# Effects of Corn Particle Size on Production Performance, Egg Quality, and Digestive Organ Indices in Laying Hens: Postprint

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## Abstract

This experiment aimed to investigate the effects of corn grinding particle size and crushing particle size on production performance, egg quality, and digestive organ indices of laying hens. In the control group diets, corn was ground using a hammer mill with screen apertures of 4.0 and 8.0 mm, while in the experimental group diets, corn was crushed using a roller mill with disc gaps of 0.3, 0.7, 1.1, and 1.5 mm. A total of 1,620 Hy-Line Brown laying hens aged 30 weeks were selected and randomly divided into 6 groups with 6 replicates per group and 45 hens per replicate for an 8-week feeding trial. The results showed that the geometric mean particle size of corn increased significantly (P<0.05) with increasing screen aperture of the hammer mill or disc gap of the roller mill. The production performance, apparent nutrient utilization rate of diets, egg quality, and digestive organ indices of laying hens in the corn crushing group were superior to those in the grinding group. When corn was ground using a hammer mill, the group with 8.0 mm screen aperture (geometric mean particle size 1,980.00 m) showed significantly higher production performance and apparent nutrient utilization rate of diets than the group with 4.0 mm screen aperture (geometric mean particle size 991.67 m) (P<0.05), while no significant differences were observed in egg quality and digestive organ indices (P>0.05). When crushed using a roller mill, the group with 0.7 mm disc gap (geometric mean particle size 1,446.30 m) exhibited better production performance than other groups, and the laying rate was significantly higher than that of the 8.0 mm screen aperture group (P<0.05), while no significant differences were found in apparent nutrient utilization rate of diets, egg quality, and digestive organ indices (P>0.05). The results indicated that for laying hen diets, crushing corn using a roller mill was superior to grinding with a hammer mill, and a disc gap of 0.7 mm (geometric mean particle size 1,446.30 m) yielded the optimal production performance, egg quality, and digestive organ indices in laying hens.

## Full Text

# Effects of Corn Crushed Particle Size on Performance, Egg Quality and Digestive Organ Indices of Laying Hens

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### Abstract

This experiment was conducted to investigate the effects of corn grinding and crushing particle size on performance, egg quality, and digestive organ indices of laying hens. In control groups, corn in the basal diet was ground using a hammer mill equipped with 4.0 mm and 8.0 mm screens. In experimental groups, corn was crushed using a roller mill with gap settings of 0.3, 0.7, 1.1, and 1.5 mm. A total of 1,620 thirty-week-old Hy-Line brown laying hens were selected and randomly allocated into six groups, with six replicates per group and 45 hens per replicate. The feeding experiment lasted for eight weeks.

The results showed that the geometric mean diameter of corn increased significantly with increasing screen size or gap setting (P<0.05). Laying hens in the crushing groups exhibited better performance, dietary nutrient apparent utilization, egg quality, and digestive organ indices compared to those in the grinding groups. When corn was ground with a hammer mill, the 8.0 mm screen group (geometric mean diameter 1,980.00  m) showed significantly higher performance and dietary nutrient apparent utilization than the 4.0 mm screen group (geometric mean diameter 991.67  m) (P<0.05), though no significant differences were observed in egg quality or digestive organ indices (P>0.05). When corn was crushed with a roller mill, the 0.7 mm gap group (geometric mean diameter 1,446.30  m) demonstrated superior performance compared to other groups, with a significantly higher laying rate than the 8.0 mm hammer mill screen group (P<0.05), while no significant differences were found in dietary nutrient apparent utilization, egg quality, or digestive organ indices (P>0.05).

These findings indicate that for laying hen feed, crushing corn with a roller mill is superior to grinding with a hammer mill. Optimal performance, egg quality, and digestive organ indices were achieved with a roller mill gap setting of 0.7 mm (geometric mean diameter 1,446.30  m).

**Keywords:** crushed particle size; laying hens; performance; egg quality; digestive organ indices

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# 1 Materials and Methods

## 1.1 Experimental Design

A single-factor experimental design was employed. A total of 1,620 healthy Hy-Line brown laying hens at 30 weeks of age, with normal feed intake, similar body weight, and consistent laying rate, were selected and randomly divided into six groups, with six replicates per group and 45 hens per replicate. The basal diet was formulated according to NRC (1994) and *Feeding Standard of Chicken* (NY/T 33—2004), combined with the Hy-Line brown laying hen feeding manual. The composition and nutrient levels of the basal diet are presented in Table 1 .

In control groups, corn in the diet was ground using a hammer mill with screen sizes of 4.0 mm and 8.0 mm, designated as Group A and Group B, respectively. In experimental groups, corn was crushed using a roller mill with gap settings of 0.3, 0.7, 1.1, and 1.5 mm, designated as Groups C, D, E, and F, respectively. All other dietary ingredients were processed identically. The experiment included a one-week pre-feeding period followed by an eight-week formal experimental period.

## 1.2 Management

The experiment was conducted in a closed chicken house with three-tier step cages, housing three hens per cage. Conventional management practices were followed. The house employed automatic artificial lighting control with a 16 h light:8 h dark cycle and light intensity of 20 lx. Room temperature was maintained at (25±5)°C with relative humidity of 40%–70%. Hens had ad libitum access to feed, which was provided at 08:00 and 14:00 daily, with feed distribution four times per day. Nipple drinkers provided free access to water. Chicken house disinfection and manure removal were performed once weekly.

## 1.3 Measurements

**1.3.1 Corn Particle Size Determination** Geometric mean diameter was determined according to ANSI/ASAE S319.4—2008. The specific procedure was as follows: 100 g of sample was placed on the top sieve of a sieve stack and vibrated for 10 min using a tap sieve shaker. The mass of material retained on each sieve was then weighed and recorded. The log geometric mean diameter was calculated using the formula:

$$\log(d_{gw}) = \frac{\sum(W_i \log(d_i))}{\sum W_i}$$

where $d_{gw}$ is the geometric mean diameter ( m), $d_i$ is the geometric mean diameter of particles on the $i$th sieve ( m), $d_i$ is the sieve opening size of the $i$th sieve ( m), $d_{i+1}$ is the sieve opening size of the adjacent sieve with larger openings than the $i$th sieve ( m), $W_i$ is the mass of material on the $i$th sieve (g), and $S_{gw}$ is the geometric standard deviation ( m).

**1.3.2 Performance Measurement** During the experimental period, daily records were maintained for each replicate, including feed intake, number of eggs, number of defective eggs (broken, misshapen, cracked, soft-shelled, or shell-less), number of culled or dead birds, time of death, and body (carcass) weight. Average daily feed intake, average egg weight, laying rate, and feed-to-egg ratio were calculated for the entire experimental period.

**1.3.3 Determination of Dietary Nutrient Apparent Utilization** The total collection method was used to collect excreta from laying hens to determine the apparent utilization of crude protein, energy, and dry matter in the diet. Apparent utilization was calculated as:

$$\text{Apparent utilization} = 100 \times \frac{\text{Total nutrient intake} - \text{Total nutrient in feces}}{\text{Total nutrient intake}}$$

Determination methods for crude protein, energy, and dry matter in diets and fecal samples were as follows: crude protein content was determined by the Kjeldahl method according to GB/T 6432—1994; energy value was measured using an IKAc2000 standard oxygen bomb calorimeter; dry matter content was determined according to GB/T 6435—2014.

**1.3.4 Egg Quality Measurement** At the end of weeks 4 and 8 of the formal experiment, 10 eggs were randomly selected from each replicate for egg quality determination (within 24 h). Measured parameters included egg weight, egg shape index, shell strength, shell thickness, yolk ratio, and Haugh unit. At the end of week 8, egg color was measured using a LabScan XE colorimeter, expressed in L, a, and b color space values, where L=0 represents black and L=100 represents white; a and b represent different color directions, with a indicating the red-green axis and b indicating the yellow-blue axis.

**1.3.5 Digestive Organ Index Measurement** At the end of week 8, two hens with good health, moderate body weight, and normal egg production were selected from each replicate and slaughtered by neck bleeding. The proventriculus, gizzard, duodenum, and ceca were removed and separated. The weight and length of the proventriculus, gizzard, duodenum, jejunum, and ileum were measured for each hen. Relative digestive organ indices were calculated, and the gizzard was scored.

### 1.4 Statistical Analysis

Experimental data were analyzed using SPSS 17.0 for one-way ANOVA. Results were expressed as "mean ± standard deviation." Differences among group means were tested for significance using Duncan' s multiple comparison test, with $P<0.05$ considered statistically significant.

## 2 Results and Analysis

### 2.1 Geometric Mean Diameter and Particle Size Distribution of Corn

The geometric mean diameter of corn is presented in Table 2 . Corn ground with a hammer mill (screen sizes of 4.0 and 8.0 mm) had geometric mean diameters of 991.67 and 1,980.00 m, respectively. Corn crushed with a roller mill (gap settings of 0.3, 0.7, 1.1, and 1.5 mm) had geometric mean diameters of 1,064.70, 1,446.30, 1,646.30, and 1,912.00 m, respectively. The geometric mean diameters of corn in Groups A and C, and Groups B and F were relatively similar.

The particle size distribution of ground and crushed corn is shown in Figure 1 [Figure 1: see original paper]. The particle size distribution differed between grinding and crushing methods. In the grinding groups (hammer mill): as screen size increased, the proportion of large particles above 2,000 m increased significantly, while the proportion of small particles below 300 m decreased significantly. In the crushing groups (roller mill): as gap setting increased, the proportion of large particles above 2,360 m increased significantly, while the proportion of small particles below 1,180 m decreased significantly. Although Groups A and C had similar geometric mean diameters, their particle size distributions differed, with particles 300 m accounting for 32.16% and 23.00%, respectively. Groups B and F had similar geometric mean diameters and nearly identical particle size distributions, with particles 2,000 m accounting for 61.70% and 60.37%, respectively, and particles 300 m accounting for 11.55% and 10.47%, respectively.

### 2.2 Effects of Corn Grinding Method and Particle Size on Performance of Laying Hens

The effects of corn grinding method and particle size on laying hen performance are presented in Table 3 . In the grinding groups: Group B had greater average daily feed intake and average egg weight than Group A, though not significantly ($P>0.05$); laying rate was significantly higher ($P<0.05$) and feed-to-egg ratio was significantly lower ($P<0.05$) in Group B than in Group A, indicating better laying performance in Group B. In the crushing groups: average daily feed intake increased significantly with increasing gap setting ($P<0.05$); Group F had the greatest average egg weight, though not significantly different from other groups ($P>0.05$); Groups D and E had significantly higher laying rates than Group F ($P<0.05$); Group D had the lowest feed-to-egg ratio, though differences among groups were not significant ($P>0.05$), indicating relatively better laying performance in Group D.

Comparing crushing versus grinding groups: although Groups A and C had similar geometric mean diameters, Group C had significantly higher average daily feed intake ($P<0.05$), greater average egg weight ($P>0.05$), significantly higher laying rate ($P<0.05$), and significantly lower feed-to-egg ratio ($P<0.05$) than Group A. Although Groups B and F had similar geometric mean diameters, Group F had significantly higher average daily feed intake ($P<0.05$), greater average egg weight ($P>0.05$), significantly higher laying rate ($P<0.05$), and greater feed-to-egg ratio ($P>0.05$) than Group B.

Based on laying hen performance data, the crushing groups exhibited better laying performance than the grinding groups, with Group D showing higher laying rate, lower feed-to-egg ratio, and higher average egg weight.

### 2.3 Effects of Corn Grinding Method and Particle Size on Nutrient Apparent Utilization in Diet of Laying Hens

The effects of corn grinding method and particle size on nutrient apparent utilization are presented in Table 4 . In the grinding groups: Group B had higher crude protein apparent utilization than Group A, though not significantly ($P>0.05$), while energy and dry matter apparent utilization were significantly higher in Group B than in Group A ($P<0.05$). In the crushing groups: Group C had the highest crude protein, energy, and dry matter apparent utilization, significantly higher than Group E ($P<0.05$), but not significantly different from other groups ($P>0.05$).

Comparing crushing versus grinding groups: although Groups A and C had similar geometric mean diameters, Group C had significantly higher crude protein, energy, and dry matter apparent utilization than Group A ($P<0.05$). Although Groups B and F had similar geometric mean diameters, Group B had higher crude protein, energy, and dry matter apparent utilization than Group F, though not significantly ($P>0.05$).

Based on dietary nutrient apparent utilization data, Group C showed the highest crude protein, energy, and dry matter apparent utilization, followed by Groups B, F, and D.

### 2.4 Effects of Corn Grinding Method and Particle Size on Egg Quality of Laying Hens

The effects of corn grinding method and particle size on egg quality are presented in Table 5 . At week 4, in the grinding groups: no significant differences were observed in eggshell strength, shell thickness, or yolk ratio between Groups A and B ($P>0.05$); egg shape index was significantly lower in Group A than in Group B ($P<0.05$), though both were oval-shaped; Haugh unit was higher in Group A than in Group B, though not significantly ($P>0.05$). In the crushing groups: no significant differences were observed in eggshell strength, shell thickness, or egg shape index among groups ($P>0.05$); yolk ratio was significantly higher in Groups C and F than in Group E ($P<0.05$); Haugh unit was significantly higher in Groups C and D than in Group F ($P<0.05$).

Comparing crushing versus grinding groups: although Groups A and C had similar geometric mean diameters, Group C had significantly greater shell thickness and yolk ratio ($P<0.05$) and significantly lower Haugh unit ($P<0.05$) than Group A. Although Groups B and F had similar geometric mean diameters, Group F had significantly lower Haugh unit than Group B (P<0.05), with no significant differences in other parameters (P>0.05).

At week 8, in the grinding groups: no significant differences were observed in any parameters between Groups A and B (P>0.05). In the crushing groups: shell thickness was significantly greater in Group F than in Group C (P<0.05), with no significant differences in other parameters (P>0.05). Comparing crushing versus grinding groups: although Groups A and C had similar geometric mean diameters, no significant differences were observed in any parameters (P>0.05). Although Groups B and F had similar geometric mean diameters, Group F had significantly greater eggshell strength and shell thickness (P<0.05) and higher Haugh unit (P>0.05) than Group B.

The effects of corn grinding method and particle size on egg yolk color are presented in Table 6 . In the grinding groups: the a* value was significantly greater in Group A than in Group B (P<0.05). In the crushing groups: the L* value was significantly greater in Groups E and F than in Groups C and D (P<0.05); the a* value was significantly greater in Group F than in Groups C, D, and E (P<0.05); the b* value was significantly greater in Groups E and F than in Groups C and D (P<0.05). Comparing crushing versus grinding groups: although Groups A and C had similar geometric mean diameters, the a* value was significantly greater in Group A than in Group C (P<0.05). Although Groups B and F had similar geometric mean diameters, the L* value was significantly greater in Group F than in Group B (P<0.05), while the b* value was significantly lower in Group F than in Group B (P<0.05).

Based on egg quality and yolk color data throughout the experimental period, Group D exhibited better egg quality.

### 2.5 Effects of Corn Grinding Method and Particle Size on Digestive Organ Indices of Laying Hens

The effects of corn grinding method and particle size on relative digestive organ weights are presented in Table 7 . In the grinding groups: gizzard relative weight was higher in Group B than in Group A, though not significantly (P>0.05). In the crushing groups: proventriculus, duodenum, and ileum relative weights were higher in Group D than in other groups (P>0.05); gizzard and jejunum relative weights were higher in Group D than in Groups C and E, and slightly lower than in Group F, though not significantly (P>0.05).

Comparing crushing versus grinding groups: although Groups A and C had similar geometric mean diameters, proventriculus, gizzard, and duodenum relative weights were greater in Group C than in Group A, though not significantly (P>0.05). Although Groups B and F had similar geometric mean diameters, gizzard relative weight was greater in Group F than in Group B, while proventriculus, duodenum, jejunum, and ileum relative weights were lower in Group F than in Group B, though not significantly (P>0.05).

The effects of corn grinding method and particle size on relative intestinal length are presented in Table 8 . In the grinding groups: duodenum, ileum, and small intestine relative lengths were greater in Group B than in Group A (P>0.05), while only jejunum relative length was slightly lower in Group B than in Group A, though not significantly (P>0.05). In the crushing groups: duodenum, jejunum, ileum, and small intestine relative lengths were greater in Group D than in Groups C, E, and F, though not significantly (P>0.05).

Comparing crushing versus grinding groups: although Groups A and C had similar geometric mean diameters, duodenum, jejunum, ileum, and small intestine relative lengths were greater in Group C than in Group A, though not significantly (P>0.05). Although Groups B and F had similar geometric mean diameters, duodenum, ileum, and small intestine relative lengths were greater in Group B than in Group F, though not significantly (P>0.05).

Additionally, gizzard scoring revealed no ulcers in any group. Therefore, based on digestive organ index data, Group D exhibited superior digestive organ indices compared to other groups.

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## 3 Discussion

### 3.1 Effects of Grinding Method on Corn Particle Size

The grinding effect of feed ingredients is typically expressed as geometric mean diameter, and grinder type generally affects the grinding outcome. Currently, roller mills and hammer mills are the most commonly used equipment for grinding raw materials in feed processing. Meng Luli et al. [9] found that when corn was ground to 700.00  m, the total grinding cost of roller mills was significantly lower than that of hammer mills, and the final product from roller mills showed a uniform distribution with fewer fine particles. Helmann et al. [10] reported that roller mills were more energy-efficient than hammer mills when processing coarse particles. Zhang Yanming et al. [8] used a hammer mill to grind corn and found that geometric mean diameters were 552.87, 647.31, and 704.15  m when using screen sizes of 4.5, 6.0, and 8.0 mm, respectively, with ground corn showing concentrated distribution in the <400 and 1,000–1,500  m ranges. Qin Yonglin [11] ground raw materials using a hammer mill with screen sizes of 2.5, 3.0, 4.5, 5.0, 7.0, and 8.0 mm, finding that geometric mean diameter increased with screen size, consistent with results reported by Wang Weiguo [12-13], Yang Jie [14], and Sun Qibo et al. [15].

In this experiment, corn ground with a hammer mill (screen sizes of 4.0 and 8.0 mm) had geometric mean diameters of 991.67 and 1,980.00  m, respectively. Corn crushed with a roller mill (gap settings of 0.3, 0.7, 1.1, and 1.5 mm) had geometric mean diameters of 1,064.70, 1,446.30, 1,646.30, and 1,912.00  m, respectively. Geometric mean diameter increased significantly with increasing screen size or gap setting. Furthermore, particle size distribution analysis revealed that corn ground with a 4.0 mm hammer mill screen contained excessive fine particles below 300 m, indicating over-grinding. In contrast, the 8.0 mm screen group produced uniform particle size distribution, similar to the effect of roller mills, consistent with the aforementioned research findings.

### 3.2 Effects of Corn Particle Size on Performance of Laying Hens

Feed manufacturers in China generally use relatively large screen sizes (typically 5-8 mm) for laying hen feed production. Currently, limited research has been conducted on the effects of feed grinding particle size on laying hen performance, and inconsistent results may be attributed to differences in diet processing and experimental animal conditions. Wang Weiguo et al. [16] used a hammer mill to grind corn and soybean meal with screen sizes of 5.0, 7.0, and 8.0 mm to formulate three diets with different grinding particle sizes for a comparative feeding trial with laying hens. The results showed no significant effects of the three grinding particle sizes on laying hen performance, though under the experimental conditions, a 7.0 mm screen size was relatively better for controlling grinding particle size in laying hen feed. Gao Tianquan [17] fed Roman pink-shell laying hens with six diets formulated with corn ground to 600, 800, 1,000, 1,200, 1,500, and 1,800 m, finding that feed intake and laying rate increased with increasing corn particle size from 600 to 1,500 m. Corn grinding particle size significantly affected average egg weight at each stage, with the highest average egg weight achieved at 1,500 m during the early laying period and entire period. No significant effects of corn grinding particle size on feed-to-egg ratio were observed at any stage. Safaa et al. [18] fed Roman laying hens with three diets formulated with corn ground to 774, 922, and 1,165 m, reporting that except for a significant increase in feed intake with increasing corn particle size, no significant differences were observed in laying rate, feed-to-egg ratio, or egg quality. Zhang Chunlan [4] fed Roman pink-shell laying hens with three diets formulated with corn ground to 671.56, 824.97, and 1,001.70 m, finding that feed intake and laying rate increased significantly with increasing corn particle size at each stage, while no significant effects were observed on average egg weight or feed-to-egg ratio.

In this experiment, when corn was ground with a hammer mill, the 8.0 mm screen group (geometric mean diameter 1,980.00 m) showed significantly better laying hen performance than the 4.0 mm screen group (geometric mean diameter 991.67 m), consistent with results reported by Gan Yuening et al. [2] showing that the 8.0 mm screen group had higher daily egg mass, laying rate, and average egg weight than the 4.0, 6.0, and 10.0 mm screen groups. When corn was crushed with a roller mill, the 0.7 mm gap group (geometric mean diameter 1,446.30 m) demonstrated optimal laying hen performance, with a significantly higher laying rate than the 8.0 mm hammer mill screen group, consistent with research by Gao Tianquan [17].

### 3.3 Effects of Corn Particle Size on Nutrient Apparent Utilization in Laying Hen Diets

Numerous studies have demonstrated that grinding particle size is closely related to nutrient digestibility in diets. Larger feed particle surface area increases contact opportunities with digestive enzymes or microorganisms, thereby enhancing nutrient solubility in digestive fluids and improving nutrient digestibility and utilization. Wang Weiguo et al. [16] ground corn and soybean meal with screen sizes of 5.0, 7.0, and 8.0 mm to formulate three diets with different grinding particle sizes for a comparative feeding trial with laying hens. The results showed some effects on dry matter and crude protein digestibility, though differences were not significant. Wang Weiguo et al. [19] also studied the in vitro protein digestibility of seven different raw materials (corn, wheat bran, dehulled soybean meal, hull-on soybean meal, conventional soybean meal, cottonseed meal, and rapeseed meal) ground with five screen sizes (0.6, 1.0, 1.5, 2.5, and 4.0 mm), finding that crude protein in vitro digestibility of all raw materials increased with decreasing particle size. Zhang Yanming et al. [7] ground corn and soybean meal with screen sizes of 4.5, 6.0, and 8.0 mm, formulated experimental diets through two-way interactions, and fed them to Hy-Line gray laying hens, reporting that corn particle size significantly affected dietary crude protein metabolic rate, which decreased with increasing corn and soybean meal particle size. Kilburn et al. [20] and Parsons et al. [21] investigated the effects of feed grinding particle size on dry matter, nitrogen, amino acids, and gross energy, reaching the same conclusion.

However, smaller grinding particle size does not always improve nutrient utilization. Li Qingxiao et al. [22] studied diets formulated with soybean meal ground to four particle sizes (529, 449, 334, and 210  m), finding that grinding particle size had no significant effect on energy and dry matter digestibility, though the 449  m group showed the highest energy and dry matter digestibility, and crude protein digestibility was significantly higher than in the two groups with smaller particle sizes. In this experiment, when corn was ground with a hammer mill, the 8.0 mm screen group (geometric mean diameter 1,980.00  m) showed higher crude protein, energy, and dry matter apparent utilization than the 4.0 mm screen group (geometric mean diameter 991.67  m). When corn was crushed with a roller mill, the 0.3 mm gap group (geometric mean diameter 1,064.70  m) showed the highest crude protein, energy, and dry matter apparent utilization, higher than the 8.0 mm hammer mill screen group, consistent with the principle that smaller particle size leads to higher nutrient digestibility.

### 3.4 Effects of Corn Particle Size on Egg Quality of Laying Hens

Egg quality generally includes several indicators: shell strength, shell thickness, egg shape index, yolk ratio, Haugh unit, and yolk color. Shell strength and thickness are important for shell quality and egg transportation. Egg shape index is expressed as the ratio of longitudinal to transverse diameter, typically ranging from 1.30 to 1.35. Yolk ratio reflects the proportion of yolk to whole egg, with higher values indicating better egg quality; fresh eggs have yolk indices of 0.38–0.44. Haugh unit measures albumen quality and egg freshness and is an important international standard for egg quality assessment, with fresh eggs having Haugh units above 80. Yolk color is an indicator of yolk color intensity and significantly affects commercial value and price.

Gan Yuening et al. [2] found that grinding corn with hammer mill screen sizes of 4.0, 6.0, 8.0, and 10.0 mm and feeding the formulated diets to Lueyang black-bone chickens resulted in no significant differences in shell thickness, shell strength, egg shape index, albumen height, yolk color, or Haugh unit among different corn grinding particle size groups. Zhang Yanming et al. [8] reported that increasing screen size from 4.5 to 8.0 mm had no significant effects on egg weight, egg shape index, specific gravity, Haugh unit, yolk index, or shell thickness. Safaa et al. [18] found that changing corn particle size in diets for peak-laying hens had no effect on yolk ratio. Zhang Chunlan [4] reported that corn particle size had no significant effects on specific gravity, shell strength, or Haugh unit. Deaton et al. [23] fed laying hens diets formulated with corn ground to 514–873  m and observed no significant differences in shell strength from 23 to 72 weeks of age. In this experiment, different particle sizes of corn ground with a hammer mill or crushed with a roller mill had minimal effects on egg quality, consistent with the aforementioned research findings.

### 3.5 Effects of Corn Particle Size on Digestive Organ Indices of Laying Hens

Numerous studies have shown that feed grinding particle size significantly affects gastrointestinal physiological function in chickens. Parsons et al. [21] reported that gizzard weight and relative gizzard weight increased significantly with increasing corn particle size. Additionally, Jiménez-Moreno et al. [24] demonstrated that gizzard weight increased with feed particle size, with coarse grinding promoting gizzard development, consistent with findings by Nir et al. [25-26], Engberg et al. [27], and Svihus et al. [28]. Feeding coarsely ground feed increases gizzard size, possibly due to enhanced muscle development to accommodate increased grinding activity. In contrast, finely ground feed causes proventriculus dilation, though reports differ on whether it simultaneously increases proventriculus weight [29]. Jones et al. [30] found that feeding finely ground pellets resulted in underdeveloped gizzards and induced proventriculus dilation and hypertrophy. Engberg et al. [27] observed that finely ground feed passed through the stomach into the duodenum, jejunum, and ileum at a faster rate, and long-term feeding of finely ground diets led to gizzard atrophy and small intestine hypertrophy. Rodgers et al. [31] reported that finely ground feed resulted in lower pH in gizzard contents, affecting gizzard development. Additionally, fine grinding increased the incidence of gastric ulcers, though this varied depending on feed physicochemical properties, moisture content, and other factors. Zhang Chunlan et al. [32] fed Roman pink-shell laying hens diets formulated with corn ground to 671.56, 824.97, and 1,001.70  m, finding that smaller corn particle size resulted in higher gastric ulcer scores in laying hens, with the smallest particle size group showing significantly higher ulcer scores than the coarse particle size group.

In this experiment, when corn was ground with a hammer mill, the 8.0 mm screen group (geometric mean diameter 1,980.00 m) had higher gizzard relative weight than the 4.0 mm screen group (geometric mean diameter 991.67 m), with greater duodenum, ileum, and small intestine relative lengths, though only jejunum relative length was slightly lower, with no significant differences. When corn was crushed with a roller mill, the 0.7 mm gap group (geometric mean diameter 1,446.30 m) had higher proventriculus, duodenum, and ileum weights, and greater duodenum, jejunum, ileum, and small intestine relative lengths than other groups, though not significantly. Importantly, no ulcers were found in any group, possibly due to the relatively large corn particle sizes used in this experiment.

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## 4 Conclusion

1. The geometric mean diameter of corn increased significantly with increasing hammer mill screen size or roller mill gap setting. When using hammer mill screen sizes of 4.0 and 8.0 mm and roller mill gap settings of 0.3 and 1.5 mm, corn geometric mean diameters were at similar levels, though their particle size distributions differed.
2. Laying hens in crushing groups exhibited better performance, dietary nutrient apparent utilization, egg quality, and digestive organ indices than those in grinding groups.
3. For laying hen feed, crushing corn with a roller mill is superior to grinding with a hammer mill. Optimal performance, egg quality, and digestive organ indices were achieved with a roller mill gap setting of 0.7 mm (geometric mean diameter 1,446.30 m).

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*Note: Figure translations are in progress. See original paper for figures.*