Macrominerals: calcium, phosphorus and electrolytes

In breeder diets, macromineral nutrition focuses on skeletal development during the rearing phase and egg production; eggshell quality and embryo development during the adult phase; with specific challenges during the transition phase (pre-lay) between rearing and onset of production. Most of the research in macrominerals has been conducted in commercial layers, and this data can be applied to the layer breeder and with some differences for broiler breeders.

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In broiler breeders, mineral concentration of the diet along with the feed restriction programme allows better estimation of the daily mineral intake. However, there are differences in mineral recommendations when genetic lines are compared with some of the most recent updates (Table 1).

This review will focus on the macromineral requirements of the broiler breeder female in pre-lay and production phases.

Calcium and phosphorous

Calcium (Ca) and phosphorus (P) are macrominerals that are important for skeletal development, eggshell quality, reproductive performance, and diverse metabolic functions. In general, dietary Ca tends to be fed at higher levels than required. However, feeding large particle limestone increases the retention time in the gizzard, increasing Ca availability for subsequent intestinal absorption during the period of shell formation.

With mash diets, it is easier to supply larger Ca particles, and due to the continuous Ca absorption, there may be a reduction in the mobilisation of Ca from bone (less bone resorption). In addition, a bigger particle size stimulates gizzard functionality and prolongs feeding time, which is beneficial for gut health and welfare. Using non-colostomised breeders, Ekmay and Coon (2009) showed that larger particle limestone tends to reduce P excretion along with a significant increase in percent tibia ash and the specific gravity of the egg.

This study also indicated that the particle size (smaller or larger) of Ca source may not have an influence on urinary excretion of Ca and P but may influence retention.

In the 6-wk breeder study, the P excretion was not different but there was a numerical improvement of 2.09% P retention and 3.69% Ca retention when breeders were fed larger size limestone particles compared to the breeders fed smaller particles.

Previous data on commercial laying hens revealed a significant decrease in P excretion with increasing dietary levels of NPP when hens were fed large limestone particles compared to small particle limestone.

They also found that feeding larger particle size limestone significantly increased the specific gravity of the eggs compared to feeding smaller particle limestone (1.087 vs. 1.085). The increase of dietary Ca from 2.25% to 3.25% with 0.25% NPP gradually improved eggshell quality, while 0.4% dietary NPP did not affect the eggshell quality.

Similar observations were reported by Narvaez-Solarte et al. (2006) who observed an improvement in eggshell quality when dietary Ca was increased from 2.6% to 4.2%, with a quadratic response, showing the best shell weight at 3.56% Ca; however, the authors used 0.35% NPP in the diet and the feed intake of laying hens was much lower than that of broiler breeders even if they are restricted fed.

The National Research Council (NRC, 1994) suggests that broiler breeders housed on litter only need 3.91g of Ca per day, and this value can be obtained with diets containing between 2.3% and 2.6% Ca (assuming a daily feed intake between 150g to 170g, from peak to the end of egg production, respectively).

However, only the Brazilian tables suggest similar levels, while most commercial references are higher (2.8-3.6%). Research diets from North Carolina State University (NCSU) are intermediate, ranging from 2.7% to 3.0%, when one or two breeder diets are implemented under controlled and commercial conditions, respectively, and this without affecting eggshell quality (specific gravity and broken eggs).

During bone resorption, hydroxyapatite is released from bone supplying Ca and P for shell calcification, thereby also balancing P excretion.

If excessive Ca is supplied in the diet, the bone mineralisation decreases.

As a consequence, less P is released into the bloodstream and, with less P for kidney acid-base homeostasis, more H+ will be excreted as water, increasing litter moisture and the occurrence of dirty eggs.

Some attempts to improve eggshell quality in breeders have studied the effects of feeding during the afternoon, however eggs with thicker eggshells might reduce hatchability, or the birds become distracted from the mating activity. However, adding only the additional Ca (as big particles) in the afternoon seems ideal in improving eggshell quality, especially in brown layers where 65% of the Ca should be in particles of 2mm to 4mm. This also encourages hens to move from slats to the litter floor, improving the mating activity.

Since egg size increases and feed intake and eggshell quality decrease with age there is an advantage to phase feeding Ca and P. Ca levels can be increased over time by 0.2% with the addition of extra limestone at 5kg/MT to the diet between 45 weeks and 55 weeks of age. One reason for a decline in shell quality over time is the gradual loss in Ca deposition efficiency and withdrawal from medullary bone.

Although the medullary bone reserve is essential for shell formation regardless of diet, its role is somewhat reduced if the bird has some Ca absorbed from the digestive tract during the night. This situation supports the idea of afternoon feeding of Ca to provide a Ca source in the digestive tract that can slowly be released during the night, supporting eggshell formation. Ideally, a mixture of fine and coarse particles should be used because this gives both rapid and slow release of Ca for metabolic needs.

Calcium tetany

Ca tetany is poorly defined in broiler breeder hens but results from acute hypocalcemia. It is characterised by impaired mobility, increased mortality, and a lack of any gross lesions that would explain the impaired mobility. It is unlikely to see this problem due to low Ca levels in the breeder diet.

However, there are risk factors that affect proper Ca supply, such as poor uniformity, feed space, early photostimulation triggering

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		Ross[1]	Cobb[2]	FEDNA[3]	CVB[4]	Brazilian Tables[5]
Calcium (g/kg)	Rearing	9-15	9.5-12	9-12		8.8-17
	Production	30-34	30-32	30-35	29-33	25-27
Available P (g/kg)	Rearing	4.5-4.0	4.2	3.8	–	4.1
	Production	3.6-3.2	4.2-3.2	3.5-3.3	–	2.4-2.6
Retained P CVB (g/kg)	Rearing	–	–	3.2	–	–
	Production	–	–	2.8-2.7	–	2.5-2.3
Sodium (g/kg)	Rearing	1.8-2.3	1.5-2.4	1.6-1.7	1.4-1.8	1.8-1.7
	Production	1.8-2.3	1.5-2.4	1.6-1.8	–	1.5-1.64
Chloride (g/kg)	Rearing	1.8-2.3	1.5-2.5	1.5-2.9	–	1.6-1.5
	Production	1.8-2.3	1.5-2.4	1.5-2.6	–	1.7-1.8
Potassium (g/kg)	Rearing	6.0-9.0	6.0-9.0	5-5.5	6.0-9.0	5.5
	Production	6.0-9.0	6.0	4.5-5.5	–	4.2-4.6

[1](Aviagen, 2021), [2](Cobb Vantress, 2019), [3](Santoma and Mateos, 2018), [4]CVB, (2017) [5](Rostagno et al., 2017)

Table 1. Macromineral requirements in broiler breeders in rearing and production. Range indicates values between 4 to 24 weeks of age for rearing and between first egg and 64 weeks of age.

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production too quickly, small particle sized Ca, and even leaving the pre-lay diet with a medium Ca level for too long before changing to production levels.

Typical post-mortem findings include an active but congested ovary, a partially or fully formed egg in the oviduct, and possibly damage to the back of the bird from male abuse.

Treatment of Ca tetany is through Ca supplementation in the form of oyster shell or large particle limestone at 2-5g/bird/day for three consecutive days followed by three days of rest.

This treatment should continue until mortality is under control. Nutritional knowledge suggests that amendment of vitamin D and bicarbonate levels are recommended as these compounds increase Ca absorption and improve dietary electrolyte balance.

Phosphorus

The P needs of broiler breeder hens for production and progeny performance have not been well investigated.

The NRC (1994) recommends 350 mg of NPP; however, the industry usually supplies around 600-640mg NPP/d (150-160g/d x 0.4% avP). Previous studies have shown evidence that increasing P intake above 0.4% available P confers no additional benefit to production.

Triyuwanta et al. (1992) showed that increasing available P to amounts as high as 1% in the diet in dwarf broiler breeders did not improve egg production, egg weight, or shell quality. Only marginal improvements were seen in fertility, hatchability, and hatching weight, and no improvements were seen in two-week progeny body weight or seven-week-progeny body weight.

On the other hand, very little research has been conducted on lower NPP in broiler breeder diets. Chandramoni et al. (1998) showed that egg production, shell weight per unit surface area (SWUSA), and egg content were not improved with a total P above 0.43% in caged layers; while Keshavarz (2000) found no differences in egg production in layer hens fed low levels of NPP (0.15-0.10%) and phytase.

Similar results were reported by Sodsee (2013), who did not find significant differences in egg production and shell quality for breeder hens fed either 0.25% or 0.4% NPP (with daily intake ranging from 0.34 to 0.55g NPP at peak feed intake) and with 3.25% Ca in the diet.

The study by Triyuwanta et al. (1992) showed that the current practice of feeding 600mg NPP/d to breeders may not be necessary.

The industry starts around those values and then decreases to 480-500 mg NPP/d (150-156g/d/hen x 0.32% NPP) and the Brazilian tables (Table 1) suggest 400mg NPP/d, which is slightly higher than the 338mg/d (0.41% total dietary P (718mg/bird/d)) found by Wilson et al. (1980) for egg production. To reach 400mg NPP for feed intakes from 153g/d to 167g/d the diets should have 0.26% to 0.24% NPP, which is lower than the commercial recommendation for genetic broiler lines.

The P requirement is also fulfilled in phase feeding, but in contrast to Ca, available P is normally reduced in the production phase (Table 1). Only the Brazilian tables suggest a slight increment in the concentration (0.02%) to counteract the normal reduction in daily feed allocation that is used in broiler breeders.

Ekmay and Coon (2010, 2011) evaluated the effect of particle size on Ca and P excretion and found that Ca excretion significantly increased with higher P intake.

Feeding breeders large particle limestone did not improve shell quality or tibia bone strength but this trial was only conducted for six weeks.

However, the authors concluded that NPP can be fed at 0.2% (288mg/d), without impacting performance and at 0.25% NNP (360mg/d) to ensure bone integrity.

Plumstead et al. (2007) conducted floor pen feeding studies with breeders housed on slats to determine the water soluble excretion while feeding corn/soybean/phytase diets (Table 2).

The researchers fed corn-soy diets and added 0.10% AvP made available from phytase to the breeder diets and suggested that 0.37% AvP was needed for maximum fertility if pullets were reared from 10 weeks of age on corn/soybean and phytase diets.

However, eggs and chicks per hen housed were numerically diminished when hens were fed 0.37% NPP.

Electrolytes -sodium, chloride, and potassium

Potassium (K+) is the primary cation in the intracellular fluid (ICF), while sodium (Na+) and chloride (Cl-) are the primary ions in the extracellular fluid (ECF). Each of these ions is involved in the regulation of acid-base balance via extracellular and intracellular buffering.

In the diet, the electrolyte balance between the cation, Na+, K+, and the anion Cl- can be expressed as a formula Na++K+-Cl -mEq/kg, which is known as dietary electrolyte balance (DEB).

These electrolytes play a major role in osmotic regulation, cell physiology, animal metabolism, and body fluid acid-base balance.

Endogenous acid production and rates of renal clearance can be affected by supplying the diet with these electrolytes. In most situations 250mEq/kg is optimum

Table 2. Effect of varying dietary non-phytate P (NPP) levels with or without added phytase enzyme on performance variables of broiler breeders from 29 to 64 weeks of age. Adapted from Plumstead et al. (2007).

Item	NPP (%)	Added phytase (FTU/kg)	Eggs per hen housed (n)	Feed per dozen eggs (g)	Hen-day egg production (%)	Fertility* (%)	Chicks per hen housed (n)
Treatment							
A	0.37	—	158.0	$2,999^{xy}$	62.09^{b}	97.5^{A}	143.6
B	0.27	500	164.5	$3,038^{x}$	62.12^{b}	95.0^{B}	145.2
C	0.19	—	163.9	$3,068^{x}$	61.24^{b}	95.5^{B}	145.3
D	0.09	500	170.8	$2,875^{y}$	65.18^{a}	95.3^{B}	152.4
SEM			3.74	46.7	0.893	—	3.26
P Value			0.178	0.059	0.041	‹0.001	0.269

a,b Means within the same column with no common superscript differ (P≤0.05). A,B Means within the same column with no common superscript differ (P≤0.01). x,y Means within the same column with no common superscript differ (P≤0.10). * The SE for fertility was not available because of the categorical nature of the data for normal physiological functions.

However, the individual elements need to be carefully revised since it is possible to reach 250mEq/kg with very extreme levels of Na+ and Cl-.

Low dietary electrolyte balance (dEB) (<180mEq/kg) values are considered acidotic while high values (>300mEq/kg) are considered alkalotic.

The eggshell carbonate (CO_3^{2-}) is derived from metabolic CO_2 in the shell gland. Considerable amounts of hydrogen ions are produced during this process, which results in an altered acid-base balance. Thus, excess H+ ions are often compensated by panting thereby, this compensation induces a moderate respiratory alkalosis that causes a reduction in blood bicarbonate (HCO_3-) that may lead to eggshell problems during heat stress when panting is exacerbated.

Although the addition of $NaHCO_3$ to feed or water will not correct respiratory alkalosis, it may mitigate eggshell problems.

Sodium

Daily Na+ requirements for egg production, feed efficiency, egg weight, fertility, and hatchability of meat-type breeder hens have been established at 150mg/d whereas sodium intake in excess of 320mg/d were shown to reduce fertility. Although Harms et al. (1995) did not find effects on egg production and egg mass with Na+ levels above 114 and 105 mg, respectively, the Brazilian tables (Table 1) recommend higher levels (250 mg/d) similar to the minimum recommendations established by the genetic companies (calculated >240 mg/d).

This difference might be due to trial conditions with a low number of hens per pen vs commercial conditions.

High sodium levels are related to increased litter moisture; however, water restriction of broiler breeders is applied to avoid excessive water intake.

Chloride

Although Harms and Wilson (1984) reported that 254mg of chloride (Cl-) per hen daily resulted in the best overall performance of broiler hens as measured by egg production and hatchability, the NRC (1994) recommends 185mg/d, which is 20% higher than Na+.

In contrast, the Brazilian tables Table 1) recommend 220 mg/d, which is 12% higher than Na+. High Cl- levels (0.4-0.5%) can exacerbate Ca excretion and deficiency.

Also, high Cl- concentrations in the blood can negatively affect the transport of HCO_3-, which may further affect eggshell quality. By reducing chloride in the diet there is an increment in bicarbonate reabsorption from the kidney that benefits the eggshell formation process.

However, Nys (1999) found that chloride levels below 0.2% were detrimental to eggshell quality.

Potassium

Potassium (K+) is primarily within the cells, with similar functions to Na+in the plasma and interstitial fluid, such as acid-base balance, osmotic pressure, and membrane potential regulation. K+ also activates a number of intracellular enzymes and it is required for normal heart activity. Replacing Na+ with K+ has shown to maintain dEB while reducing ascites mortality in broiler raised at high altitudes.

The NRC (1994) suggests a K+ requirement of 0.30% for broilers. In contrast, Oliveira et al. (2005) reported that the optimum body weight gain was achieved with K+ levels of 0.63% from 8-21 day of age, 0.71% from 22-42 d of age, and 0.80% from 43-53 d of age. To maintain optimum live performance in broilers, practical diets are formulated with K+ levels that are two to three times higher than those suggested by the NRC (1994).

The role of K+ in the regulation of the acid-base balance has been investigated by many researchers, especially in relation to heat stress conditions in broilers. Belay et al. (1992) reported that heat-stressed broilers exhibited an increased urinary excretion of K+.

The respiratory alkalosis from heat stress-induced panting has been associated with a negative balance of K+ due to increased excretion of K+. Borges et al. (2007) reported the onset of respiratory alkalosis in broilers when supplemented K+ was supplemented as potassium bicarbonate ($KHCO_3$).

Smith and Teeter (1987) observed improved thermotolerance of broilers when supplemented with K salts (KCl) in drinking water. Rao et al. (2002) reported a K+ intake of 1.8 to 2.3g/d for optimum body weight gain in broilers under heat stress conditions. However, Ait-Boulahsen et al. (1995) observed increased body weight gain and feed intake when dietary K+ was supplemented as 0.6% KCl in heat-stressed birds, together with a reduction in blood pH, resulting in less severe alkalosis.

Similarly, Ahmad et al. (2008) noticed that 0.6% KCl supplementation in drinking water reduced the blood pH to 7.31 of broilers of 42 days of age. The possible reasons for the changes in blood pH may have been due to the acidogenic effects of Cl- ions.

More recent studies demonstrated that during heat stress in broilers the blood Ca was correlated with K+, P, pH, and pCO_2, and before and after heat stress blood pH was positively correlated with plasma K+.

Breeder faecal excreta moisture and macrominerals

In laying hens, Smith et al. (2000) demonstrated that increased dietary P resulted in a greater percent of excreta moisture in laying hens. Ziaei et al. (2008) recorded that reduced dietary P increased the dry matter of excreta, which resulted from increased retention of P.

In broiler breeder hens, Joardar et al. (2019) reported an interaction between dietary AvP and K+ on the percent of excreta faecal moisture. The supplemental addition of dietary 0.2% K (as potassium carbonate) to 0.3% AvP breeder diets resulted in reduction of percent faecal moisture in breeder hens when compared with 0.2% K addition to 0.5% AvP-fed breeders.

The data suggests that the effect of AvP on faecal moisture output seems to be manifested in presence of K+. Therefore, the addition of 0.2% K had a transitory effect on the reduction of the faecal moisture with 0.3% AvP in breeder diets, during the onset of lay.

The dietary treatments did not influence the breeder egg characteristics measured over time, although lower faecal moisture might reduce dirty eggs.

Conclusion

There are differences in macromineral requirements during the onset of lay and peak laying period in breeder hens. Both limestone particle size and solubility are important considerations for maintaining eggshell quality throughout the laying cycle.

Dietary phosphorus and potassium have been shown to affect faecal moisture during the onset of lay. Therefore, taken together, the dietary macromineral and dietary electrolytes are important considerations in breeder nutrition to optimise laying performance. ■

References are available from the authors on request