concluded that supplementation of garlic improves the performance of broilers when added at the rate of 1% of broiler ration and can be a viable alternative to antibiotic growth promoter in the feeding of broiler chicken.

Bacteriophage are virus that infect and kill bacteria. An 0.05% bacteriophage cocktail dietary supplementation during the finisher period would be economical and effective as a safe alternative to antibiotics for raising broilers under intensive farming systems (Upadhaya *et al.,* 2021). Immunomodulators are agents which specifically modulate immune system regulating immunity and disease resistance. In poultry it is most important for the growth, disease resistance, FCR, body weight gain as production output mainly depends on the health and immunity of the birds. Different types of immunomodulators are prebiotics, probiotics, phytochemicals, turmeric rhizome powder, cinnamon, thyme, essential oils and carvacrol, vitamins (A, C, E), minerals, adjuvants, polysaccharides, herbs like aloe vera etc. The primary objective of immunomodulation is to improve host resistance to external and internal attacks by the microbes or other infectious agents Immunomodulators can used as alternatives to antibiotics, antimicrobials etc. for the improvement of the immune system. As immune system is directly related to the disease resistance, gut health etc hence they must be used in combination and/or alone according to the needs. They also improve the qualities of feed and immune molecules enhancing all possibilities to fight against diseases as well as maintain health of birds. However, they are not popular and not included in the poultry feed on routine basis. Hence, more studies should be done and efforts should be made to popularise it (Das *et al.,* 2020).

Table 2. Meta analysis of combined effects of additives

Effects	References
Synbiotic product containing Enterococcus faecium bacteria and FOS as a prebiotic, and immunomodulating substances from marine algae (ficophytic substances) significantly increase the average daily body weight gain, improve the gut health and can be used as a growth promoter in broiler diets.	(Awad *et al*., 2009)
Probiotics and phytobiotics can have beneficial synergistic effects on the intestinal microbiota in young chickens	(Ren *et al*., 2019)
Combination of 1% herbal mixture with enzyme feed additives in broiler feed can be effective alternative to antibiotic growth promoter	(Singh *et al*., 2020)
Supplementation of probiotics and/or organic acids enhanced humoral and cell mediated immune response in broilers.	(Ebeid *et al*., 2021)

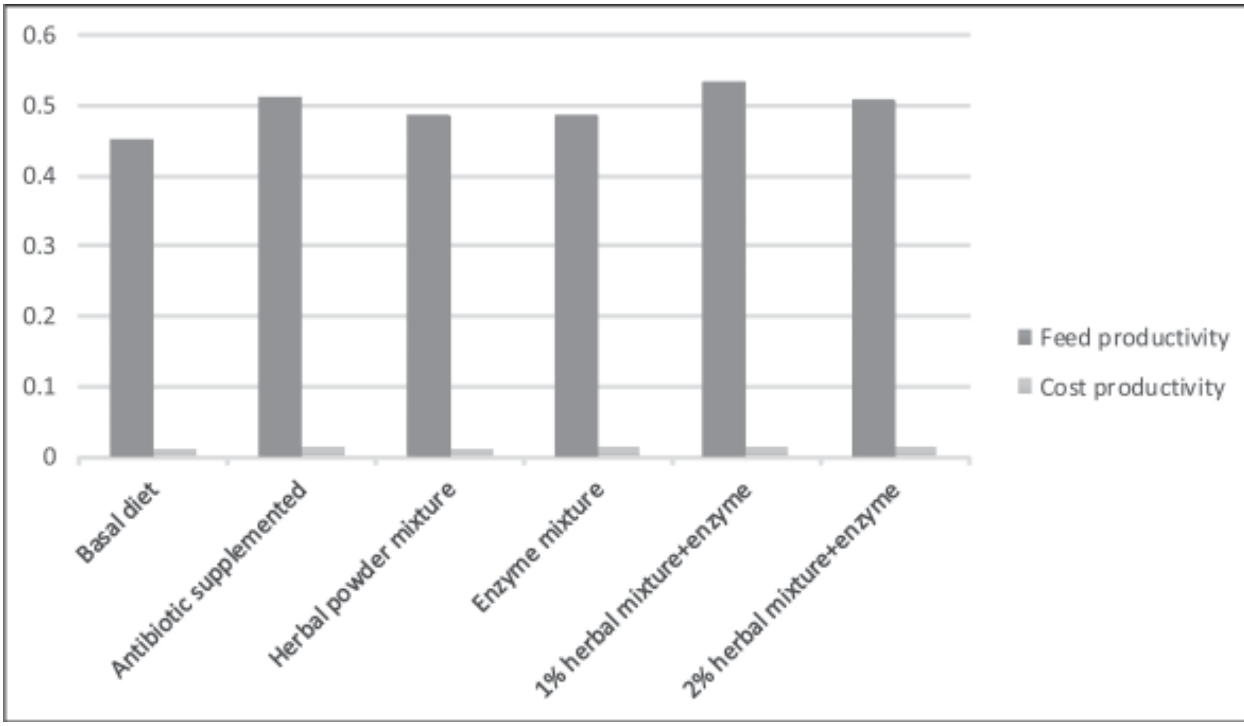

Fig. 1. Representation of feed productivity and cost productivity (Singh *et al.,* 2020)

Focus on gizzard development

Fore gut, particularly gizzard, if fully developed, can be regarded as an important barrier in preventing pathogenic bacteria from entering the distal intestinal tract (Svihus, 2011).The inclusion of dietary structural components, such as coarse particles, insoluble fibre sources and whole grains, in poultry diets should be given consideration. The major motivation for inclusion of structural components in poultry diets is to stimulate gizzard development and its functionality, which will favourably influence gut health and the bird's ability to better utilise nutrients (Ravindran and Abdollahi, 2017).

A large and well-developed gizzard is able to grind feed particles more thoroughly (Amerah *et al.,* 2007), to elevate pancreatic enzyme secretion through increased release of cholecystokinin (Svihus, 2011), to increase proteolysis by pepsin, trypsin and other endogenous proteases in the small intestine, to improve gastrointestinal tract motility and to improve nutrient digestibility (Amerah and Ravindran, 2008).

Synthetic amino acid supplementation

The careful supplementation of synthetic amino acids has the potential to boost the overall amino acid balance and to decrease the level of crude protein in the poultry diet. Dietary synthetic amino acid supplementation to poultry diets improved feed conversion efficiency and reduced nitrogen excretion (Beski *et al.,* 2015). Synthetic DL-Met and Met analogue are now widely used in commercial production diets to reduce crude protein (CP) levels (Vieira *et al.,* 2016).

Natural sources of tryptophan (chick peas, sunflower seeds, pumkin seeds), herbal lysine (spirulina, fenugreek seeds, soyabean), herbal methionine (amla, soya bean, garlic, silybum, bhringraj), herbal choline (soyabean, almonds, red potatoes, cruciferous vegetables like cauliflower, brocolli) are also used. Herbal Methionine is the natural alternate to dl-Methionine as it is obtained from those plants which have same action mechanism in the body as that of synthetic dl-methionine. Herbal methionine (HerboMethione) as a source of active methionine is effective in its optimum activity for proper protein accretion and other functions in poultry birds so that they can reach better growth and performance potential. Thus, Supplementation of Herbomethione has a positive influence on the performance of broiler chickens, when compared to synthetic DL-methionine (Halder and Roy, 2007). Also, Khose *et al.* (2018) concluded that supplementation of herbal choline at 0.500 kg/

ton of feed was more beneficial in terms of improving the bird's performance.

Feed enzyme technology – Next generation

The 'next-generation' enzymes will be close to being 'perfect', with : A high specific activity per unit of protein, good thermostability during feed processing, high activity in the typical pH range of the animal gut, resistance to gastric proteases and good stability under ambient temperatures. Preparations with multiple enzyme activities may provide a competitive strategy to improve nutrient utilisation in poultry diets. For increasing enzyme thermo stability, put a "coating" around the enzyme. Coated enzyme preparations can easily withstand the pelleting process, however they are more complicated to produce and the preparation quality is very dependant of the coating quality. Coated enzyme preparations are known to show slower release kinetics within the animal gut, by contrast the naturally thermostable enzymes start working immediately after ingesting.

Supplementation of exogenous enzyme in the diets is considered modifications to overcome the adverse effects of Non-Starch Polysaccharide (NSPs). Enzymes break down the NSPs, reduce intestinal viscosity and subsequently get better nutrients digestibility by improving gut performance (Amerah, 2015). Technologies are also being evolved to maintain enzyme activities in their dry enzyme products in order to protect them from the heat, moisture and high pressures generated during feed processing and a number of thermostable enzymes, especially phytases, are now commercially available. Supplementation of phytase had positive effect on production performance and egg weight was comparatively higher in phytase supplemented group in free range lohman brown layers (Akyurek and Orhan, 2016).

Another recently used exogenous enzyme is proteases of microbial origin. The economic benefits of these exogenous proteases are achieved through improved digestibility of dietary protein. Multi protease enzyme application supports protein digestibility throughout the gastrointestinal tract by combining three types of proteases, each having different pH optima. So, multienzyme product containing multiple proteases can be used to reduce protein waste in the poultry ration and deliver considerable economic value. A product Kemzyme® map is a dry, a multisubstrate enzyme an example of multienzyme containing NSP (Non-Starch Polysaccharide) enzymes, multi-proteases and multi-amylases from Kemin. KEMZYME protease is a patented multi-protease solution containing acid, neutral and alkaline proteases. The product has an innovative thermostable and enteric coating for protection during feed milling and targeted release in the gastrointestinal tract.

Importance of early nutrition

Early nutrition means providing the required nutrients to the birds either during the period when the embryo is developing or immediately after hatch until birds attain a fully matured digestive system. The delayed intake of water and nutrients to chicks could lead to a diminishing of their overall growth performance with adverse effects on breast meat. The most extreme consequence of delayed feeding is increased mortality (Willemsen *et al.,* 2010). Early feeding strategies have been suggested and developed to diminish or possibly reverse the negative effects of delayed feeding. These strategies range from in ovo feeding to specially designed post-hatch diets.

The administration of digestible nutrients into the amnion of embryos can bring an improvement in bird quality, increased glycogen reserves, fast development of the total digestive tract superior skeletal health, better muscle growth rate, higher body weight gain, improved feed conversion and enhanced immune function. For example, probiotics supplementation in early life prevent pathogenic infections, amino acids (L-arginine, L-lysine, L-histidine, threonine) are beneficial in growth performance, vitamin C and E boost immunity, carbohydrates increase glycogen stores and creatine supplement promotes muscle growth (Peebles, 2018). Future early nutrition would be feeding complex symbiotic that would replace feed additives and supplements in the post-hatch feed and is more beneficial to the overall poultry industry (Jha *et al.,* 2019). Zhu *et al.* (2019) concluded that in ovo feeding of 3 mg vitamin C at day 15 could improve the antioxidant activity to some extent and immune function in plasma.

Nutrigenomics

The introduction of genomics approach in nutritional sciences lead to the scientific area called 'nutrigenomics' (Asmare and Negewo, 2019).The emergence of nutrigenomics has helped to develop feeds that can be matched to genotypes of animals for a better productivity and health (Ghormade *et al.,* 2011). Nutrigenomics will relate optimal diet to choose from many and different nutritional availability. To evaluate the interaction between diets and genes, DNA microarray techniques and quantitative real-time Polymerase Chain Reaction (PCR) and DNA sequencing can be applied (Morozova and Marra, 2008). There is limitation in nutrigenomic information how to effectively analyze and correlate genes and nutrition conversion.

Gut microbiota

Gut integrity is as important as good microbiota balance. Intestinal integrity for commercial poultry can be defined as the maintenance of intestinal health to enable the expression of the full genetic potential for growth and yield, and to fully utilise the dietary nutrients. Normal biota plays a significantly major role in maintaining gut structure, strengthening the gut mucosal barrier and protein metabolism of the gut. In situations where the profiles are shifted by various pathogenic biota (e.g. clostridium and coliforms), there is significant inflammation and damage to the mucosal layer and the barrier function. Coccidiosis is a major cause of poor gut integrity, and an effective anti-coccidial programme must be in place for maintaining good healthy conditions. Raw material quality is another contributing factor. Thus, raw materials that irritate the gut must be closely monitored (Ravindran and Abdollahi, 2017). However, the development of molecular biotechnology has offered new tools to study the composition, diversity, predicted function and interaction of gut microbiota in different sections of the gastro intestinal tract. 16S rRNA based next generation sequencing is a powerful tool to investigate the biological and ecological roles of the gastro intestinal microbiota in chicken (Shang *et al.,* 2018).

Skewing of sex

In general, gender of animal offspring is quite important to livestock producers. In poultry, egg produced farmers would choose hens because only hens will produce eggs. Poultry sperm cannot be manipulated to preselect the sex of offspring (Saleh and Iriyanti, 2010). The method of providing basic element like sodium, potassium, calcium and phosphorous in diet is quite economical, safe and can be done at home (Vahidi and Sheikhha, 2007). But, Saleh and Iriyanti (2010) concluded that different amount of ions in the diet of hens could not have a significant effect on the percent fertility, hatchability and sex ratio of chicks.

CONCLUSIONS

NIRS is important rapid test to predict nutrient composition of diet. Production prediction models may remain a valuable tool for formulation of practical diet solutions. Supplement of exogenous enzymes is beneficial to poultry industries and environment too. Alternative raw material may be used to increase efficiency of bird with low cost for economic benefits. Natural growth promoter must be used as alternative to antibiotics in diets. Supplementation of bacteriophage is a safe alternative to antibiotics in poultry. For increase in productivity and to obtain highly feed efficient birds, the nutritional demand of embryos must be taken into consideration. Feed and good husbandry practices must be provided to the exploit full genetic potential of birds.

FUTURE PROSPECTS

Future nutritional research should focus on issues related to identify barriers for effective digestion and for utilization of nutrients. Poultry nutritionist must combine their expertise with those specialised in other biological sciences to improve production efficiency with reduced issues of food safety, environment and bird welfare. Efforts need to be focus on more pre and perinatal nutrition.

REFERENCES

Abedini, M., Shariatmadari, F., Torshizi, M. A. K. and Ahmadi, H. 2018. Effects of zinc oxide nanoparticles on performance, egg quality, tissue zinc content, bone parameters, and antioxidative status in laying hens. *Biol.Trace Element Res.* 184: 259-267.

Aftab, U. 2009. Utilization of alternative protein meals with or without multiple-enzyme supplementation in broilers fed low-energy diets. *J. Appl. Poult. Res.* 18: 292-296.

Akyurek, H. and Orhan, Z.C. 2016. Effects of phytase supplementation on the performance and egg quality of free-range layers, *Int. J. Curr. Res.* 8: 44142-44147.

Alagawany, M., Elnesr, S. S. and Farag, M. R. 2018. The role of exogenous enzymes in promoting growth and improving nutrient digestibility in poultry. *Iranian J. Vet. Res.* 19: 157-164.

Alloui, M. N., Szczurek, W. and Swiatkiewicz, S. 2013. The Usefulness of Prebiotics and Probiotics in Modern Poultry Nutrition: a Review. *Annals Ani. Sci.* 13: 17-32.

Amerah, A. M. 2015. Interactions between wheat characteristics and feed enzyme supplementation in broiler diets. Anim. *Feed Sci. and Tech.* 199: 1-9.

Amerah, A. M. and Ravindran, V. 2008. Influence of method of whole-wheat feeding on the performance, digestive tract development and carcass traits of broiler chickens. *Ani. Feed Sci. and Tech.* 147: 326-339.

Amerah, A. M., Ravindran, V., Lentle, R. G. and Thomas, D. G. 2007. Feed particle size: Implications on the digestion and performance of poultry. *World's Pout. Sci. J.* 63: 439-455

Angel, R., Saylor, W. W., Mitchell, A. D., Powers, W. and Applegate, T. J. 2006. Effect of dietary phosphorus, phytase, and 25-hydroxycholecalciferol on broiler chicken bone mineralization, litter phosphorus, and processing yields. *Poult. Sci.* 85: 1200-1211.

Anonymous. 2019. 20th livestock census-2019 all India report, Ministry of Fisheries, Animal Husbandry & Dairying, Department of Animal Husbandry & Dairying Animal Husbandry statistics division, *Krishi Bhawan, New Delhi. pp:*13-15

Applegate, T. J., Joern, B. C., Nussbaum-Wagler, D. L. and Angel, R. 2003. Water-soluble phosphorus in fresh broiler litter is dependent upon phosphorus concentration fed but not on fungal phytase supplementation. *Poult. Sci. 82:* 1024-1029.

Ashayerizadeh, A., Dastar, B., Shargh, M. S., Mahoonak, A. S. and Zerehdaran, S. 2018. Effects of feeding fermented rapeseed meal on growth performance, gastrointestinal microflora population, blood metabolites, meat quality, and lipid metabolism in broiler chickens. *Livestock Sci.* 216: 183-190.

Asmare, B. 2014. Biotechnological advances for animal nutrition and feed improvement. *World J. Agri. Res.* 2: 115-118.

Asmare, B. and Negewo, T. 2019. The potential of nutrigenomics from viewpoint of animal nutrition: a mini review. *SVU-Int. J. Vet. Sci.* 2: 75-81.

Awad, W. A., Ghareeb, K., Abdel-Raheem, S. and Bohm, J. 2009. Effects of dietary inclusion of probiotic and synbiotic on growth performance, organ weights, and intestinal histomorphology of broiler chickens. *Poult. Sci.* 88: 49-56.

Bao, Y.M. and Choct, M. 2009. Trace mineral nutrition for broiler chickens and prospects of application of organically complexed trace minerals: *A review. Anim. Prod. Sci.* 49: 269-282.

Bao, Y.M., Choct, M., Iji, P.A. and Bruerton, K. 2007. Effect of organically complexed copper, iron, manganese and zinc on broiler performance, mineral excretion and accumulation in tissues. *J. Appl. Poult. Res.* 16: 448-455.

Bedford, M. and Cowieson, A. J. 2012. Exogenous enzymes and their effects on intestinal microbiology. Anim. *Feed Sci. Tech.* 173: 76-85.

Beski, S. S., Swick, R. A. and Iji, P. A. 2015. Specialized protein products in broiler chicken nutrition: *A review. Anim. Nut.* 1: 47-53.

Bolan, N. S., Szogi, A. A., Chuasavathi, T., Seshadri, B., Rothrock Jr, M. J. and Panneerselvam, P. 2010. Uses and management of poultry litter. *World's Poult. Sci. J.* 66: 673-698.

Cowieson, A. J., Bedford, M. R. and Ravindran, V. 2010. Interactions between xylanase and glucanase in maize-soy-based diets for broilers. *British Poult. Sci.* 51: 246-257.

Das, D., Roul, A. K., Muduli, S., Nath, S. and Sabat, G. P. 2020. Immuno modulation in poultry. *Pharm. Innov,* 9: 467-472.

Das, L., Bhaumik, E., Raychaudhuri, U. and Chakraborty, R. 2012. Role of nutraceuticals in human health. *J. Food Sci.Tech.* 49: 173-183.

Ebeid, T., Al-Homidan, I., Fathi, M., Al-Jamaan, R., Mostafa, M., Abou-Emera, O.,El-Razik, M.A. and Alkhalaf, A. 2021. Impact of probiotics and/or organic acids supplementation on growth performance, microbiota, antioxidative status, and immune response of broilers. *Italian J. Ani. Sci.* 20: 2263-2273.

El-Razek, A., Makled, M. N., Galal, A. E. and El-Kelawy, M. I. 2020. Effect of split feeding system on egg production and egg quality of dandarawi layers. *Egyptian Poult. Sci. J.* 40: 359-371.

Ghormade, V., Khare, A. and Baghel, R. P. S. 2011. Nutrigenomics and its applications in animal science. *Vet. Res. Forum,* 147-155.

Halder, G. and Roy, B. 2007. Effect of herbal or synthetic methionine on performance, cost benefit ratio, meat and feather quality of broiler chicken. *Int. J. Agric. Res,* 2: 987-996.

Hashemi. S. R. and Davoodi. H. 2010. Phytogenics as New Class of Feed Additive in Poultry Industry. *J. Ani.Vet. Adv.* 9: 2295-2304.

Hassan, S., Hassan, F. U. and Rehman, M. S. U. 2020. Nano-particles of trace minerals in poultry nutrition: Potential applications and future prospects. *Bio. Trace Element Res.* 195: 591-612.

Huyghebaert, G., Ducatelle, R. and Van Immerseel, F. 2011. An update on alternatives to antimicrobial growth promoters for broilers. *The Vet. J.* 187: 182-188.

Jha, R. and Berrocoso, J. D. 2015. Dietary fiber utilization and its effects on physiological functions and gut health of swine. *Animal.* 9: 1441-1452.

Jha, R., Singh, A. K., Yadav, S., Berrocoso, J. F. D. and Mishra, B. 2019. Early nutrition programming (in ovo and post-hatch feeding) as a strategy to modulate gut health of poultry. *Front. Vet. Sci.* 6:82.

Kabir, S. M. 2009. The role of probiotics in the poultry industry. *Int. J. Mol. Sci.* 10: 3531-3546.

Kamely, M., He, W., Wakaruk, J., Whelan, R., Naranjo, V. and Barreda, D. R. 2020. Impact of reduced dietary crude protein in the starter phase on immune development and response of broilers throughout the growth period. *Frontiers in Vet. Sci.* 7: 436.

Karangiya, V. K., Savsani, H. H., Patil, S. S., Garg, D. D., Murthy, K. S., Ribadiya, N. K. and Vekariya, S. J. 2016. Effect of dietary supplementation of garlic, ginger and their combination on feed intake, growth performance and economics in commercial broilers. *Vet. World.* 9: 245.

Khan, M., Chand, N., Khan, S., Khan, R. U. and Sultan, A. 2018. Utilizing the house fly (Musca Domestica) larva as an alternative to soybean meal in broiler ration during the starter phase. *Brazilian J. Poult. Sci.* 20: 9-14.

Khose, K. K., Manwar, S. J., Gole, M. A., Ingole, R. S. and Rathod, P. R. 2018. Efficacy of herbal choline as a replacement of synthetic choline chloride in diets on growth performance of broilers. *J. Livestock Res.* 8: 313-322.

Kolluri, G., Tyagi, J. S. and Sasidhar, P. V. K. 2020. Research Note: Indian poultry industry vis-à-vis coronavirus disease 2019: a situation analysis report. *Poult. Sci.* 100: 100828

Latshaw, J. D. and Moritz, J. S. 2009. The partitioning of metabolizable energy by broiler chickens. *Poult. Sci.* 88: 98-105.

Lemons, M. E., Brown, A. T., McDaniel, C. D., Moritz, J. S. and Wamsley, K. G. S. 2021. Starter and carryover effects of feeding varied feed form (FF) and feed quality (FQ) from 0–18 d on performance and processing for two broiler strains. *J. of Appl. Poult. Res.* 30: 100206.

Leytem, A. B., Plumstead, P. W., Maguire, R. O., Kwanyuen, P. and Brake, J. 2007. What aspect of dietary modification in broilers controls litter water-soluble phosphorus: less Dietary phosphorus, phytase, or calcium?. *J. Env. Quality,* 36: 453-463.

MacLeod, M., Gerber, P., Mottet, A., Tempio, G., Falcucci, A., Opio, C., Vellinga, T., Henderson, B. and Steinfeld, H. 2013. Greenhouse gas emissions from pig and chicken supply chains - a global life cycle assessment. Food and Agriculture Organization of the United Nations. *ISBN* 97 92-5-107944-7.

Marchesini, G., Serva, L., Garbin, E., Mirisola, M. and Andrighetto, I. 2018. Near-infrared calibration transfer for undried whole maize plant between laboratory and on-site spectrometers. *Italian J. Ani. Sci.*17: 66-72.

Meremikwu, V. N., and Obikaonu, H. O. 2020. Effect of phase feeding on performance and economy of production of heavy broiler chickens. *Nigerian J. Anim. Sci.* 22: 186-193.

Mishra, A., Swain, R. K., Mishra, S. K., Panda, N. and Sethy, K. 2014. Growth performance and serum biochemical parameters as affected by nano zinc supplementation in layer chicks. *Indian J. Anim. Nut.* 31: 384-388.

Mohammed, H.H., El-Sayed, B.M., Abd El-Razik, W.M., Ali, M.A. and Abd El-Aziz, R.M. 2014. The influence of chromium sources on growth performance, economic efficiency, some maintenance behavior, blood metabolites and carcass traits in broiler chickens. *Glob. Vet.* 12: 599-605.

Morozova, O. and Marra, M. A. 2008. Applications of next-generation sequencing technologies in functional genomics. *Genomics.* 92: 255-264.

Nisha, A. R. 2008. Antibiotic residues-a global health hazard. *Vet. World.* 1: 375-377.

Patil, V., Gupta, R., Rajendran, D. and Kuntal, R. S. 2017. Comparative study on feed formulation software - a short review. *Int. J. Res. Grathaalayah.* 5: 105-115.

Patra, A. and Lalhriatpuii, M. 2019. Progress and prospect of essential mineral nanoparticles in poultry nutrition and feeding—a Review. *Bio. Trace Element Res.*1-21.

Peebles, E. D. 2018. In ovo applications in poultry: a review. *Poult. Sci.* 97: 2322-2338.

Penn, C. J., Mullins, G. L., Zelazny, L. W., Warren, J. G. and McGrath, J. M. 2004. Surface runoff losses of phosphorus from Virginia soils amended with turkey manure using phytase and high available phosphorus corn diets. *J. Env. Quality.* 33: 1431-1439.

Rao, S.R., Prakash, B., Raju, M.V., Panda, A.K., Kumari, R.K. and Reddy, E.P. 2016. Effect of supplementing organic forms of zinc, selenium and chromium on performance, antioxidant and immune responses in broiler chicken reared in tropical summer. *Biol. Trace Elem. Res.* 172: 511-520.

Ravindran, V. 2012. Advances and Future Directions in Poultry Nutrition: An Overview. *Korean J. Poult. Sci.* 39: 53-62.

Ravindran, V. 2013. Poultry feed availability and nutrition in developing countries. *Poult. Development Rev.* 2: 60-63.

Ravindran, V. and Abdollahi, M. R. 2017. Achieving sustainable production of poultry meat Volume 2, In: Advances and future directions in poultry feeding: an overview. 1st ed. BurleighDodds Science Publishing. *New-zealand. pp.*113-130.

Reddy, D. V 2015. Applied Nutrition Livestock, Poultry, Rabbits and Laboratory Animals. 3rd ed. Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi. pp: 189-225.

Ren, H., Vahjen, W., Dadi, T., Saliu, E. M., Boroojeni, F. G. and Zentek, J. 2019. Synergistic effects of probiotics and phytobiotics on the intestinal microbiota in young broiler chicken. *Microorganisms*. 7: 684.

Restaino, E. A., Fernández, E. G., La Manna, A. and Cozzolino, D. 2008. Prediction of the nutritive value of pasture silage by near infrared spectroscopy (NIRS). *Chilean J. Agri. Res.* 69: 560-566.

Sakomura, N. K., Silva, E. P., Dorigam, J. C., Gous, R. M. and St-Pierre, N. 2015. Modeling amino acid requirements of poultry. *J. Appl. Poult. Res.* 24: 267-282.

Saleh, D. M. and Iriyanti, N. 2010. The effect of adding sodium-potassium and calcium-magnesium to the diet of native chicken hen on sex ratio of native chicks. *Ani. Prod.* 12: 12-15

Saminathan, M., Sieo, C. C., Kalavathy, R., Abdullah, N. and Ho, Y. W. 2011. Effect of prebiotic oligosaccharides on growth of Lactobacillus strains used as a probiotic for chickens. *African J. Micro. Res.* 5: 57-64.

Shang, Y., Kumar, S., Oakley, B. and Kim, W. K. 2018. Chicken gut microbiota: importance and detection technology. *Frontiers Vet. Sci.* 5: 254.

Sigolo, S., Zohrabi, Z., Gallo, A., Seidavi, A. and Prandini, A. 2017. Effect of a low crude protein diet supplemented with different levels of threonine on growth performance, carcass traits, blood parameters, and immune responses of growing broilers. *Poult Sci.* 96: 2751–2760

Singh, J. and Gaikwad, D. S. 2020. Phytogenic Feed Additives in Animal Nutrition. In:Natural Bioactive Products in Sustainable Agriculture. Springer, Singapore. pp. 273-289.

Singh, P., Singh, V.K., Tiwari, D., Gautam, S., Singh, V.B. and Vipin. 2020. Effect of Phytobiotic and Exogenous Enzyme Supplementation on Economic Efficiency and Cost of Production of Broiler Chickens. *Int. J. Curr. Micro. Appl. Sci.* 9: 1852-1860.

Soto, C., Avila, E., Arce, J., Rosas, F. and McIntyre, D. 2013. Evaluation of different strategies for broiler feed formulation using near infrared reflectance spectroscopy as a source of information for determination of amino acids and metabolizable energy. *J. Appl. Poult. Res.* 22: 730-737.

Svihus, B. 2011. The gizzard: function, influence of diet structure and effects on nutrient availability. *World's Poult. Sci. J.* 67: 207-224.

Swain, P. S., Prusty, S., Rao, S. B. N., Rajendran, D. and Patra, A. K. 2021. Advances in Poultry Nutrition Research In: Essential Nanominerals and Other Nanomaterials in Poultry Nutrition and Production. IntechOpen.

Upadhaya, S. D., Ahn, J. M., Cho, J. H., Kim, J. Y., Kang, D. K., Kim, S. W., Kim, B.H. and Kim, I. H. 2021. Bacteriophage cocktail supplementation improves growth performance, gut microbiome and production traits in broiler chickens. *J. Anim. Sci. Biotech.* 12: 1-12.

Vahidi, A. R. and Sheikhha, M. H. 2007. Comparing the effects of sodium and potassium diet with calcium and magnesium diet on sex ratio of rats' offspring. *Pak. J. Nut.* 6: 44-48.

Vieira, S. L., Stefanello, C. and Cemin, H. S. 2016. Lowering the dietary protein levels by the use of synthetic amino acids and the use of a mono component protease. *Anim. Feed Sci.* Tech. 221: 262-266.

Waldroup, P. W., Jiang, Q. and Fritts, C. A. 2005. Effects of supplementing broiler diets low in crude protein with essential and nonessential amino acids. *Int. J. Poult. Sci.* 4: 425-431.

Wang, M. J., Chen Huang, J. T., Huang, J. W. and Chen, S. E. 2017. Evaluation of the toxicity of nano-calcium carbonates and their effects on antiheat stress in laying hens. *J. Chinese Society Ani. Sci.* 46: 223-234.

Willemsen, H., Debonne, M., Swennen, Q., Everaert, N., Careghi, C., Han, H., and Decuypere, E. 2010. Delay in feed access and spread of hatch: importance of early nutrition. *World's Poult. Sci. J.* 66: 177-188.

Windisch, W., Schedle, K., Plitzner, C. and Kroismayr, A. 2008. Use of phytogenic products as feed additives for swine and poultry. *J. Anim. Sci.* 86: 140-148.

Yakubu, H. G., Kovacs, Z., Toth, T. and Bazar, G. 2020. The recent advances of near-infrared spectroscopy in dairy production—a review. *Critical Rev. Food Sci. Nut.* 1-22.

Zhao, C. Y., Tan, S. X., Xiao, X. Y., Qiu, X. S., Pan, J. Q. and Tang, Z. X. 2014. Effects of dietary zinc oxide nanoparticles on growth performance and antioxidative status in broilers. *Bio. Trace Element Res.* 160: 361-367.

Zhu, Y. F., Li, S. Z., Sun, Q. Z. and. Yang, X. J. 2019. Effect of in ovo feeding of vitamin C on antioxidation and immune function of broiler chickens. *Animal,* 13: 1927-1933.