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Electrolytes, Stress & Performance — A matter of balance!

Over view

When we talk about healthy animals producing at their optimum efficiency, we are really concerned about the health and activity of the billions of cells which make up their bodies. Each cell is like a chemical factory which contains approximately 50,000 genes, controlling around 2000 chemical reactions all the time and using up energy to produce waste. No cell can function efficiently without a balanced electrolyte system. Ions of sodium, potassium and chlorine are the key electrolytes having a range of critical functions in the well being of cells and therefore animals.

The concentration and balance of electrolytes in a bird's intracellular and extracellular fluids are critical for life and are therefore tightly regulated. Among the dietary minerals, chloride is the negatively charged and sodium and potassium are the positively charged electrolyte mineral. A bird's dietary requirement for these minerals must be considered in two ways: the minimum amount of each needed for cellular functions and the balance between different electrolytes necessary to optimize important osmotic (diffusion of water through cell membranes) and acid-base relationships.

When exposed to high temperature, birds increase their respiratory rate (to dissipate heat by evaporation) resulting in higher losses of CO_2, and consequent increase in blood pH. The acid-base balance is further disrupted by the increased electrolyte excretion through urine and faeces. Electrolyte supplementation to the diet has been shown to restore the acid-base balance and improve bird's performance.

The body fluids (present in and outside the cells) carry oxygen and carbon dioxide, move nutrients to the tissues, remove waste and distribute enzymes and hormones to their target tissues. To function efficiently the body cells must have a constant, balanced environment, which is provided by the fluids surrounding them. These fluids must be regulated for composition, volume, temperature and distribution….. all must be maintained in balance.

Cell activity requires difference in electric potential. When electrolytes (sodium, potassium, chloride and bicarbonate) are added to water they ionize (become active) and create electric differential. Electrolytes in ionized form carry an electric charge, either negative or positive. The body needs a continuous supply of fluids and electrolytes in required amounts to balance the internal environment.

Acid: Base Balance

(Expressed as pH in the range of 1-14)

The pH in and around a cell is roughly neutral, around 7. A cell is like a small chemical factory; chemical reactions occur all the time using up energy and producing waste. Under normal conditions balance is achieved through buffering when acids are neutralized by bases. Bicarbonate is the main buffer. However, when abnormal conditions arise, which lead to a rise in the deep body (internal) temperature, the normal control system begins to assist it.

Electrolyte Imbalance

When animals are being raised under stressful conditions the margin between balance and imbalance is often very small. Ions of the key electrolytes are involved in metabolic pathways and if the diet supplies less than what is required, or losses occur through stress, cell functions such as manufacture of proteins, carbohydrates and fats are reduced.

Appetite is affected immediately, metabolic rate rises. While in emergency mode the body marshals its resources to try to restore balance. In doing this, resources are not directed to productivity that the essential ingredients are readily available for the metabolism of cells. A good example of a situation leading quickly to electrolyte imbalance is panting in birds. In higher temperatures more water is drunk. With the additional urine excreted, more electrolytes are lost and a steady replacement is called for.

Prevention of electrolyte imbalance should be obviously approached through incorporation of appropriate cations and anions in diet formulations. However it must be accepted that diet is only one factor influencing potential imbalance, and so general bird management and welfare also becomes of prime importance. Electrolyte balance is usually gauged by consideration of $Na^{+}K^{-}Cl$ balance in the diet, and under most dietary situations this seems a reasonable

Table 1: **Electrolyte content of feed ingredients**

	% of ingredient			
Ingredient	**Na**	**K**	**C1**	**Na+K-C1 (mEq)**
Corn	0.05	0.38	0.04	108
Wheat	0.09	0.52	0.08	150
Milo	0.04	0.34	0.08	82
Soybean meal	0.05	2.61	0.05	675
Canola meal	0.09	1.47	0.05	400
Meat meal	0.55	1.23	0.90	300
Fish meal	0.47	0.72	0.55	230
Cottonseed meal	0.05	1.20	0.03	320

calculation.

Under practical conditions, electrolyte balance seems to be more challanging when chloride levels are high. On the other hand, use of $NaHCO_3$ to replace NaCl, as is sometimes recommended during stress, can lead to a deficiency of chloride. Changes in diet electrolyte balance most commonly occur when there is a major change in ingredient usage, and especially when animal protein sources replace soybean meal and vice versa. Table1 outlines electrolyte content and electrolyte balance of some major feed ingredients

Dietary Electrolyte Balance

"Electrolytes" are defined as all solubilized compounds containing cations (Na^+, K^+) and anions (Cl^-) which give the solution the capacity to conduct an electric current. Feed additives which provide these monovalent mineral compounds may probably be correctly termed as electrolyte "salts" or "supplements" and electrolytes are liquid. Dietary electrolyte balance (DEB) in poultry diets is calculated based on total levels of Na, K, and Cl which can be obtained by lab analysis. The ability of Na or K to neutralize hydroxyl groups (OH^-) and of Cl to neutralize hydrogen ions (H^+) is expressed in terms of "milliequivalents" (mEq) which takes into account the atomic weight of each element or molecular weight of each molecule along with their respective valency or charge. In poultry nutrition, DEB is expressed as Na + K - Cl in mEq/kg or diet or in mEq/100 g of diet. Broiler and breeder diets usually have DEB indexes ranging from about 100 to 250 mEq/kg or 10.0 to 25.0 mEq/100 g.

The DEB value of diets differing in Na, K, and Cl may be the same because the index has two cationic and one anionic mineral component. The formula for determining mEq/100 g is [(mg in diet) x (valence)] / [atomic or formula weight, g]. The Na, K, and Cl total levels must first be within acceptable range, not deficient and not excessive or toxic, in order to support and not limit growth or reproduction. It becomes an econometric concern to nutritionists to determine the optimal levels of Na, K, and Cl in broiler chicken and broiler breeder diets to accomplish performance objectives. The factors for figuring DEB are based on the total content of nutrients in poultry diets, but in reality, bioavailability of nutrients affects the actual amount of nutrients absorbed by the intestine into the bloodstream. Monovalent ions (Na, K, Cl) have a higher coefficient of absorption than divalent ions (Ca, Mg, P, S). These monovalent minerals are essential for synthesis of tissue protein, maintenance of intracellular and extracellular homeostasis, electrical potential of cell membranes, enzymatic reactions, and osmotic pressure, and acid-base balance.

Key Dietary Electrolytes

The principal dietary electrolytes are:

SODIUM (Na^+)

POTASSIUM (K^+)

CHLORIDE (Cl^-)

Electrolyte	Functions
Sodium (Na+)	1. Sodium makes up about 2% of the total body weight. 2. It mostly occurs in the blood and fluids around the cells (extra-cellular predominantly) where it maintains osmotic pressure. 3. It is involved in the control of the blood viscosity and plasma volume. 4. It is responsible for water regulation and osmolarity. 5. Sodium is involved in the electrical charges along the nerve fibers which regulate neuro-muscular functions. 6. Sodium also activates certain enzyme systems and facilities the absorption of glucose and other nutrients from the gut and kidney. 7. Although kidneys are remarkably competent in maintaining sodium homeostasis, in certain conditions (diarrhea, vomiting, excessive sweating or some types of kidney damage, insufficiency of adrenal cortex), sodium is lost from the body. 8. Alkalogenic i.e. tends to increase pH of body fluids.

Electrolyte	Functions
Potassium (K+)	1. K+ is the most important ion inside the cells (intracellular cation). There is almost as much potassium inside the cell as there is sodium in the body fluids. 2. The most important function of potassium is in the physiology of the muscles. 3. Like sodium it activates some enzyme systems and is concerned with flow of electric impulses along nerves. 4. An excess of chlorine has frequently been shown to be responsible for disturbing this balance. 5. Alkalogenic i.e. tends to increase pH of body fluids. 6. The potential energy resulting from the separation of the sodium and potassium cations (a kind of tension between them across the cell membrane) drives nerve impulses and other forms of cellular communication.

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Electrolyte	Functions
Chlorine (Cl-)	1. Chlorine occurs in the cells and in the extracellular fluids. 2. It is stored in the skin and subcutaneous tissue. 3. It is also essential in the production of hydrochloric acid in the stomach which is vital for digestion. 4. Acidogenic i.e. tends to derease pH of body fluids

They are also called "Key Homeostatic Elements" and they have a very active metabolism.

Dietary Electrolyte Balance (DEB) is related to performance

At high ambient temperatures and relative humidity dietary electrolyte balance must be optimized as it is closely related to productive performance

For optimal production the formula (Na^+ + K^+ - Cl^-) mEq/Kg of diet should have a certain value for certain environmental temperatures.

Borges *et al*, found that diets with 40mEq/Kg reduced feed intake ($p<0.01$) & weight ($p<0.01$) & diets with 340mEq/Kg resulted in worse feed conversion ($p<0.05$).

Weight gain and feed conversion showed quadratic responses, with minimum and maximum points of 235 and 202mEq/Kg, respectively. Feed intake was greatest with 264mEq/Kg showing that the Na: Cl imbalance caused by high Na^+ contents and high electrolytes ratios can decrease feed intake by birds.

Applicability of the DEB in Diet Formulation Strategies

A proper dietary electrolyte balance is mandatory to maintain the acid base homeostasis and to get best live performance. A different value of DEB has been calculated for certain environmental temperatures. In view of its importance in temperature regulation in the production of animals, higher values of DEB has been proposed when high relative humidity accompanies high temperatures. However there is a considerable margin of safety with respect to buffering capacity before depressed performance resulting from a low or high DEB is noted.

The Na^+ (mostly extracellular cation) and the K^+ (primarily intracellular cation), if in excess, requires Cl^- and water for elimination through the kidneys. Divalent cations ($Ca2^+$ and $Mg2^+$) or anions (sulfate ($So42^-$) and phosphate (average valence 1.8+) as H2PO4- ~20% and $HPO42^+$ ~80%, the major intracellular buffer conjugate acid-base pair) have weaker effects than the monovalent elements.

CALCULATION OF DEB: DEB = Na^+ + K^+ - Cl^- mEq/kg DM of diet

Electrolyte	Molecular weight	Valence	If % in diet is	mg/kg	mEq/kg
Sodium (Na^+)	23.0	+1	0.18	0.18*10000	0.18*10000/23.0/1
Potassium (K^+)	39.1	+1	0.90	0.90*10000	0.90*10000/39.1/1
Chloride (Cl^-) (Na^+) + (K^+) – (C^-)	35.5	-1	0.24	0.24*10000	0.24*10000/35.5/1

To calculate dietary mEq,
Convert the percentage of element to mg/Kg i.e. multiply % by 10,000
Divide by molecular weight of element
Multiply by valency eg 1 for Na^+, K^+ and Cl^-

The acid-base balance is influenced by the environment and the diet. The maintenance of this balance can be an important measure to improve the performance of broilers raised under high temperatures and to overcome the harmful effects of respiratory alkalosis resulting from heat stress. Diets formulated with high Cl content (NH4Cl, HCl and CaCl2) decrease blood pH in broilers, adversely affecting their growth under thermo neutrality. However, acid or base intake, electrolyte balance, the environment, their interactions and implications on the performance of birds still have to be defined. Prevention of electrolyte imbalance can be achieved by incorporating cations and anions in the diet, being usually expressed in mEq/kg (Mongin, 1981). However, electrolyte availability may be influenced by intestinal and renal homeostatic regulation and by the greater absorption of monovalent ions.

Effect of DEB on Stress Physiology

One of the most important goals of farm animal growers today is to minimize stress during production. The importance of stress minimization becomes abundantly clear when one examines the physiological effects of long-term stress on animals.

Once metabolic attempts to combat or avoid a stressor have proved futile, the bird must acclimate to the stressor to preserve homeostasis. This is accomplished through the activation of the hypothalamic pituitary adrenal system [1]. This facilitates a hormonal cascade beginning with the release of corticotropin-releasing factor from the hypothalamus, which then stimulates the anterior pituitary to secrete adrenocorticotrophic hormone (ACTH). The ACTH then signals the adrenals to release the stress hormone corticosterone (CS). When blood CS levels remain elevated, many deleterious effects to the performance of the bird can occur, one of the most detrimental is the catabolism of structural proteins through CS-induced gluconeogenesis. This metabolic shift is well documented in birds treated with CS or ACTH, which typically demonstrates a significant decrease in body weight. Furthermore, this decrease in BW has been observed despite increased feed intake. Because the chief goal of the broiler producer is to achieve optimal meat production at the lowest possible cost, the former information clearly emphasizes the importance of research directed to circumventing or alleviating physiological stress during production.

A considerable amount of research has also been conducted regarding nutritional programs for heat-stressed animals. Researchers have demonstrated that diets with properly calculated DEB may have the potential to improve broiler survival during heat stress. Based on different research, it is also apparent that during times of stress, birds prefer to utilize glucose for energy, because blood glucose is increased by both the action of catecholamines (i.e., epinephrine and norepinephrine) and the action of CS secreted during the stress response.

Borges et al (2003) reported that a practical DEB range of 220 to 240 mEq/kg minimum should be adequate for broiler chickens in summer. It was also found that the minimum level of dietary sodium bicarbonate needed to prevent excessive mortality in heat stressed broilers after 28 days of age is about 0.40%.

According to Borges (2003), lower weight gains of broilers raised at high temperature are directly proportionate to decreased feed intake, as well as to the greater difficulty of losing heat to the environment when relative humidity is high.

Optimal DEB for growing broilers varies with ambient temperature being 250 meq/kg for moderate temperature (18° to 26°c) and 350 meq/kg for high temperature (25° to 35°c). Increasing DEB stimulated feed intake, possibly due to increasing Na levels in these feeds (0.15 to 0.45%). The DEB of 240 meq/kg diets had total NA and CL levels of 0.35 and 0.366% instarter feed and 0.35 and 0.294% in grower feed, respectively.

Effect of DEB and other Nutrients

The dietary electrolyte balance is an indication of the metabolisable ions that can generate or consume acid during metabolism. Diets with negative DEB are more likely to cause metabolic acidosis than diets with positive DEB. Metabolic acidosis has been implicated with reduced feed intake. DEB may also affect energy, amino acids, vitamin, and mineral metabolism. Excess dietary alkalinity (positive DEB) may increase lysine oxidation and thus, increase the requirement for lysine. Dietary ingredient selection strongly infuence with DEB. For example, piglets fed with a diet high in non-starch polysaccharide (15%) an unusual diet for young pigs, benefit from low DEB (100 meq/kg), whereas pigs fed with a diet lower in non-starch polysaccharide (10%) benefit from higher DEB (200 meq/kg). Nutrient digestibility particularly dry matter, energy, protein and chlorine are also affected in a similar fashion by DEB. Murakami *et al* (2001) suggested that DEB affects the absorption of monosaccharides and amino acids and it follows that reduced intestinal uptake of these nutrients would compromise birds performance.

Effect of DEB on phytase enzymes

The inclusion of microbial phytase in poultry diets is an increasingly common practice. Several recent studies conducted have shown that exogenous phytase enhances protein and energy utilization in poultry. However the extent to which microbial phytase improves available energy and amino acids digestibility is variable, and the factors responsible for the observed variability in nutrient utilization have not been completely identified. Factors that may contribute to this variability are complex and include concentration and sources of dietary phytate, dietary concentrations of Ca, non phytate P, amino acids and the level and type of added phytase apart from electrolyte balance of diets. Ravindran V et al. (2008) suggested that variability in phytase response in nutrient utilization in part may be attributed to differences in dietary electrolyte levels as added phytase modifies the effective DEB of practical diets. Na affects the DEB level, and the fact that phytate induces the transfer of Na into the gut lumen implies that phytate is effectively influencing the DEB of intestinal digesta. As it is strongly believed that DEB may influence the magnitude of amino acid response to exogenous phytase, preserving an optimum DEB becomes the paramount task for the nutritionist (Selle and Ravindran, 2007)

DEB on Broilers Performance

Broiler chickens have an optimal DEB of around 250 mEq/kg (Mongin, 1981). However the optimal DEB value for broilers may vary with temperature. A DEB of 250 mEq/kg is suitable for broilers being grown in moderate temperature but for the birds being reared in high temperature 350 mEq/kg is suitable, according to Fixter et al. (1987). It has been shown that broiler chicken death losses caused by heat stress can be prevented or reduced by changing DEB through electrolyte supplementation to diets. Heavier broilers (approaching market age) are sensitive to high-temperature challenges. This sensitivity can be explained by the fact that broilers have greater difficulty keeping thermal homeostasis due to the larger body mass and high rate of metabolism associated with rapid growth.

A recent study says that the DEB 50, 150 and 250 maintained better blood pH, pCO_2 and HCO_3 concentrations during acute heat stress periods than that of 0 and 350. The blood heterophil and lymphocyte percent as well as heterophil: lymphocyte ratio were remained unaffected. The lowest DEB (0 mEq/kg) diet reduced the feed intake and promoted metabolic acidosis. A 350 mEq/kg DEB, promoted water intake and metabolic alkalosis probably due to high levels of dietary $NaHCO_3$. This study conducted by the Faculty of Veterinary and Animal Sciences, PMAS Arid Agriculture University, Rawalpindi, Pakistan concluded that overall better performance was recorded with DEB 50, 150 and 250 mEq/kg.

According to Borgatti LMO, Dietary electrolytic balance influenced weight gain and feed gain ratio from 1 to 21 days, and best results were observed when diets contained a DEB between 290 and 330 mEq/kg. An extensive study reported the effect of altering the dietary mineral balance for broiler chicks. In general, increased levels of anions resulted in a higher incidence of tibial dyschondroplasia and twisted legs.

DEB on performance of laying hens

Decline in laying performance and eggshell quality are the primary responses of laying hens subjected to acute heat stress. Egg production rate decreases and egg weight increases as age advances. Egg quality and composition also changes in accordance with the level of production and age of layer. A critical balance among the Na, K and Cl in laying poultry diet is important to ensure the recovery of egg productivity, feed efficiency and egg quality. Eggshell quality is of major importance to the egg industry worldwide and may be affected by the DEB. Many studies conducted shows the relationship between the dietary electrolyte balance (DEB) and eggshell quality. The proper dietary electrolyte balance should not only maintain acid-base homoeostasis, but also achieve optimal egg production and feed conversion ratio (Hughes, 1988). In the metabolism of poultry, particular in layers, the Na and HCO_3 have a distinguished importance in egg productivity and shell formation. The formation of the eggshell in poultry is affected by the acid-base balance in blood because the acid-base rate of the blood is a restrictive factor for the accumulation of $CaCO_3$ in eggshell (Mehner and Hartfiel, 1983). Mongin (1968) also noted that the first restrictive factor of the egg shell formation was the Ca and the second factor was the HCO_3 ions so the breakage, which was observed in egg shell in hot weathers, had been caused by a decrease in blood CO_2 levels depending on the increased respiration speed.

According to Nobakht et al. (2007) increasing DEB to 360 mEq/ kg in early laying period can improve eggshell quality during laying. Consequently, during establishment of layer hen diets, minimum requirement for each mineral given by NRC should be provided in the first attempt, then the dietary electrolyte balance should be adjusted during different production periods.

DEB on performance of SWINE

The relative proportion of the monovalent mineral cations and anions have been shown to influence the acid-base status in many species including swine. Several studies have been conducted to determine the response of pigs to a range of electrolyte balance (85 to 341 meq/kg) in practical corn-soy diet containing adequate levels of all amino acids. Growth and feed intake appears to be maximum for positive balances of Dietary Electrolyte Balance (up to 341 meq/kg Na^+ K^-cl), but were decreased at 85 meq/kg ($p<0.05$). Acid-base balance was adversely affected in swines with diets at 0 meq/kg. Results of different experiments carried out defined an interesting relationship between dietary electrolyte balance and acid-base status in swine. This relationship appears to be related directly or indirectly to growth and feed intake. As dietary electrolyte balance is reduced from the basal level of 175 meq/kg, blood pH and bicarbonate concentration drop, indicative of a metabolic acidosis. Addition of $NaHCO_3$ provides a considerable margin of safety with respect to buffer capacity before depressed performance resulting from low electrolyte balance can be noticed.

Conclusion

Several management procedures are being performed to minimize the deleterious effects of stress; among these one is dietary electrolyte balance (DEB). Addition of salts in the diet or water can beneficially affect the acid-base equilibrium of animals. The effect of acid-base balance on the different metabolic processes of animals has been studied by many livestock researchers. Several other works are being conducted to expand our understanding on the essential role that dietary electrolytes exert on the acid-base balance. The pattern of change in acid-base balance depends on the effects of stressors on the condition and rate of metabolism, respiration, and the mechanism of H^+ equivalent ion exchange. However, interpretation of acid-base balance disorders, especially during stress, is complicated by the fact that many relevant variables change simultaneously and in many instances, in opposite directions, depending on the species, sex, age, and type of stressor. Though the effect of heat stressors on electrolytes in birds is well known, but more learning is required to understand how other stress factors induce stress that is likely to influence welfare and performance of birds.

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