New prospects exist for trace mineral nutrition

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TRACE mineral nutrition in poultry is a complicated subject due to the large number of minerals and dietary inclusion levels as well as substantial interactions between the minerals.

Macrominerals are required in quantities great enough to be expressed as a percentage of the diet and include calcium, phosphorus, sodium, potassium, magnesium and chloride. Microminerals, or trace elements, are those required in smaller amounts and include copper, zinc, manganese, iodine, iron and selenium.

Copper, zinc and manganese are metal cations with numerous essential functions in the body. The predominant role of copper, zinc and manganese is as structural or catalytic components of enzymes. Copper is essential for energy production (cytochrome c oxidase), connective tissue formation (lysyl oxidase), antioxidant defense (copper/zinc superoxide dismutase), pigment formation (tyrosinase), iron transport and metabolism (ceruloplasmin) and hormone and neurotransmitter synthesis (dopamine beta-monooxygenase) (Cater and Mercer, 2005).

Zinc has structural and catalytic functions in proteins, including enzymes involved in bone synthesis, resorption and remodeling (Ford, 2004; Vallee et al., 1991), the protein metallothionein that plays a role in intracellular metal metabolism and storage (Cousins et al., 2006; Davis and Cousins, 2000) and as a modulator of immune function. Zinc modulates the inflammatory response (Peterson et al., 2008), development of immune organs and functionality of immune cells (Rink and Haase, 2007).

Manganese provides antioxidant protection (manganese-super oxide dismutase; de Rosa et al., 1980) and is a cofactor for many other enzymes (Au et al., 2008). Like zinc and copper, manganese functions in bone metabolism (Beattie and Avenall, 1992).

As a result of the vast number of functions with which these minerals are involved, signs of deficiency can vary.

In general, copper deficiency in poultry is normally associated with bone abnormalities, impaired immune responses and anemia (Savage et al., 1966). Zinc deficiency generally results in reductions in feed intake, bodyweight gain, hatchability and feather growth (Keinholz et al., 1966), as well as pancreatic insufficiency (McCormick, 1984). Manganese deficiency reduces the activity of manganese-super oxide dismutase (Li et al., 2010), induces perosis or lameness (Luo et al., 2007) and increases abdominal fat deposition (Lu, 2007).

Due to their highly reactive nature, the gross excess of copper, zinc and manganese can cause significant pathologies. Copper toxicity is less of a concern in poultry than in other species such as sheep, although toxicity symptoms like reductions in feed intake and bodyweight gain can be seen when feeding extremely high amounts of copper, i.e., greater than 500 parts per million (Luo, 2005; Miles et al., 1998).

Zinc toxicity (greater than 500 ppm) can irritate the gastrointestinal tract, cause reduced absorption of other nutrients and systemically will disrupt the functions of proteins, enzymes and DNA (National Research Council [NRC], 2005; Lu et al., 1990).

A high level of manganese (greater than 3,000 ppm) reduces feed intake in chicks (Black et al., 1985) and can also lead to progressive neurological deterioration (Finley and Davis, 1999) and impaired hemoglobin formation (Hartman et al., 1955).

Sources

There are numerous sources of copper, zinc and manganese, including animal and plant products, mineral salts (e.g., sulfates, oxides), chelated or complexed minerals (e.g., zinc methionine) and immune cells (Rink and Haase, 2007).

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hydroxy minerals, e.g., tribasic copper chloride (TBCC).

The latter two categories represent relatively new technologies in the production of minerals that offer several advantages over traditional mineral sulfates and oxides. It is notable that the chelated mineral category includes a number of potential substrates for mineral binding, including amino acids, peptides and polysaccharides, and there are differences in quality between chelated or complexed mineral sources. High-quality chelated minerals and hydroxy minerals offer advantages over traditional mineral sulfates and oxides for several reasons, including higher relative bioavailability, lower risk of toxicity, higher stability in feed and greater bioefficacy.

First, hydroxy and high-quality chelated minerals generally have higher relative bioavailability (RBV) compared to traditional mineral sources. Improved RBV means that more of the nutrient is absorbed in a form that can be used by the animal (Littell et al., 1997). While it can be difficult to compare RBV trials due to variation in experimental design (e.g., source used, timeline, depletion of the animal, type of diet used, etc.), the general response to hydroxy and high-quality chelated minerals is a 10-20% improvement in RBV.

This can be explained by the chemical properties of ionic-bound sulfated minerals, which dissociate very readily in the presence of moisture. Once the free mineral has dissociated, it will bind to other components such as phytates or tannins and, thus, not be available to the animal for absorption or use. Oxide-bound minerals, in contrast, have very strong covalent bonds, which prevent dissociation in the gastrointestinal tract and, thus, reduce RBV.

Moderately covalent-bound minerals like hydroxy and chelated minerals will have more stability in feed and the gastrointestinal tract but, due to solubility in the gastrointestinal environment, will be available at appropriate locations for mineral absorption (Guo et al., 2001; Linder, 1991).

For example, when broiler chicks were fed ionically bound copper sulfate compared to covalently bound TBCC, more copper was unavailable (not-extractable) when copper sulfate was fed (Figure 1; Naziripour and Klasing, 2010). This means that more copper from TBCC was available for absorption throughout the gastrointestinal tract as opposed to solely in the upper gastrointestinal tract.

Second, hydroxy and high-quality chelated minerals are generally less toxic than sulfated minerals. Again, this is presumably due their chemical nature and slower release and more uniform exposure to the absorptive area of the small intestine.

In fact, the upper gastrointestinal tract of chicks fed copper sulfate had significantly higher levels of metallothionein expression. As stated earlier, metallothionein functions in mineral metabolism and is thought to act as a “sink” in the gastrointestinal tract to prevent excessive absorption of a mineral (Bauerly et al., 2005). Thus, chicks fed copper sulfate appear to be turning on a mechanism to prevent toxicity, while those fed TBCC did not have the same induction (Figure 2; Naziripour and Klasing, 2010).

Third, and again due to their chemical nature, hydroxy and high-quality chelated minerals are more stable in feed and vitamin/trace mineral mixtures, thus reducing losses of other expensive nutrients in the feed. TBCC has been shown to maintain vitamin E levels in feed and vitamin/trace mineral mixtures at levels 10-30% higher than when copper

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### Figure 2. Metallothionein expression in the upper gastrointestinal tract of broiler chicks fed different types of copper

*Within a tissue type, means are significantly different (P < 0.05).*

### Figure 4. E. coli killing in the lower gastrointestinal tract of broiler chicks fed different types and levels of copper

*a,b,c* Means with different superscripts are significantly different (P < 0.05).
sulfate had more anti-inflammatory properties (Arias and Koutsos, 2005).
Broiler breeders have shown an improvement in egg numbers and egg zinc content in response to being fed chelated zinc (Hudson et al., 2004). The effects of higher egg zinc are not well established, but pouls from turkey breeder hens fed supplemental zinc methionine tended to have higher primary immune organ weights and leukocyte zinc content compared to pouls from hens fed zinc sulfate (Kidd et al., 2000).

The NRC (1995) recommendation for zinc for growing broilers is 40 ppm, but higher levels may modulate immunity; broilers fed 80 ppm zinc had higher antibody responses to sheep red blood cells (Gajula et al., 2011).

Similarly, higher levels of manganese than established to prevent deficiency may modulate physiology. The NRC (1994) recommendation for manganese in broiler diets is 60 ppm, but recent research suggests that a higher level (120-130 ppm) may be needed (Li et al., 2010) based on increased heart manganese-super oxide dismutase messenger RNA levels (Li et al., 2011) and delayed type hypersensitivity responses (Gajula et al., 2011).

Replacing some or all sulfate forms of minerals with hydroxy or high-quality chelated minerals would likely have positive effects. For example, a chelated trace mineral mix consisting of copper, zinc, manganese and selenium improved leg health in turkey toms throughout growout (Ferket et al., 2009).

Of all of these examples indicate that the more optimal bond strength of both hydroxy and high-quality chelated minerals is the key to their improved efficacy. It could account for their being absorbed throughout a longer length of the intestines (and, thus, higher RBV) as well as having more area of the gastrointestinal tract to affect the microflora and immune function of growing animals.

Recent research in mineral absorption and regulation of transport has broadened the understanding of the mechanisms regulating trace mineral metabolism. Recent research in poultry has suggested that increased mineral requirements of broiler chicks may be warranted, which may be due to the method of determination of mineral requirements (e.g., use of purified diets in the past) and/or increased needs of new genetic strains of birds.

New technologies in mineral production and the advent of minerals that have optimal bond strength and stability, such as high-quality organic minerals and TBCC, afford great opportunities to optimize management of birds for performance, well-being and environmental considerations.

References


Ferket, P.R., et al. 2009. Organic trace minerals and 25-hydroxylcholcalcelalifer affect performance characteristics, leg abnormalities and biomechanical properties of leg bones of