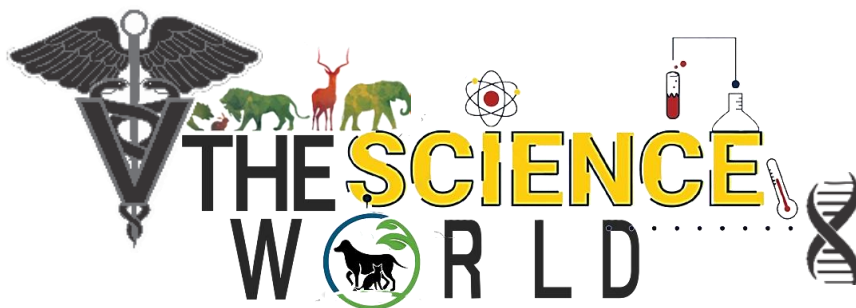




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Nutritional Strategies for Strengthening Immunity in Farm Animals

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Abstract

Nutrition plays a central role in maintaining immune competence in farm animals and poultry, as immune responses require adequate supplies of energy, protein, amino acids, vitamins and minerals. Marginal nutritional deficiencies may impair disease resistance before visible deficiency signs or production losses become apparent. This article reviews the nutritional basis of immunity and discusses the roles of energy, protein and amino acids, trace minerals and vitamins in supporting innate and adaptive immune responses. Particular attention is given to zinc, copper, selenium, chromium, iron, vitamins A, D, E and C, and feed additives that influence gut-associated immunity. Evidence from livestock and poultry studies indicates that nutritional responses depend on species, physiological stage, basal diet, nutrient source and supplementation level. Balanced, species-appropriate feeding with evidence-based supplementation is therefore essential for supporting immune function and animal health.

Keywords: Animal nutrition; Immune competence; Trace minerals; Vitamins; Feed additives

Introduction

Nutrition and immunity are closely interconnected in livestock and poultry. A diet may support visible growth and production while still being inadequate for optimum immune function. Subclinical shortages of protein, energy, vitamins or trace minerals can weaken disease resistance before obvious deficiency signs become apparent. As nutritional status declines, immune competence may be affected earlier than growth, fertility or overt clinical health, making hidden deficiencies particularly important under field conditions (Wikse, 1992). Because conventional feeding standards are commonly designed around maintenance, growth and reproductive performance, the nutrient concentration that supports the strongest immune response is not necessarily identical to the level required merely to prevent deficiency (Klasing, 2001).



The Immune System and Its Nutritional Demands

The immune system operates through two complementary arms. Innate immunity provides rapid, non-specific protection through physical barriers, phagocytic cells and soluble defense mechanisms, whereas adaptive immunity develops highly specific responses through B- and T-lymphocytes. During phagocytosis, neutrophils and macrophages undergo a respiratory burst and generate reactive oxygen metabolites that help destroy engulfed microorganisms (Fantone et al., 1982). These protective reactions are metabolically demanding and therefore depend on an adequate supply of energy, amino acids, vitamins and minerals. Immune activation also changes how nutrients are distributed in the body. Cytokine-mediated responses can redirect substrates from skeletal muscle and other tissues toward leukocyte proliferation, antibody synthesis and acute-phase protein production. At the same time, the host may restrict the availability of certain nutrients to invading organisms; sequestration of minerals such as iron is one example of nutritional immunity (NRC, 2001). Diet can additionally influence immune regulation through hormones and cellular signaling. Severe protein-energy malnutrition and zinc deficiency, for instance, may alter glucocorticoid activity and thereby impair T-cell function (Prasad, 1991).

Energy and Immune Competence

Energy deficiency is a common nutritional constraint in farm animals, particularly when feed quality or availability is poor. Protein-energy malnutrition can depress both cellular and humoral defenses. Earlier work showed reduced complement activity in protein-energy-malnourished cattle (Woodward et al., 1980). Negative energy balance is also associated with changes in metabolic and immune function during physiologically demanding periods, including early lactation (Wathes et al., 2009).

Experimental studies in growing lambs demonstrate that immune function may be preserved at the expense of growth when energy is limited. Energy restriction reduced performance and compromised immune responses in lambs (Nagalakshmi et al., 2006b; Singh et al., 2013). Singh et al. (2013) observed poorer nutrient utilization, growth and cell-mediated immunity when dietary energy density was reduced. These findings emphasize that feeding programs should provide enough metabolizable energy not only for production but also for the metabolic cost of mounting an immune response.

Protein and Amino Acids

Protein deficiency has long been associated with impaired resistance to infection because immune tissues require amino acids for cell proliferation, cytokine production, antibodies and other defense molecules (Reddy and Frey, 1993). Several amino acids, including



glutamine, arginine, methionine, cysteine, threonine, glycine and tryptophan, participate in pathways that support immune-cell function and intestinal integrity (Li et al., 2007). In growing lambs, Nagalakshmi et al. (2006a) reported that the protein concentration adequate for a target growth rate was lower than the level associated with better immunocompetence. In older lambs, moderate protein restriction did not necessarily depress growth immediately, but humoral and cell-mediated responses were reduced (Nagalakshmi et al., 2007). A marked restriction of dietary protein also depressed immune responses in sheep, followed by recovery after realimentation (Sahoo et al., 2009). Similarly, reducing protein supply in crossbred calves lowered antibody response even when later growth was not markedly affected (Sahoo et al., 2002). Low-crude-protein diets supplemented with essential amino acids can be useful in pigs, but the reduction in total protein must be carefully controlled. Proper amino-acid balance can support intestinal development and reduce post-weaning problems, whereas excessive protein reduction can compromise performance or health (Yue and Qiao, 2008; Powell et al., 2011; Gloaguen et al., 2014).

Trace Minerals and Immunity

Zinc

Zinc is essential for epithelial integrity, antioxidant defense, lymphocyte function, phagocytosis and cytokine production. In livestock, supplemental zinc has frequently been associated with improved antibody production and cell-mediated immunity. Zinc supplementation enhanced antioxidant enzyme activity and immune responses in calves and buffalo heifers (Parashuramulu et al., 2013; Satyanarayana et al., 2017). Improved antibody titers were also reported in zinc-supplemented lambs and crossbred calves (Nagalakshmi et al., 2009; Mandal et al., 2007). Source and dose influence the response. Organic zinc forms such as zinc methionine, zinc lysine, zinc proteinate and zinc propionate have been evaluated alongside inorganic sources. Greater delayed-type hypersensitivity or other immune responses were reported in cattle receiving supplemental zinc (Engle et al., 1997; Kegley et al., 2001). In weaned pigs, zinc supplementation altered innate and adaptive immune indices, including phagocytic activity and T-cell populations (Kloubert et al., 2018). Thus, adequate zinc is important, although high-dose supplementation should be guided by species requirements and safety considerations rather than assuming that more is always better.

Copper

Copper contributes to immune defense through copper-dependent enzymes and antioxidant systems, including superoxide dismutase. It also participates in connective-tissue



integrity and immunoglobulin-related processes (Cousins and Hempe, 1990; Roth and Koshland, 1981). Studies in cattle and sheep have shown that copper supplementation can modify antibody titers, ceruloplasmin, superoxide dismutase activity and cell-mediated responses, although results vary with basal copper status, source and dose (Dorton et al., 2003; Senthil Kumar et al., 2009). Other experiments have reported little or even unfavorable immune change when basal dietary conditions or mineral interactions differed, illustrating that copper supplementation should be based on actual dietary need (Ward and Spears, 1993; Ward et al., 1997).

Selenium

Selenium is incorporated into several selenoproteins that protect cells from oxidative injury. Glutathione peroxidase systems are particularly important in limiting lipid and membrane damage, and selenium works closely with vitamin E in antioxidant defense (Boitani and Puglisi, 2008). Adequate selenium has been linked with improved neutrophil activity, antibody production and disease resistance in ruminants (Spears, 2000; Sordillo, 2005). Supplementation with selenium and vitamin E increased antibody production in vaccinated sheep in one study (Giadinis et al., 2000). In broilers, dietary selenium source and level influenced glutathione peroxidase activity, antioxidant capacity and immune indices; organic selenium and nano-selenium have also been investigated (Cai et al., 2012; Bakhshalinejad et al., 2018). In dairy cows, selenium yeast improved selenium status and several antioxidant measures compared with inorganic sodium selenite (Gong et al., 2014).

Chromium

Chromium participates in carbohydrate, lipid and protein metabolism and has been studied as a nutritional aid during stress. Transport, infection and heat stress may alter chromium metabolism, and some studies associate chromium supplementation with lower stress responses and improved immune measures (Underwood and Suttle, 2001; Bahrami et al., 2012). In transport-stressed lambs, increasing dietary chromium was associated with changes in humoral and cell-mediated immune responses (Al-Mufarrej et al., 2008). Chromium supplementation has also enhanced antibody response to tetanus toxoid in cattle (Faldyna et al., 2003), although other work found no clear improvement in selected immune responses of calves (Arthington et al., 1997).

Iron

Iron is required for hemoglobin, oxygen transport and numerous enzymes, but its relationship with immunity is complex because both the host and pathogens require it. During



infection, the body can lower circulating iron availability as part of a defense strategy. Transport proteins such as transferrin and lactoferrin can restrict microbial access to iron. Conversely, true iron deficiency, especially in young animals receiving milk-based diets, may impair cell-mediated immunity and leukocyte bactericidal activity. Therefore, iron nutrition should aim for adequacy rather than indiscriminate supplementation.

Vitamins as Immune Modulators

Vitamins support hematopoiesis, lymphocyte development, neutrophil and natural-killer-cell activity, antibody synthesis and antioxidant protection. Antioxidant nutrients such as vitamins E and C, carotenoids, zinc and selenium can help control reactive oxygen species generated during immune activation (Chew and Park, 2004).

Vitamin A

Vitamin A and its metabolites influence lymphoid tissues, cytokine expression, antibody production and the function of several immune-cell populations (Semba, 1999). In dairy cows, vitamin A supplementation above a basal recommendation altered antioxidant and immune measures (Jin et al., 2014). In broilers, supplemental vitamin A has also been associated with improved immunological response to Newcastle disease vaccination (Faluyi and Agbede, 2017).

Vitamin D

Vitamin D has immunomodulatory actions in both innate and adaptive immunity, including effects on antimicrobial defense mechanisms (Vanherwegen et al., 2017). However, supplementation does not consistently improve every immune endpoint. In broilers, different vitamin D sources and levels produced limited effects on selected macrophage and hypersensitivity measures (Fritts et al., 2014), and vitamin D or its metabolites did not markedly alter cytokine production or immunoglobulin-G concentration in healthy dairy cows in another study (Yue et al., 2018).

Vitamin E and Vitamin C

Vitamin E is a major lipid-soluble antioxidant that protects cell membranes and can influence prostaglandin and leukotriene production. It also supports macrophage phagocytosis (Konjufca et al., 2004). In dairy cattle, vitamin E intakes above minimum requirements have been proposed for supporting immune function during the periparturient period (Weiss, 2002). In heat-stressed broilers, dietary vitamin E at 100 or 200 mg/kg improved primary and secondary antibody responses and macrophage phagocytic activity (Niu et al., 2009). Vitamin E supplementation has also reduced intestinal oxidative injury associated with Newcastle



disease virus challenge (Rehman et al., 2018). Vitamin E and vitamin C may act complementarily: vitamin E primarily protects lipid membranes, while vitamin C contributes to water-soluble antioxidant defense and leukocyte function. Combined supplementation improved Newcastle disease antibody titers in broilers in the study of Bhatti et al. (2016). Vitamin E combined with selenium likewise enhanced antibody responses in poultry compared with either nutrient alone in the work of Kanchana and Jeyanthi (2010).

Feed Additives and Gut-Associated Immunity

The gastrointestinal tract is a major immunological interface, so feed additives that modify intestinal microbes, epithelial integrity or fermentation can indirectly influence systemic health. Probiotics, prebiotics, organic acids, enzymes, essential oils and selected herbal products have all been investigated for immunomodulatory effects. An *Enterococcus faecium* probiotic increased specific IgA responses after *Salmonella Enteritidis* vaccination in laying hens (Beirao et al., 2018). *Saccharomyces boulardii* supplementation was also associated with improved antibody responses in growing lambs (Nagalakshmi et al., 2010). In weaned pigs, combinations of organic acids and medium-chain fatty acids influenced immunological and digestive responses (Kuang et al., 2015; Wang et al., 2016). Essential-oil supplementation has been associated with changes in lymphocyte proliferation, immunoglobulins and intestinal health (Li et al., 2012; Halas et al., 2011). Plant-derived additives have also been studied. Oregano essential oil fed to sows helped counter oxidative stress during late gestation and early lactation and influenced subsequent piglet performance (Tan et al., 2015). Studies in lambs reported improved humoral and cell-mediated immune responses following supplementation with *Emblica officinalis*, *Withania somnifera* or *Tinospora cordifolia* (Nagalakshmi et al., 2015; Nagalakshmi et al., 2007; Nagalakshmi et al., 2008). These products should nevertheless be used at evidence-based doses and as complements to, not replacements for, balanced nutrition and appropriate veterinary health programs.

Practical Implications

For farm animals, the objective should be nutritional adequacy across the entire production cycle rather than simply correcting visible deficiency. Energy and protein supply must match physiological demand, while trace minerals and vitamins should be provided in balanced amounts that account for basal feed composition, bioavailability and interactions among nutrients. Periods of heat stress, transport, weaning, early lactation, rapid growth and disease challenge may increase the importance of antioxidant and immune-supporting



nutrients. At the same time, excessive supplementation can be wasteful or harmful, particularly for trace minerals.

Conclusion

Immune competence depends on a coordinated supply of energy, protein, amino acids, vitamins and minerals. Marginal deficiencies may impair resistance to disease before production losses or classical deficiency signs become obvious. Evidence from livestock and poultry studies shows that zinc, copper, selenium, chromium, iron and vitamins A, D, E and C can influence different components of innate and adaptive immunity. Feed additives that support intestinal health may provide additional benefits. Accordingly, ration formulation for health should consider not only the minimum nutrient concentrations needed to prevent deficiency but also the nutritional demands created by stress, vaccination, infection and high production. The most effective strategy is a balanced, species-appropriate diet supported by evidence-based supplementation.

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