Effects of different limestone particle sizes in the diet of broiler breeders post molting on their performance, egg quality, incubation results, and pre-starter performance of their progeny

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ABSTRACT An experiment was conducted to test the hypothesis that a coarse limestone diet improves productivity, reproductive performance and the calcium utilization of molted broiler breeders. In total, 640 broiler breeder females, 73-week-old and sixty-four 27-week-old cockerels, Cobb 500, were evaluated during 10 weeks, according to a randomized block design composed of 4 treatments with 8 replicates each. Treatments consisted of diets with the inclusion of 100% fine limestone - fine PS (0.2 mm GMD - geometric mean diameter); PS1: 30% fine limestone + 70% limestone with 1.0 mm GMD; PS2: 30% fine limestone + 70% limestone with 2.0 mm GMD; and PS3: 30% fine limestone + 70% limestone with 3.0 mm GMD. Calcium retention in the gizzard of the breeders, bone characteristics, and breeder performance, egg characteristics, eggshell quality, incubation performance, chick quality and yield, chick pre-starter live performance, and chick bone characteristics were determined. There was no significant difference (P > 0.05) in the rate of lay, percentage of non-settable eggs, egg weight, egg shape index, egg specific gravity, eggshell weight, thickness, and percentage hatchability and egg weight loss of broiler breeders fed with diets with different limestone particle sizes. The chick quality and yield, chick pre-starter live performance, and chick bone characteristics were not affected (P > 0.05) by any of the limestone particle sizes. It was concluded that live and reproductive performance parameters of broiler breeders post molting is not affected by limestone particle size in the feed.

Key words: broiler breeder, calcium, egg quality, incubation

INTRODUCTION

Many factors affect the chick embryo and consequently hatching quality and broiler growth potential, including egg storage, duration of incubation, and breeder age (Almeida et al., 2008; Hamidu et al., 2011). Previous studies have determined that egg weight (Ulmer-Franco et al., 2010) and hatching weight (Vieira et al., 2005) increase as broiler breeders age. In addition, albumen characteristics, albumen/yolk ratio, embryo survival, and hatchability are also influenced by broiler breeder age (Vieira and Moran, 1998, 1999). According to Zakaria et al. (2009) weight loss is higher in eggs of older breeders as compared with those of younger breeders, and may be ascribed to the deterioration of eggshell quality. This is a result of the accumulation of fat in the uterus, which impairs calcium deposition in the eggshell, intestinal calcium absorption, and calcium release from the bloodstream, resulting in increasingly thinner eggshells as breeder’s age

(Al-Batshan, et al. 1994; Rayan et al., 2010). Eggshell porosity and thickness strongly influence embryo development and hatchling quality (Narushin and Romanov, 2002). The production of good-quality hatchlings requires eggs to present more than 1.080 egg specific gravity (Roque and Soares, 1994; Narushin and Romanov, 2002).

Induced molting is a commercial practice that aims at improving the reproductive performance of broiler breeders and at restoring egg quality (Verheyen and Decuypere, 1986; Buhr and Cunningham, 1994; Tona et al., 2002). Many studies have reported that eggshell and albumen quality, hatchability, and juvenile growth performance are positively influenced by molting (Decuypere and Verheyen, 1986; Attia et al., 1994; Tona et al., 2002). Relative hatching weight (hatching weight to egg weight ratio) is higher after than before molting in mature broiler breeders (Tona et al., 2002), and the eggs of molted hens lose less weight during incubation, possibly due to better eggshell structural characteristics (Christensen and McCorkle, 1982).

Calcium solubility in layers is influenced by several factors, including calcium source, particle size, time of retention in the gizzard, and interaction with other feedstuffs (Ajakaiye et al., 1997). Studies with layers
have reported long gizzard retention times of large particles of limestone, which release calcium slowly and uniformly during the period of eggshell formation (Zhang and Coon, 1997; Leeson and Summers, 1997), thereby allowing the retention of calcium in the medullary bones of the birds (Rao and Roland, 1992). Manangi and Coon (2006) observed the dietary inclusion of limestone with larger particles reduced phosphorus excretion and improved egg specific gravity, which is an eggshell quality measurement.

The objective of the present study was to compare the dietary inclusion of limestone with different particle sizes on the live performance of broiler breeders, eggshell quality, parental and progeny skeletal structure, and broiler performance.

**MATERIAL AND METHODS**

The experiment was approved by the Ethics Commission for Experimental Use of Animals of the Federal University of Paraná, Brazil (0431/2011).

A commercial flock of Cobb 500 broiler breeders (640 females and 64 males) was utilized. Before the experimental period, all birds were submitted to the same management practices, following the Cobb 500 Breeder Management Guide (Cobb-Vantress, 2005). At 22 weeks of age the flock was transferred to a production house (open-side house), where they remained up to 63 weeks of age.

The females were submitted to the traditional system of induced molting at 65 weeks of age, and then transferred to the experimental house at 73 weeks of age and distributed in 32 pens, measuring 12.0 m$^2$ each (3.0 × 4.0 m). The experimental house was open-sided with fibrocement roof and polypropylene side curtains, and had a concrete floor covered with new wood-shaving litter. The house was equipped with trough feeders for females, tube feeders for males, nipple drinkers, and nests for manual egg collection. Artificial light was supplied by incandescent lamps.

Birds were individually weighed and distributed to the pens according to 2 weight classes: light (2.5 to 3.0 kg) or heavy (3.1 to 3.5 kg) in order to obtain homogenous experimental units. Sixty-four 27-week-old cockerels (3.700 ± 0.050 kg) were housed with the females. During the experimental period, eggs were collected five times daily (08:00, 10:30, 13:00, 15:30, and 17:30 h) and classified as settable or non-settable (cracked/broken) eggs.

**Experimental Design and Diets**

The chicks were randomly allocated into 4 dietary treatments, and each treatment had 8 replicates with 20 hens and 2 cockerels per experimental unit. Birds were distributed in a randomized complete block design where weight class was the criterion for the establishment of the blocks. The experimental treatments consisted of diets containing limestone with different particle sizes, as determined by geometric mean diameter (GMD): fine particle size (FPS), with 100% fine-particle limestone (GMD of 0.2 mm); 1.0 mm particle size (PS1) with 30% fine limestone and 70% limestone with 1.0 mm GMD; 2.0 mm particle size (PS2), with 30% fine limestone and 70% limestone with 2.0 mm GMD; and 3.0 mm particle size (PS3), with 30% fine limestone and 70% limestone with 3.0 mm GMD.

Feeds was in mash form and formulated on a corn and soybean meal basis (Table 1). All diets contained equal calcium and limestone levels. Limestone was analyzed for GMD, particle-size distribution (geometric standard deviation – GSD), and calcium content (Table 2). Females in all treatments were offered the same amount of feed calculated according to egg production (5% production – 130 g ration; 10% - 133 g; 20% - 136 g; 30%...

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### Table 1. Composition and nutritional levels of the experimental diets.

<table>
<thead>
<tr>
<th>Ingredients (%)</th>
<th>FPS</th>
<th>PS1</th>
<th>PS2</th>
<th>PS3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>66.4</td>
<td>66.4</td>
<td>66.4</td>
<td>66.4</td>
</tr>
<tr>
<td>Soybean meal 46% CP</td>
<td>22.4</td>
<td>22.4</td>
<td>22.4</td>
<td>22.4</td>
</tr>
<tr>
<td>Limestone</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Kaolin</td>
<td>1.70</td>
<td>1.70</td>
<td>1.70</td>
<td>1.70</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.20</td>
<td>1.20</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>Soybean oil</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Vitamin and mineral supplement</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>DL-methionine</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Choline chloride</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>L-lysine</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

1. FPS: 100% fine limestone (0.2 mm GMD - geometric mean diameter).
2. PS1: 30% fine limestone + 70% limestone with 1.0 mm GMD.
3. PS2: 30% fine limestone + 70% limestone with 2.0 mm GMD.
4. PS3: 30% fine limestone + 70% limestone with 3.0 mm GMD.

### Table 2. Limestone geometric mean diameter (GMD), geometric standard deviation (GSD), and calcium content.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>GMD mm</th>
<th>GSD %</th>
<th>Ca %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone 0.2 GMD</td>
<td>0.23</td>
<td>1.11</td>
<td>38.2</td>
</tr>
<tr>
<td>Limestone 1.0 GMD</td>
<td>1.13</td>
<td>1.42</td>
<td>38.2</td>
</tr>
<tr>
<td>Limestone 2.0 GMD</td>
<td>1.91</td>
<td>1.19</td>
<td>38.2</td>
</tr>
<tr>
<td>Limestone 3.0 GMD</td>
<td>2.92</td>
<td>1.32</td>
<td>38.2</td>
</tr>
</tbody>
</table>
Eggshells were washed under running water and dried. Parameters, eggs were individually identified and broken. For the determination of eggshell parameters, intact egg width and length with a digital caliper (Lee Tools, model 684132, São Paulo, Brazil) at 37.5°C for 15 hours. Eggshells were then weighed and their relative weight calculated. Eggshell thickness was measured at 3 different regions with the digital caliper to calculate average eggshell thickness. Both eggs and eggshells were weighed in a digital precision scale (0.001 g).

Incubation responses were evaluated using the eggs laid between weeks 78 and 79. The eggs were collected, disinfected, and individually weighed and identified. Until setting, eggs were stored for a maximum period of 7 days in an environmentally controlled room (19 to 21°C and 60 to 80% RH). Six trays of 96 eggs were incubated per treatment (one tray per replicate). Eggs were incubated in a CASP machine (model Mg124, CASP, Amparo, SP, Brazil) at 37.5°C (99.5°F) and 52.5% RH in trays identified per replicate and randomly distributed in the incubation trolleys. On day 18, eggs were transferred to a CASP Hatcher (model Ug21, CASP, Amparo, SP, Brazil) at 36.5°C and 65% RH until hatch. Egg trays were weighed empty and with the eggs before being placed in the incubator and at the time of transfer to the hatcher in order to determine egg weight loss during incubation. Hatchlings were removed from the hatcher, counted, and weighed at the 504th incubation hour. Each hatchling was visually examined and classified as a first- or second-quality chick. First-quality chicks were defined as clean, dry, free from contamination, free of deformities (no skin lesions, well-formed beak, good leg conformation), and with the navel completely closed, with no yolk sac or dried membranes protruding from the navel. Hatching rate was calculated as the ratio between viable hatchlings and the total number of incubated eggs. Hatch yield was calculated as the ratio between total egg weight at setting and hatching weight. In order to evaluate fertility and embryo mortality, non-hatched eggs were counted and submitted to embryo diagnosis.

In total, 1,456 good quality chicks (364 per treatment) were reared in different pens in an experimental broiler house at a density of 12 chicks/m² at 30 to 32°C until 7 days old, and live performance (feed intake, weight gain, and feed conversion ratio) was evaluated. Chicks were housed according to their breeder’s treatment, totaling 14 replicates with 26 birds each. A photoperiod of 22 h of light and 1 h of dark was applied. Birds were fed a standard broiler pre-starter diet (3,000 kcal metabolizable energy/kg, 23.00% crude protein) ad libitum. At the end of the experimental phase, 3 chicks per replicate were sacrificed by neck dislocation and the right tibiae were collected for the determination of calcium and ash contents.

When hens were 83 weeks old, 8 hens per treatment were sacrificed after 8, 10, 12, and 28 hours of feed fasting. The digestive tract was collected, and gizzard content was removed, weighed, and dried in a forced-ventilation oven (16 h at 105°C). Gizzard content was analyzed for dry matter, calcium, and ash contents (AOAC, 1995) in order to estimate calcium (limestone) retention percentage in the gizzard at different times after feeding. Both tibiae were collected: the left tibiae was used to measure bone density and breaking strength, whereas the right tibiae was analyzed for ash and calcium contents.

The left tibia was cooked in boiling water for one minute to remove meat, proximal cartilage, and the fibula, and then immersed in ethylic ether for 24 h for the complete removal of fat residues. After complete ether evaporation, bones were dried in an oven at 65°C for 24 h, weighed, and placed in a muffle at 600°C for subsequent determination of bone ash and calcium contents (AOAC, 1995). The right tibiae were subjected to the same procedure of meat, cartilage, and fat removal. After drying, tibiae were weighed (Tecnal, model BG – 400, Piracicaba, Brazil), and their length was measured using a digital caliper. To determine bone density, Archimedes’ principle was applied (Rath et al., 1999). After that, bones were dried again in an oven (65°C for 24 h) and their breaking strength was determined by applying a perpendicular force at the speed of 5 mm/min with a 30 mm diameter cylindrical knife at the midpoint between epiphyses (EMIC apparatus, model DL2000, INSTRON, Paraná, Brazil). Bone breaking strength was determined as the maximum strength required to break the bone completely.

**Statistical Analysis**

The assumptions of residue normality and homoscedasticity were analyzed by the tests of
Table 3. Post-molting rate of lay and egg characteristics of broiler breeders fed diets containing limestone with different particle sizes.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FPS ¹</th>
<th>PS1 ²</th>
<th>PS2 ³</th>
<th>PS3 ⁴</th>
<th>SEM ⁵</th>
<th>Linear</th>
<th>Quadratic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of lay (%)</td>
<td>69.8</td>
<td>72.4</td>
<td>69.9</td>
<td>69.5</td>
<td>0.486</td>
<td>0.56</td>
<td>0.52</td>
</tr>
<tr>
<td>Cracked/broken eggs (%)</td>
<td>5.26</td>
<td>5.80</td>
<td>5.38</td>
<td>5.26</td>
<td>0.154</td>
<td>0.47</td>
<td>0.45</td>
</tr>
<tr>
<td>Egg weight (g)</td>
<td>71.0</td>
<td>71.0</td>
<td>71.2</td>
<td>70.5</td>
<td>0.165</td>
<td>0.45</td>
<td>0.39</td>
</tr>
<tr>
<td>Egg shape index</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.006</td>
<td>0.98</td>
<td>0.97</td>
</tr>
<tr>
<td>Egg specific gravity (g/ml)</td>
<td>1.07</td>
<td>1.06</td>
<td>1.06</td>
<td>1.06</td>
<td>0.003</td>
<td>0.22</td>
<td>0.27</td>
</tr>
<tr>
<td>Eggshell weight (g)</td>
<td>6.36</td>
<td>6.39</td>
<td>6.31</td>
<td>6.33</td>
<td>0.021</td>
<td>0.98</td>
<td>0.93</td>
</tr>
<tr>
<td>Eggshell thickness (mm)</td>
<td>0.39</td>
<td>0.39</td>
<td>0.39</td>
<td>0.39</td>
<td>0.001</td>
<td>0.99</td>
<td>0.98</td>
</tr>
<tr>
<td>Eggshell (%)</td>
<td>8.95</td>
<td>8.99</td>
<td>8.88</td>
<td>8.93</td>
<td>0.023</td>
<td>0.89</td>
<td>0.95</td>
</tr>
</tbody>
</table>

¹ FPS: 100% fine limestone (0.2 mm GMD - geometric mean diameter).
² PS1: 30% fine limestone + 70% limestone with 1.0 mm GMD.
³ PS2: 30% fine limestone + 70% limestone with 2.0 mm GMD.
⁴ PS3: 30% fine limestone + 70% limestone with 3.0 mm GMD.
⁵ SEM: standard error of the mean.
⁶ P: Probability level.

Shapiro-Wilk and Bartlett, respectively. Data were then submitted to one-way ANOVA at 5% probability level. Data were subjected to orthogonal polynomial analysis (linear and quadratic trends). Calcium level in the gizzard content was analyzed by the test of Friedman at 95% probability level.

RESULTS AND DISCUSSION

The dietary inclusion of limestone with different particle sizes did not affect the evaluated performance and egg characteristics of broiler breeders after molting (Table 3). The use of mixtures of limestone with different particle sizes has been suggested as a tool to improve calcium solubility, and therefore, to obtain better egg physical characteristics (Zhang and Coon, 1997; Pizzolante et al., 2006). Rao and Roland (1992) suggest that the partial replacement of fine limestone by coarse limestone in the diet may be beneficial when eggshell thickness problems are observed. However, no changes in egg shape index or eggshell weight, percentage, and thickness (P > 0.05) were observed in the present experiment, as well as in the percentage of cracked or broken eggs as a function of treatments. Eggshell defects reduce fertility and hatchability and increase embryo mortality (Roque and Soares, 1994, Nakage et al., 2002).

Egg specific gravity was not different among the different treatments (P > 0.05). However, the values obtained in the present study were lower than those recommended for optimal hatchability and chick quality, 1.080 g/mL (Ingram et al., 2008), and may increase the embryo mortality (Narushin and Romanov, 2002). In this study the broiler breeders were raised in an open-sided house, and although the average temperature was approximately 23.5°C during the experimental period, the minimum and the maximum temperatures recorded were 15.4°C and 41.9°C, respectively. This variation may have been the reason for the lower egg specific gravities observed in this study. Similarly lower values were also observed by Chung et al., (2005) and Ajakaiye et al., (2011), although in normal environmental temperature conditions.

The different limestone particle sizes in the diet did not affect (P > 0.05) tibial ash, calcium, or phosphorus contents, neither tibial breaking strength in 82-week-old post-molting broiler breeders (Table 4). In addition to being essential for eggshell formation, calcium plays an important role in chicken bone integrity (Moreki et al., 2011). Any deficiency in calcium supply or metabolism results in weaker bones and eggshells (Roberson, 2004). Broiler breeders are submitted to feed restriction regimes, and consume their daily meal in 2 to 4 hours after feed is supplied in the morning. As

Table 4. Post-molting tibial ash and calcium content, breaking strength, and density of broiler breeders fed diets containing limestone with different particle sizes.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FPS ¹</th>
<th>PS1 ²</th>
<th>PS2 ³</th>
<th>PS3 ⁴</th>
<th>SEM ⁵</th>
<th>Linear</th>
<th>Quadratic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashes (%)</td>
<td>58.4</td>
<td>58.2</td>
<td>58.8</td>
<td>59.1</td>
<td>0.30</td>
<td>0.67</td>
<td>0.49</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>23.2</td>
<td>23.3</td>
<td>23.9</td>
<td>23.9</td>
<td>0.16</td>
<td>0.64</td>
<td>0.87</td>
</tr>
<tr>
<td>Breaking strength (kgf)</td>
<td>38.8</td>
<td>37.2</td>
<td>34.6</td>
<td>35.6</td>
<td>0.94</td>
<td>0.34</td>
<td>0.43</td>
</tr>
<tr>
<td>Density (g/ml)</td>
<td>0.91</td>
<td>0.92</td>
<td>0.86</td>
<td>0.88</td>
<td>0.01</td>
<td>0.80</td>
<td>0.91</td>
</tr>
</tbody>
</table>

¹ FPS: 100% fine limestone (0.2 mm GMD - geometric mean diameter).
² PS1: 30% fine limestone + 70% limestone with 1.0 mm GMD.
³ PS2: 30% fine limestone + 70% limestone with 2.0 mm GMD.
⁴ PS3: 30% fine limestone + 70% limestone with 3.0 mm GMD.
⁵ SEM: standard error of the mean.
⁶ P: Probability level.
the amount of calcium present in the digestive tract at the time of eggshell deposition, usually during the night, is low, a significant fraction of calcium is removed from the skeleton for eggshell formation. The higher contribution of skeletal calcium for eggshell formation, the worse the eggshell quality (Williams et al., 2000a,b). According to Witt et al. (2009), increasing limestone particle size may improve tibial bone strength in layers, possibly due to bone morphometric characteristics and not to higher calcium deposition, because bone weight does not change. On the other hand, in studies evaluating dietary calcium levels and limestone particle size for commercial layers, Cheng and Coon (1990), and Pelcia et al. (2011) did not observe any effect of limestone particle size on bone quality, only of dietary calcium content.

It was expected that increasing dietary limestone particle size would improve the physical-chemical characteristics of the tibiae of the hens as a result of the gradual release of calcium from the gizzard to the small intestine, thereby increasing calcium absorption time and utilization and reducing bone mobilization. However, this was not observed. The analysis of the amount of calcium retained in the gizzard 28 h after feeding (Figure 1) did not show any differences in calcium release to the small intestine as a function of particle size \( (P > 0.05) \). These results are different from those reported in studies with commercial layers. For instance, Rao and Roland (1992) and Zhang and Coon (1997) evaluated different dietary limestone particle sizes for white layers (at 79 and 88 weeks of age, respectively), and observed higher calcium retention in the gizzard 4, 12, and 24 hours after feeding as particle size increased.

Embryo development, hatchability, and post-hatch growth are not only influenced by incubation conditions, but also by egg characteristics, including egg weight (Dalanezi et al., 2005; Ulmer-Franco et al., 2010). However, in the present experiment, eggs were submitted to the same incubation management and presented similar weights. The results in Table 5 show that the evaluated treatments had no influence on hatchability, egg weight loss during incubation, or chick quality \( (P > 0.05) \).

During incubation, egg weight loss by evaporation is controlled by the relative humidity of the incubator and it is influenced by eggshell quality (Peebles et al., 2001; Rosa et al., 2002). Egg weight loss during incubation has been associated with incubation results and used as a tool to evaluate incubation yield (Tullett and Burton, 1993). Higher losses may cause dehydration and high initial embryo mortality, whereas lower losses may promote high late embryo mortality, and the embryos are not able to inflate their lungs due to the excessive amount of water (Santos et al., 2009). Almeida et al. (2006) showed evaporative losses of 14 to 15% in older breeder eggs, because they present thinner eggshells, lower area to volume ratio, and higher water content in the albumen compared with eggs of younger breeders. The egg weight loss in the present experiment was between 10.35% and 10.64%, below that considered as the optimal value (Aviagen, 2010), but embryo mortality and chick yield were not different. Rosa et al. (2002) obtained optimal hatchability when eggs lost 10.3% of their weight, which is consistent with the values obtained in the present study.

Chick yield (hatching weight as a percentage of set egg weight) is a simple method of checking the hatching time, which in turn is influenced by eggshell quality. Yields between 67% and 68% are considered optimal for chick livability and growth, but higher than 68% is considered high and may compromise chick livability during the first week of grow-out (Aviagen, 2010). Neither eggshell quality or chick yield were influenced by the evaluated treatments \( (P > 0.05) \) in the present experiment. Despite being higher than 70%, chick quality and first-week performance were not affected.

Chick average body weight was evenly distributed at placement \( (P > 0.05) \) and no growth potential differences, as measured by weight gain \( (P > 0.05) \) during their first seven days of life (pre-starter phase; Table 6), were detected among chicks derived from broiler breeders fed different limestone particle sizes. This result confirms the absence of any influence of the evaluated treatments on eggshell quality, and consequently on chick growth performance. No differences in feed intake and feed conversion ratio were detected either \( (P > 0.05) \).

Tibial ash and calcium contents of 7-day-old chicks were not affected by the treatments, and ranged between 46.4% and 47.3% and between 17.9% and 18.6%, respectively \( (P > 0.05) \). No changes in tibial weight were detected (Table 6).

The results of the present experiment indicate that post-molting performance and reproduction parameters of broiler breeders were not influenced by different limestone particle sizes. The dietary inclusion of coarse limestone particles did not affect the post-molting bone
LIMESTONE IN POST MOLTING BROILER BREEDER DIETS

Table 5. Hatchability, egg weight loss, chick yield, and chick quality of second-cycle broiler breeders fed diets containing limestone with different particles sizes.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FPS</th>
<th>PS1</th>
<th>PS2</th>
<th>PS3</th>
<th>SEM</th>
<th>Linear</th>
<th>Quadratic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg initial weight (g)</td>
<td>71.3</td>
<td>71.3</td>
<td>71.3</td>
<td>71.5</td>
<td>0.11</td>
<td>0.34</td>
<td>0.27</td>
</tr>
<tr>
<td>Egg weight loss (%)</td>
<td>10.6</td>
<td>10.3</td>
<td>10.6</td>
<td>10.5</td>
<td>0.12</td>
<td>0.74</td>
<td>0.73</td>
</tr>
<tr>
<td>Hatchability (%)</td>
<td>92.6</td>
<td>89.2</td>
<td>91.9</td>
<td>91.6</td>
<td>0.46</td>
<td>0.59</td>
<td>0.58</td>
</tr>
<tr>
<td>First-quality chicks (%)</td>
<td>89.1</td>
<td>86.9</td>
<td>89.3</td>
<td>88.7</td>
<td>0.44</td>
<td>0.74</td>
<td>0.72</td>
</tr>
<tr>
<td>Second-quality chicks (%)</td>
<td>3.47</td>
<td>2.55</td>
<td>2.78</td>
<td>2.19</td>
<td>0.22</td>
<td>0.46</td>
<td>0.55</td>
</tr>
<tr>
<td>Chick yield (%)</td>
<td>70.3</td>
<td>70.9</td>
<td>71.0</td>
<td>70.9</td>
<td>0.16</td>
<td>0.10</td>
<td>0.12</td>
</tr>
</tbody>
</table>

1FPS: 100% fine limestone (0.2 mm GMD - geometric mean diameter).
2PS1: 30% fine limestone + 70% limestone with 1.0 mm GMD.
3PS2: 30% fine limestone + 70% limestone with 2.0 mm GMD.
4PS3: 30% fine limestone + 70% limestone with 3.0 mm GMD.
5SEM: standard error of the mean.
6P: Probability level.

status of broiler breeders or their progenies’ growth potential.

REFERENCES


