The Interaction of Nutrition and Health in Beef Cows

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The original intent of this presentation and paper was to address the interaction of cow nutrition and subsequent health status and immunity. The problem is that there is just little direct research that address beef how nutrition and health. There is a body of work that addresses dairy cow nutrition and health status, but in my opinion that is an entirely different model. Therefore, this presentation and paper will emphasis some general nutrition principles that relate to health and immunity. In cattle all physiological processes in the body, the immune system included, are influenced by the nutritional status of the animal (Carroll and Forsberg, 2007). Therefore the past and present nutritional status is an important modulator of the immune function in cattle that can influence the performance and reproduction of beef cattle.

Immunity

In cattle immunity is generally classified (Figure 1) as either innate (natural) or acquired (specific). Innate immunity includes physical barriers (skin, mucus, saliva), chemical barriers (acid stomach), and blood borne system including the complement cascade and phagocytes. These systems are naturally present, the first line of defense, and not influenced by any prior exposure to disease (Chandra, 1997). The acquired system includes T-cell immunity (cell-medicated immunity) which provides defense against intracellular pathogens and tumors and B-cell immunity (humoral immunity) to fight extracellular microbial infections. The acquired system is adaptive and are specific to prior to exposure to microorganisms and antigens, thus vaccination works in this system.

Diet Effects on Immunity

Intake of the diet is the first means that nutrition affects health and immunity. Low intake and thus low nutrient intake can negatively affect the mechanism by which the diet affects immunity. The diet supplies the substrates that are required for the development, maintenance, and function of the immune system (Klasing, 2002). The general nutrients that are familiar are important components to the mechanism that supports the immune system include energy, protein-amino acids, minerals, vitamins, and fats. The various nutrients that are important to the proper function of the immune system and the mechanism that they support are outlined in Table 1. The immune system requires substrates to support the anabolic and proliferative processes associated with immune cell function, antibody production, and liver protein production.

Table 1. Nutritional modulators of immune mechanisms

Nutrient	Mechanism
All nutrients	Supply substrates for immune system function
Energy, protein, feeding pattern	Regulate immunity through altering balance of hormones
Fatty acids, vitamins A, D, E	Direct regulatory on cells of immune system
Trace minerals	Important components of enzymatic reactions
Iron, biotin, manganese	Deprave pathogens of nutrients
Antioxidants	Reduce damage caused by immune response
Non-starch polysaccharides, lectin, sugars	Physical and chemical actions of feeds in the intestine

Adapted from Klasing (2002)

The immune system is similar to other high priority tissues (brain, nervous system) in that it has many similar means to extract nutrients with high efficiency when stimulated. As such concentrations of glucose and amino acids in the blood are important, but nutrients can be withdrawn from other supporting tissues when needed. These supporting tissues include muscle and other storage tissues. This stimulus to withdraw nutrients from other tissues is initiated by the inflammatory response. The relatively small size of the immune system, high priority transport and ability to withdraw nutrients from other systems indicates that the immune system can function across a wide range of dietary nutrient concentrations (Klasing, 2002) although potentially not its full capacity. Immune function is just one metabolic function within the body and likely has different dietary requirements for some substrates compared to growth or reproduction. As a result, the dietary requirement for some nutrients may be greater when the immune system is stimulated compared to a minimally active immune system.

Nutritional immunity is the process where the body controls the concentration of nutrients available for pathogens to decrease their rate of replication. Primarily immune cells retain certain trace minerals when they destroy pathogens, thus denying the trace mineral to other pathogens for use. Likewise nutrients, particularly fats, can directly affect the immune system and component pieces altering the type, duration, and severity of response of the immune system (Klasing, 2002). This regulatory effect over the immune system is a balance. In some cases the presence of a stimulatory nutrient can up-regulate the function of one aspect of the immune system while suppressing other aspects of the immune system. Thus, the immune challenge dictates if the stimulatory nutrient is beneficial or not. Fish oil is a classic example of this effect. Fish oil suppresses the inflammatory response while stimulating the macrophage-T cell response. Other nutrients including fat soluble vitamins, amino acids, and some minerals also are indicated to have direct effects on the immune system (Galyean et al., 1999; Klasing, 2002; Carroll and Forsberg, 2007). The effect of diet amount and nutrient composition has been documented to affect circulating hormones that modulate the immune system. Hormones including insulin, glucagon, glucocorticoids, and insulin-like growth factor 1 are responsive to the diet and have subsequent actions on the immune system. Chronic feed restrictions depress several functions of the acquired immune system, whereas very moderate restriction can increase immune function. Additionally, protein:energy and feeding pattern can affect hormone concentrations that influence immune systems function. The diet is also important in minimizing the extent that the immune system actions affect healthy tissues. The supply of antioxidants to protect healthy cells and tissues is important to localize the damage of infection. The immune system utilizes substances at the site of infection to kill pathogens that are detrimental to healthy tissues.

Nutritional Inputs

Energy

The maintenance of the immune system is a daily metabolic cost to the animal that is incorporated into the maintenance energy cost of the animal. Likewise, activation of the immune system and the fever response incurs an energy cost to the animal (Carroll and Forseberg, 2007). Estimates of 10 to 13% increase in the metabolism are associated with an immune response for every degree increase in body temperature. In addition to the energy expenditure associated with the increase in body temperature, there is an energy cost associated with production of the antibodies and liver proteins. The re-directing of energy resources to support an immune response means that energy is not available for productive purposes associated with body weight gain, reproduction, or lactation.

Therefore, in situations of sickness when diet intake is decreased, nutrient supply is limited, and energy expenditure is increased, cow energy stores found in fat tissue and lean muscle tissue become important. The reserve of energy available from fat and muscle underscore the necessity of maintaining cows in adequate body condition particularly in times of physiological stress. When cows are in a decreased body condition in which energy and protein reserves are limited, the animals immunity defense mechanism may be impaired (Chandra, 1997). Little research exists, but it is certainly feasible to consider that limited energy supplies can negatively affect the integrity of the body's physical barriers, mucus, and other innate immune functions (Chandra, 1997).

Protein

Many of the components of the innate and acquired immune system require protein and amino acids for synthesis and function. As such, during a disease or infection proteins and amino acids are diverted from normal functions to support the synthesis of immunoglobulins, T-cell and B-cell mediated immunity, and catabolized for energy production (Scrimshaw and SanGiovanni, 1997). Similar to the energy discussion, protein stores in lean muscle are an important substrate resource to support the immune system. Inadequate protein nutrition impairs cell-mediated immunity, and immunoglobulin production. Additionally, poor protein nutrition leads to compromised production of immunoglobulin production that supports colostrum quality which is important for subsequent calf performance.

Micronutrients

The micronutrients in the diet (trace minerals and vitamins) can have profound effects on the immunity and health of cattle. Figure 1 integrates the immune system and important micronutrients. Four general concepts are related to micronutrient and immunity (Chandra, 1997). (1) Changes in the immune response occurs early in the decrease in micronutrient intake; (2) The decreased immune response is dependent upon the nutrient, interactions with other nutrients, the severity of the deficiency, presence of infection, age of the animal; (3) immune system abnormality predicts the outcome and risk of infection; (4) excessive intake is also associated with impaired immune function. In fact, Cole (1993) suggested that for young stressed cattle trace mineral requirements are no greater than healthy unstressed cattle. Likewise, Olson et al. (1999) reported decreased reproductive performance in two-year old cows feed two-times NRC recommendation of copper, cobalt, manganese, and zinc compared to normal mineral recommendations.

Minerals

Trace minerals affect immunity and health primarily through their function in important enzyme activity associated with energy metabolism, cellular protein-dependent synthesis, and DNA replication. There is inconsistent data reported in the literature regarding the beneficial effects of mineral supplementation beyond what is considered needed for normal physiology (Carroll and Forsberg, 2007).

Zinc. Zinc is reported to be a cofactor for more than 300 different enzymes that modulate many physiological processes (Carroll and Foresberg, 2007), indicating the vast importance this trace mineral has in metabolism in the animal. In multiple reports zinc is identified to be important for several immunological functions including both innate and acquired immune systems, tissue integrity, protein synthesis and inflammation (Carroll and Foresberg, 2007; Erickson et al., 2000). The immune system is a rapid response system that relies on many enzymes to function, which zinc is an important component. Potential limitations of zinc in the body could lead to limitation of enzyme activity and the response potential of the immune system. In ruminants the effect of zinc status may have less importance in immune function for healthy cattle, but definitive positive impact in stressed cattle. Research with stressed calves has demonstrated that zinc supplementation can decrease bovine respiratory disease associated deaths by 52% (Carroll and Foresberg, 2007), but no effect on performance or health. The impact of zinc may be dictated by the specific immune stimulus, animal's mineral status, concentration and bioavailability of the supplemental zinc, and the animal itself.

Copper. Copper is considered an essential nutrient and important in many physiological and metabolic processes. However, supplemental copper's direct effect on immunity is not fully compelling (Duff and Galyean, 2007). Mechanistically, copper is key for the enzyme superoxide dismutase which is vital for phagocytes when they engulf pathogens (Suttle and Jones, 1989). Copper's immunological role has been reported to be important for antibody production, inflammation and neutrophil phagocytosis (Erickson et al, 2000; Schrimshaw and Sangiovanni, 1997, Carrol and Forsberg, 2007). Copper supplementation has not been reported to increase performance or morbidity of cattle in summary literature (Galyean et al., 1999, Carroll and Forsbery, 2007; Duff and Galyean 2007).

Selenium. Definitive deficiencies of selenium exist regionally, particularly in Florida. Selenium is an important component of the antioxidant system through the glutathione peroxidase enzyme. Deficiency of selenium can contribute to oxidative stress in animals. Oxidative stress is detrimental to cellular metabolism including damaging DNA and affecting cell membranes and integrity (Carroll and Forsberg, 2007). Supplemental selenium has been documented to increase or enhance neutrophils and macrohphage phagocytosis (Duff and Galyean, 2007; Erickson et al., 2000). Other research has demonstrated that supplemental selenium has enhanced antibody response and production of specific antibodies against *Escherichia coli* (Carroll and Forsberg, 2007). Transfer of positive immune function from dam to calf has been documented by Reffett Stabel et al (1989). However, supplemental selenium has not been demonstrated to increase cattle performance measured by body weight gain.

Chromium. Generally considered an essential mineral for carbohydrate metabolism through maintenance of normal blood glucose and a cofactor of insulin, chromium has definitive metabolic function (Carroll and Forsberg, 2007). In beef cattle chromium has been reported to positively affect growth performance, feed efficiency, morbidity rate, and immune response. Generally, the immune system stimulation conferred by chromium has been is cattle subjected to a stressor. Feeder calves have demonstrated increased serum immunoglobulin M and G and enhanced antibody response when supplemented with high-chromium yeast (Moonise-Shageer and Mowat, 1993). Chromium may function to alleviate the stress-induced suppression of the immune system, thus the beneficial effect in times of stress, but limited to no affect in non-stress situations.

Vitamins

Vitamin deficiencies have long been known to induce immune system disorders. Nearly every aspect of the immune system has a dependency on an adequate supply of one or multiple vitamins. Vitamins have essential roles for blood immune cell production, maintenance and production of white blood cells, natural killer cells, and antibody production (Carroll and Forsberg, 2007). Vitamins are also key components of the antioxidant system by inactivating reactive oxygen species. Reactive oxygen species can destroy cellular membranes, cellular proteins, and DNA. Protection against reactive oxygen species is important for all body tissues and especially immune cells. During high stress periods and greater stimulation of the immune system the body's ability to eliminate reactive oxygen species can be overwhelmed, thus the antioxidant system of vitamins and minerals is important.

Vitamin A. Identified as retinol or beta-carotene, vitamin A is an important nutrient regarding the immune system. Vitamin A does not occur naturally, but rather as various forms of carotene in plant materials. In the body the carotenes are converted to retinol; cattle are less efficient at this conversion compared to monogastic animals (NRC, 1996), but because cattle generally consume greater amounts of forage so vitamin A levels are maintained. Vitamin A is a fat soluble vitamin and is stored in the liver, thereby requiring months for deficiencies to manifest. However, vitamin A levels are dynamic and many physiological and nutritional factors affect cattle's vitamin A status. Vitamin A is understood to be essential for maintenance of skin and mucus membranes in the respiratory and gastrointestinal tract (Carroll and Forsberg, 2007; Scrimshaw and Sangiovanni, 1997). Inadequate integrity of membranes allows for greater opportunity for bacterial and viral invasion. Deficiency of vitamin A also decreases the functional ability of natural killer cells and decreased response in white blood cells. Supplemental vitamin A to correct a deficiency is more effectively corrected through injectable sources rather than feed source because vitamin A is extensively destroyed in the rumen and abomasum. Supplementation of vitamin A has only been shown to be beneficial in deficient or marginally deficient animals, whereas no response is observed in animals that are considered adequate.

Vitamin E. Identified as tocopherol, vitamin E is another fat-soluble vitamin that is very important to the functional ability of the immune system. Vitamin E functions as part of the antioxidant mechanism, often in concert with selenium, to protect against free radical formation and damage. Vitamin E also functions to maintain the immune system, DNA repair, and is an important constituent of all cellular membranes (Carroll and Forsberg, 2007). Because of the aforementioned functions, vitamin E is found in great concentration in immune cells. Vitamin E supplementation has been demonstrated to augment the acquired immune system. Vitamin E supplementation has been reported to increase the inflammatory process, which as a result increased humoral/antibody concentration (Duff and Galyean, 2007). Studies that have examined the effect of supplemental vitamin E in immunity/stress challenge situations generally concluded that vitamin E can reduce the severity and duration of the challenge, but does not directly enhance the growth performance of the animal (Carroll and Forsberg, 2007; Duff and Galyean, 2007). Increases in growth performance are a result of a shortened stress challenge and subsequent resumption of feed intake and growth.

Vitamin B. In general practice, deficiency of vitamin B12 is not a production concern for cattle receiving a nutritionally balanced diet (Duff and Gaylean, 2007). Additionally, deficiency of vitamin B12 is difficult to distinguish from a cobalt deficiency because vitamin B12 is 4.5% cobalt (NRC, 1996). Vitamin B12 is formed in the rumen of healthy cattle through the action of the microorganisms, but is cobalt dependent. As a functional vitamin, B12 is essential to cattle for the metabolism of proprionate (an energy source produced through ruminal fermentation), cellular replication through nucleic acids, and protein metabolism. As a result, deficiency of vitamin B12 negatively affects antibody formation and white blood cell replication (Scrimshaw and Sangiovanni, 1997).

Vitamin D and C. As a practical matter supplementation of vitamins D or C to effect cattle health and immunity is equivocal. Vitamin D is important for bone formation, calcium and phosphorus regulation, and some immune function. Little storage of vitamin D occurs in cattle, but because of exposure of cattle to sunlight and consumption of sun-cured forages deficiencies are rare. Vitamin C is a component of the antioxidant system. Vitamin C acts to protect the body against free radicals and interacts with vitamin E. However, most vitamin C is degraded in the rumen, therefore cattle must rely on tissue formation of vitamin C rather than supplemental sources.

Conclusion

Overall nutritional status of cattle has important implications for productive outputs including growth, lactation, and reproduction. Nutritional status determined as simply as adequate feed intake or as specifically as vitamin status profoundly affects multiple immunological functions. Maintenance of physical barriers, antigen production, and cellular based immunity is controlled and influenced by nutrition. Adequate energy, protein, trace mineral and vitamin status are nutritional variables that are quantitatively affected by cattle producers through provision of an adequate nutritional environment. Attention to pasture, stored forage, energy-protein supplementation, and vitamin- mineral supplementation programs are a means to affect cattle immune function.

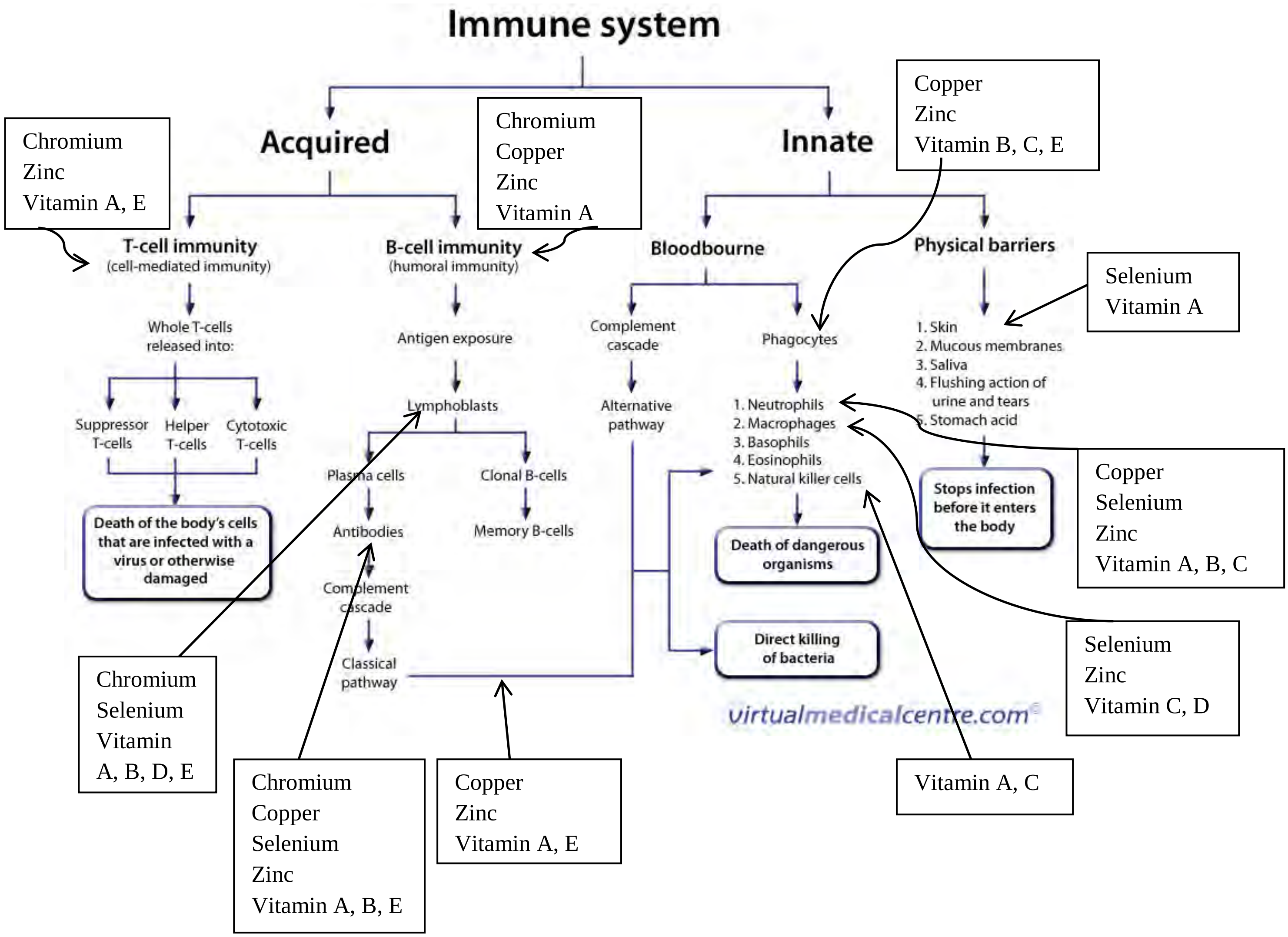

Figure 1. Interaction of the immune system and micronutrients

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