INTERACTION OF DIETARY ELECTROLYTES IN THE NUTRITION OF
POULTRY AND SWINE

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SUMMARY

The balance of dietary monovalent electrolytes has been reported to affect many performance-related parameters. When the balance is expressed as Na+K-Cl value in meq per kg of diet, growth rate, eggshell quality, calcification of bone (ref: tibial dyschondroplasia) and the utilization of arginine in the presence of excess lysine in poultry is favored by a balance of 200-300 meq per kg of diet. In swine the optimum balance for growth rate may be similar to that for poultry. Some studies suggest that NaHCO₃ or KHCO₃ supplements may enhance performance on lysine-limited diets but more research is needed to verify these findings. Practical diets for poultry and swine contain Na+K-Cl values of approximately 150-180 meq per kg. Increasing the value to 200 or more may be accomplished by supplementation of practical diets with NaHCO₃ or KHCO₃ and by avoiding excessive levels of chloride.

INTRODUCTION

During the past several years there has been renewed interest in the roles of electrolytes in animal nutrition, particularly the importance of electrolyte balance. The balance of electrolytes has been expressed in many ways, e.g. of Na/Cl or [Na+K]/Cl or Na+K-Cl. In all cases the relative molar concentrations of mono-valent cations and anions is emphasized: the relative concentrations being an important determinant of acid-base balance and having a significant impact on a variety of -production-related traits.

For this review the balance of monovalent electrolytes will be defined as Na+K-Cl, expressed in milliequivalents per kilogram of diet. In any animal in a defined physiological state, variations in Na+K-Cl can be expected to perturb acid-base status. This has a sound conceptual basis as discussed in the excellent reviews by Chan 1974 and Mongin 1981. If it is accepted for example that any diet will be electrically neutral, the positive charge associated with cations must equal the negative charge associated with anions. If Na or K is increased relative to Cl, the value of Na+K-Cl increases. As electrical neutrality must be maintained, and assuming that the dietary content of all other minerals remains constant, an organic anion must balance the increase in Na+K. This ion may be bicarbonate, lactate, citrate, or a variety of other ions. All of these are alkaline—that is they associate with H⁺ ions, and effectively neutralize these H⁺ ions during the metabolism of the organic anions to CO₂ + H₂O. Therefore an increase in the value of Na+K-Cl reflects a more alkaline acid-base status. Conversely, when the

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Na+K-Cl value decreases, H⁺ ions will balance the difference between Na⁺K and Cl⁻, and the perturbation of acid-base balance is in the direction of an acidosis.

In practical terms the Na⁺K-Cl may be altered as follows: by increasing the Na or K content of the diet by providing these minerals as alkaline salts (i.e. carbonates, acetates, lactates, etc), by increasing the chloride level by use of acid chlorides (i.e. lysine HCl, HCl) or by substitution of CaCl₂ for CaCO₃. Neutral salts, such as NaCl, KCl, Na₂SO₄, etc. do not change the value of Na⁺K-Cl and therefore do not affect acid-base balance.

Acid-base balance

Experimental evidence supports the concept that the relative proportions of Na⁺K and Cl affect acid-base balance. Hurwitz et al. 1973 varied the ratio of Na/Cl from less than 0.2 to greater than 3 in diets for broiler chicks. They observed that blood pH varied from approximately 7.1 to 7.4 over this range of electrolytes. Blood bicarbonate concentration was also positively related Na/Cl ratio. Similar data have been reported by Cohen and Hurwitz 1974, Hamilton and Thompson 1980 and Mongin 1981 for laying hens. Respiratory and renal adjustments tend to reduce the effects of electrolytes on the pH of blood. In studies of broiler chicks, (unpublished) the Na⁺K-Cl value was varied by adding 195 meq/kg NaHCO₃ or KHCO₃ to a diet having an initial Na⁺K-Cl balance of 180 meq/kg. Urinary pH significantly increased by 0.66 and 0.47 pH units respectively (p<0.05). When the Na⁺K-Cl value was decreased to -17 by substitution of CaCl₂ for CaCO₃, urine pH was reduced by 1.58 pH units. Clearly the balance of Na, K and Cl influences acid-base status, and it is possible that other consequences of electrolyte balance are related to this phenomenon.

Effects on growth

Variations of Na, K and Cl significantly influence growth rate. However the optimum balance of electrolytes cannot be determined from the current published data. Mongin'and Lacassagne 1966 varied Na and Cl levels for broiler chickens, and, obtained a parabolic response curve with optimum growth rate between 200 and 300 meq/kg of Na⁺K-Cl. Growth diminished at lower and higher values. However these values were produced by use of deficient levels of sodium or chloride. Studies by Melliere and Forbes 1966, Sauveur and Mongin 1978 and our own unpublished results suggest that growth rate may be relatively unaffected with Na⁺K-Cl values ranging from approximately 100 to 500 meq/kg. Growth rate tends to decrease markedly as the value declines below 100, but the point at which this occurs has varied from 100 to 0 or less in different studies. Practical diets based on cereal grains and soybean meal as the major sources of energy and protein usually have Na⁺K-Cl values of 150 to 180, well above the level that is needed for maximum live weight gains when the dietary levels of Na, K and Cl are safely above the minimum requirements.

Austic et al. 1982 have varied the proportion of Na and Cl in diets of young grow-wine. Dietary K was 0.34%. Na varied from 0.19 to 1.11% and chloride from 0.24 to 0.95%. The calculated values of Na⁺K-Cl ranged from -100 to +500 meq/kg. None of the treatments significantly affected growth rate or feed consumption. However the diets having Na⁺K-Cl values of 100 to 300 tended to result in the best performance.

Effects of calcification

Mongin 1970; 1978 was among the first to suggest that electrolyte balance may influence eggshell calcification. He argued that eggshell
calcification results in a metabolic acidosis due to protons generated during the conversion of CO₂ and calcium to CaCO₃. He suggested further-
more that factors that increase acid production or limit the amount of bicarbonate available to buffer the protons produced during eggshell formation will result in reduced calcification of eggshell.

Many experiments have since been conducted to test Mongin's hypothesis. These have not yielded consistent results. Mongin 1980 reviewed several papers that dealt with this subject. The results of six reports suggest that the addition of NaHCO₃ to diets for laying hens may improve eggshell quality. The diets where improvements were observed had Na⁺K⁻Cl values of approximately 140-180 meq/kg of diet without NaHCO₃ supplementation and values of 200-250 after supplementation. Of the six reports only the study of Frank and Burger 1965 indicated no improvement in shell quality due to bicarbonate. However the balance of electrolytes in the unsupplemented diet in this report was approximately 200 meq/kg. As a group these studies seemed to indicate that the addition of NaHCO₃ to practical diets to increase the value of Na⁺K⁻Cl to 200 or more may be of-value in the production of stronger eggshells. Other investigators have not obtained evidence supportive of this conclusion. Ernst et al. 1975; Hamilton and Thompson 1980 and Christmas and Harms 1982 did not observe an improvement in eggshell quality due to NaHCO₃. We also have not observed improved breaking strength or shell thickness when 174 meq/kg of NaHCO₃ or KHC⁰ was added to a basal diet having a Na⁺K⁻Cl value of approximately 130 meq/kg (unpublished data). High levels of chloride, however, decreased eggshell quality in several studies (Mongin 1980; Hamilton and Thompson, 1980; Austic and Keshavarz, unpublished). Miles et al. 1982 noted a significant increase in egg specific gravity when NaHCO₃ was added to diets containing high levels of phosphorus. The reasons for the variability among reports with regard to the beneficial effect of bicarbonate are not known. Clearly, more research is needed in an attempt to identify the factors that may account for this variability. In the meantime it may be desirable to use dietary supplements of NaHCO₃ or KHC⁰ to provide a Na⁺K⁻Cl value of 200 particularly for flocks where problems of eggshell breakage are evident.

Metabolic acidosis of renal origin exacerbates rickets and osteomalacia in humans (Nash et al. 1972; Richards et al. 1972). There is some evidence that acidosis reduces bone mineral in animals. Jones et al. 1966 for- example observed reduced bone ash in rats receiving diets supplemented approximately 6% lysine HCL. Potassium deficiency, which results in an intracellular acidosis, reduced bone ash in chicks (Gillis 1950). These reports suggest that electrolyte balance is a significant factor in bone mineralization. The most direct evidence of the involvement of Na, K and Cl balance in bone mineralization is found in studies of tibial dyschondroplasia in chicks. Leach et al. 1965 originally described this condition which is characterized by the formation of uncalcified cartilage in the growing ends of long bones, particularly in the tibiotarsus. The condition is affected by genetic selection and is reported to be exacerbated by diets containing high levels of acid chlorides and alleviated by diets enriched in bicarbonate (Leach and Nesheim 1972). This was confirmed by the work of Sauveur and Mongin 1978 who varied the Na⁺K⁻Cl value of diets for broilers over a range from nearly -200 to +400. The incidence of tibial dyschondroplasia decreased from greater than 20% to less than 10% as the Na⁺K⁻Cl value increased. The incidence was minimized at values of +250 or more,
The nature of the involvement of electrolyte balance in eggshell formation and tibial dyschondroplasia is not known. These effects may be linked to fundamental changes in calcium metabolism. Severe metabolic acidosis reduces the conversion of vitamin D₃ to the metabolically active form of the vitamin, 1,25-dihydroxycholecalciferol in rats and chicks (Lee et al. 1977; Sauveur et al. 1977). This appears to be due to reduced activity of the mitochondrial enzyme in kidney that catalyzes the hydroxylation of 25-hydroxycholecalciferol. Possibly the metabolic acidosis due to negative or low Na+K-Cl values decreases calcium utilization due to inadequate synthesis of the active form of vitamin D. Leach 1979, however, reported that 1,25-dihydroxycholecalciferol was not effective in treatment of tibial dyschondroplasia. A possible explanation for these results may be gleaned from the report of Bushinsky et al. 1982. These investigators produced metabolic acidosis in rats by administering NH₄Cl in the drinking water. Acidotic rats had lower plasma 1,25-dihydroxycholecalciferol concentrations, no alterations in plasma parathormone activity (PTH), but increased ionized calcium concentrations and increased urinary output of calcium. These investigators suggest that the increased ionized calcium is a more direct effect of acidosis, the reduced levels of 1,25-dihydroxycholecalciferol being due to feedback inhibition of kidney 25-hydroxycholecalciferol hydroxylase by the increased plasma calcium. The failure of PTH levels of plasma to change in response to increased ionized calcium suggest that acidosis may interfere with the regulatory interactions of PTH and calcium. Interestingly, total serum calcium was not altered by acidosis. Therefore acidosis, may alter the association of calcium with proteins and other constituents of blood plasma, resulting in a higher proportion of calcium in the free ionic form. Further research on this aspect of electrolyte balance may greatly improve our understanding of the interrelationships between electrolyte balance and calcification of eggshell and bone.

Interactions with amino acids

A physiological interrelationship between basic amino acids and potassium has been known for decades. Iacobellis et al. 1956, Eckel et al. 1958, Sanslone et al. 1970 and Arnauld and Lachance 1980 have demonstrated that potassium depletion in rats leads to lower concentrations of K in muscle, and increased concentrations of Na and free basic amino acids, particularly lysine. Ellory et al. 1972 provide further evidence of such an interrelationship. They reported that, in sheep having a genetic propensity for low concentrations of K in their erythrocytes, red cells have increased concentrations of Na and basic amino acids. Dickerman and Walker 1964 reported that intravenous infusion of dogs with the basic amino acids, lysine, arginine and ornithine resulted in marked increases in urinary excretion of potassium. Eckel et al. 1958 proposed that basic amino acids, being cations at physiological pH, substituted for cellular potassium when it was deficient. At present no more complete explanation can be given for this interaction.

A nutritional interaction of basic amino acids and electrolytes in poultry were first described by O'Dell and Savage 1966 who reported that the lysine-arginine antagonism in chicks was alleviated by supplementation of the diet with Na and K salts of metabolizable organic acids (e.g. carbonate, acetate and citrate salts). More recently Calvert and Austin 1981 reported that excess dietary chloride exacerbated the lysine-arginine antagonism. By varying the potassium and chloride levels in the experimental diets, the value of Na+K-Cl ranged from less than zero to +400 or +500 in two experiments. The antagonism was most marked when the Na+K-Cl value was less than zero, and diminished as the value increased.
to 400 or more. The greatest change occurred between 0 and +200.

The metabolic basis of the nutritional interaction of electrolytes lysine and arginine is not known. Some metabolic effects of electrolytes have been reported, however. Stutz et al. 1971 found that alkaline salts of K decreased the blood and tissue level of lysine when the diet contained excessive lysine. Based on the incorporation of carbon-14 labelled lysine into protein Stutz et al. 1972 concluded that the alkaline salts stimulated protein synthesis thereby decreasing plasma and tissue lysine concentrations due to the incorporation of lysine into protein. Scott and Austic 1978 found that alkaline salts of K increased the activity of the enzyme, lysine-alpha-ketoglutarate reductase (LKR), which catalyzes the initial step of lysine degradation. Thus it is possible that electrolytes influence the activity of LKR; with direct consequences on the severity of the nutritional lysine-arginine antagonism due to increases or decreases in the ability of chicks to catabolize excess dietary lysine.

Some reports describe another nutritional interaction between lysine and electrolytes in young growing swine (Liebholz et al. 1966; Madubuike et al. 1980 and Cline et al. 1983). Diets enriched in alkaline salts of potassium or sodium were reported to increase the growth of pigs fed lysine-limiting diets. This interaction appeared to have potential application since lysine is usually the first limiting amino acid in diets for swine. However, our experience indicates that more research is needed before this interaction can be fully understood or used to advantage. Although the response was observed repeatedly in our laboratories a few years ago, it has not been observed consistently during the past year. The composition of the diet has been modified and the breed of pig is different. Whether these may account for the differences in results between the current and previous experiments is not known.

The foregoing studies indicate that the balance of dietary electrolytes is an important consideration in the nutrition of monogastric species. Further research on the basic mechanisms by which the metabolism of calcium and amino acids are altered by electrolytes should provide an explanation for these phenomena at the molecular level and permit the manipulation of dietary electrolytes to the best advantage in practical diets for animal production.

REFERENCES