Influence of particle size of the main cereal of the diet on egg production, gastrointestinal tract traits, and body measurements of brown laying hens

J. Herrera, B. Saldaña, P. Guzmán, L. Cámara, and G.G. Mateos

ABSTRACT
The influence of the screen size used to grind the main cereal of the diet on egg production, gastrointestinal tract (GIT) development, and body measurements was studied in hens from 17 to 49 wk of age. Diets formed a 2 x 5 factorial with 2 main cereals (corn vs. barley) and 5 screen sizes of the cereal (4, 6, 8, 10, and 12 mm). Each treatment was replicated 5 times. No interactions between main cereal and screen size were observed for any of the traits studied. Cereal type and screen size did not affect feed intake, egg production, BW gain, or quality traits of the eggs. Eggs tended to be larger (P = 0.092) in hens fed the barley diet than in hens fed the corn diet. Also, feed conversion ratio tended to increase (P = 0.081) when the cereal of the diet was ground with a 4-mm screen as compared with the average of the other diets. At 49 wk of age, the relative weight (% BW) of the GIT and gizzard was greater (P < 0.05) in hens fed barley than in hens fed corn. An increase in the screen size increased linearly the relative weight of the GIT (P = 0.089), gizzard (P < 0.01), and liver (P = 0.056). None of the other GIT traits or body measurements was affected by the main cereal or the screen size. In summary, barley can substitute up to 45% of the corn in diets for laying hens without any adverse effect on egg production. Therefore, the use of one or other cereal will depend on their relative cost. An increase in screen size improved gizzard development but had little effect on hen productivity. Within the range studied, the size of the screen used for grinding the cereal had little effect on hen productivity, although the use of a 4-mm screen might increase feed conversion ratio and gizzard development.

INTRODUCTION
Corn (Zea mays L.) and barley (Hordeum vulgare L.) are extensively used in diets for laying hens. As an average, corn has less protein (7.5 vs. 11.3%) but more starch (63.3 vs. 51.1%), EE (3.6 vs. 2.0%), linoleic acid (LNL; 1.81 vs. 0.78%), and energy (3,280 vs. 2,800 kcal AMEn/kg) than barley (FEDNA, 2010). In addition, the nutritive value of corn is less variable than that of barley, probably because of its lower content in non-starch polysaccharides (NSP) (García et al., 2008; Jacob and Pescatore, 2012). The β-glucans and arabino-xylans present in barley increase digesta viscosity and might affect the development of the gastrointestinal tract (GIT) (Mateos et al., 2002), nutrient digestibility and absorption (Lázaro et al., 2003), and bird performance (García et al., 2008). A high content in NSP is associated also with an increase in the incidence of dirty eggs (Francesch et al., 1995; Lázaro et al., 2003). Enzyme supplementation (ES), however, reduces or even eliminates the negative effects of NSP on nutrient digestibility and egg production, improving the feeding value of barley (Gracia et al., 2003; Saki et al., 2010).

Ingredient composition and size of the screen used to grind the cereals affect the structure and particle size of the diet. Mechanoreceptors located in the beak detect differences in texture which might affect feed intake (FI) and performance in broilers (Amerah et al., 2007; Jiménez-Moreno et al., 2016) and laying hens (Safa et al., 2009; Pérez-Bonilla et al., 2014). A reduction in particle size facilitates the contact between nutrients and endogenous enzymes, improving nutrient digestibility (Parsons et al., 2006). However, fine particles result often in a less developed gizzard and GIT (Hetland et al., 2002) which might affect poultry performance (Nir et al., 1994a; González-Alvarado et al., 2007). On the other hand, when the diets are coarsely ground, bird selection increases which may affect feed efficiency (Nir et al., 1994b). These opposite effects might counteract each other and the final effect on hen productivity might depend on factors such as the characteristic and the ingredient composition of the experimental diets. However, no research is available comparing the...
influence of corn or barley of diets ground with different screen size on productive performance of hens.

Body measurements are useful criteria to predict body composition and the size and future performance of birds, including broilers (Van Roovert-Reijrink, 2013), pullets (Guzmán et al., 2015), and laying hens (Guzmán et al., 2016). However, the information available on the effects of the particle size and the characteristics of the diet on these variables in laying hens is scarce.

The hypothesis of this research was that screen size used to grind the cereal could affect FI, GIT development, and egg production in laying hens, effects that could vary depending on the cereal. The objective of this research was to compare the effects of the screen size used to grind the cereal on egg production, egg quality, GIT traits, and body measurements of brown-egg laying hens fed diets based on corn or barley.

**MATERIALS AND METHODS**

**Husbandry, Diets, and Experiment Design**

The procedures described in this research were approved by the Animal Ethics Committee of Universidad Politécnica de Madrid, in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007). In total, 500 Lohmann Brown Classic hens were housed at 16 wk of age in an environmentally controlled barn. Hens were weighed individually at 17 wk of age (1,407 ± 31.9 g BW) and randomly allotted in groups of 10 into 50 enriched cages (40 cm x 80 cm x 68 cm; Facco S.p.A., Padova, Italy) with similar average BW per cage. The cages were provided with an open trough feeder and 2 low pressure nipple drinkers. Room temperature was recorded daily throughout the experiment, with a maximum average value of 26 ± 3°C (July, first period of the experiment) and a minimum of 21 ± 3°C (February, last period of the experiment). Feed in mash form and water were provided for ad libitum consumption. The lighting program consisted in 16 h of light per day throughout the experiment.

Two diets with similar $\text{AME}_\text{eq}$ (2,750 kcal/kg) and CP (17.5%) content but differing in the main cereal used (corn vs. barley) were formulated. The diets met the nutrient requirements of laying hens as recommended by FEDNA (2008). All diets were supplemented with the same dose of a commercial enzyme complex with xylanase and $\beta$-glucanase activity (Roxzyme, DSM S.A., Madrid, Spain). In the formulation of the diets it was accepted that the inclusion of the enzyme complex increased the $\text{AME}_\text{eq}$ content of the barley by 2% (from 2,800 to 2,856 kcal/kg) but had no effects on the energy content of any of the other ingredients of the diet (FEDNA, 2010). Before feed manufacturing, the batch of each of the 2 cereals was divided into 5 portions, and each portion was ground using a horizontal hammer mill (Mecafa S.A., Ciudad Real, Spain) provided with a 4, 6, 8, 10, or 12 mm screen and then included in their respective experimental diets.

The experiment was conducted as a completely randomized design with 10 diets in a factorial arrangement with 2 main cereals and 5 screen size used to grind the cereal. Each treatment was replicated 5 times and the experimental unit was the cage with 10 hens for all measurements.

**Laboratory Analysis**

Representative samples of the feeds were ground using a laboratory mill (Retsch Model Z-I, Stuttgart, Germany) equipped with a 1-mm screen and analyzed for moisture by the oven-drying (method 930.15), total ash in a muffle furnace (method 942.05), and nitrogen by Dumas (method 985.06) using a Leco analyzer (Model FP-528, Leco Corp., St. Joseph, MI) as indicated by AOAC International (2005). Ether extract, gross energy, and the neutral detergent fiber were determined as indicated by Pérez-Bonilla et al. (2011) and expressed on an ash-free basis. The LNL content of the diets was determined by gas-liquid chromatography (GC-14B, Shimadzu, Kyoto, Japan) as shown by Grobas et al. (1999a) and the amino acid (AA) content by ion-exchange chromatography (Hewlett-Packard 1100, Waldbronn, Germany) after acid hydrolysis, as indicated by de Coca-Sinova et al. (2008). Particle size distribution and mean particle size of the diets, expressed as the geometric mean diameter (GMD) and geometric standard deviation (log normal SD; GSD), were determined in 100 g samples using a shaker equipment (Retsch, Stuttgart, Germany) provided with 8 sieves ranging in mesh from 5,000 to 40 µm as indicated by ASAE (1995). All the analyses were conducted in duplicate except for the GMD of the diets that was determined in triplicate. The ingredient composition and chemical analyses of the diets and their GMD and particle size distribution are shown in Tables 1 and 2 and Figure 1, respectively.

**Measurements**

**Hen Productivity.** Feed disappearance, egg production, and BW of the hens were determined by cage at 4 wk intervals. Any mortality was recorded and weighed as produced. All eggs produced the last 2 d of each week were weighed, and the average value of the 4 weeks was used to estimate egg weight by period. From these data, ADFI, egg production, egg weight, egg mass, feed conversion ratio (FCR) per kilogram and per dozen of eggs, and BW gain were calculated by period as well as for the entire experiment (17 to 49 wk of age).

**Egg Quality.** The number of undergrades, dirty, broken, and shell-less eggs was recorded daily by replicate in all eggs produced. An egg was considered as dirty when a spot of any kind or size was detected on the shell. Other egg quality traits, including yolk color,
thickness was measured at the two pole ends and at the
the last 2 d of each of the 8 experimental periods. Haugh
the 5 diets, with a CV below 5% in all cases.
Within each cereal, the determined chemical analyses were similar for
amin E (dl-a-tocopheryl acetate), 10 mg; vitamin Bl, 1.3 mg; vitamin
acid, 1 mg; biotin, 13 meg; choline (choline chloride), 250 mg; manganese
(1)
0.3 mg; Roxazyme, 200 mg [1,600 U of endo-1,4- /3-glucanase (EC 3.2.1.4),
(3)
3,600 U of endo-1,3 (4)-/3-glucanase (EC 3.2.1.6), and 5,200 U of endo-
1,4-/3-xylanase (EC 3.2.1.8)] supplied by DSM S.A., Madrid, Spain;
S.A., Tarragona, Spain), 60 mg.

1Provided the following (per kilogram of diet): vitamin A (trans-
yretinyl acetate), 10,000 IU; vitamin D3 (cholecalciferol), 3,750 IU; vi-
tamin E (dl-a-tocopheryl acetate), 10 mg; vitamin Bl, 1.3 mg; vitamin
B2, 5 mg; vitamin B6, 2 mg; vitamin B12 (cyanocobalamin), 13 mg;
niacin, 25 mg; pantothenic acid (d-calcium pantothetone), 10 mg; foli-
acid, 1 mg; biotin, 13 mg; choline (d-choline chloride), 250 mg; managnese
(1)
8 mg; zinc (ZnO), 63 mg; iron (FeSO4.H2O), 38 mg; copper
(CuSO4 · 5H2O), 8 mg; iodine (Cu[IO3]2), 0.7 mg; selenium (Na2SeO3),
0.3 mg; Rozaxyme, 200 mg [1,600 U of endo-1,3-1,4-/3-glucanase (EC 3.2.1.4),
3,600 U of endo-1,3 (4)-/3-glucanase (EC 3.2.1.6), and 5,200 U of endo-
1,4-/3-xylanase (EC 3.2.1.8)] supplied by DSM S.A., Madrid, Spain;
S.A., Tarragona, Spain), 60 mg.

2According to FEDNA (2010).

Figure 1. Particle size distribution of the corn (A) and barley
(B) diets. The percentage of particles smaller than 160 \( \mu m \) and big-
ger than 2,500 \( \mu m \) were negligible for all diets. Screen size (mm)

**Table 1.** Ingredient composition and chemical analyses (% as
fed basis, unless otherwise indicated) of the experimental diets.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Corn</th>
<th>Barley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>45.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Barley</td>
<td>8.8</td>
<td>45.0</td>
</tr>
<tr>
<td>Soybean meal, 47% CP</td>
<td>20.8</td>
<td>25.2</td>
</tr>
<tr>
<td>Sunflower meal, 34% CP</td>
<td>10.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Soy oil soapstock</td>
<td>4.7</td>
<td>5.3</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.49</td>
<td>1.42</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>8.2</td>
<td>8.36</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>DL-methionine, 99%</td>
<td>0.14</td>
<td>0.17</td>
</tr>
<tr>
<td>Vitamin and mineral premix &amp;( ^{1,2} )</td>
<td>0.50</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**Table 2.** Geometric mean diameter (GMD\(^1 \pm \) GSD\(^2 \), \( \mu m \)) of the experimental diets.

<table>
<thead>
<tr>
<th>Screen size (mm)</th>
<th>Corn</th>
<th>Barley</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>960 ± 2.07</td>
<td>1,045 ± 2.04</td>
<td>1,003 ± 2.04</td>
</tr>
<tr>
<td>6</td>
<td>1,041 ± 2.12</td>
<td>1,165 ± 2.07</td>
<td>1,103 ± 2.10</td>
</tr>
<tr>
<td>8</td>
<td>1,180 ± 2.20</td>
<td>1,335 ± 2.06</td>
<td>1,258 ± 2.13</td>
</tr>
<tr>
<td>10</td>
<td>1,232 ± 2.21</td>
<td>1,458 ± 2.08</td>
<td>1,345 ± 2.15</td>
</tr>
<tr>
<td>12</td>
<td>1,302 ± 2.20</td>
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</tr>
</tbody>
</table>

1GMD = Geometric mean diameter.
2GSD = Geometric standard deviation (log normal SD).

**Haugh units**, and shell thickness were measured in 12 fresh eggs collected randomly from each cage replicate the last 2 d of each of the 8 experimental periods. Haugh units and yolk color (Roche Color Fan) were measured using a multitester equipment (QCMSystem, Technical Services and Supplies, Dunnington, York, UK). Shell thickness was measured at the two pole ends and at the middle section of the egg shell with a digital micrometer (model IT-014UT, Mitutoyo, Kawasaki, Japan) and the average of the 3 measurements of each of the 12 eggs was used for further analyses. Shell strength and shell color were measured in 6 eggs collected randomly from each replicate the same days. Egg shell strength, expressed in g/cm\(^2\), was evaluated applying increased pressure to the broad pole of the egg using a press meter (Egg Force Reader, SANOVO Technology A/S, Odense, Denmark). Shell color was measured using a Minolta colorimeter (Chroma Meter Model CR-200, Minolta Corp., Ramsey, NJ) and the Hunter color values, L\( ^{+} \) (lightness), a\( ^{+} \) (green to red), and b\( ^{+} \) (blue to yellow), were recorded.

**Gastrointestinal Tract Traits and Body Measurements.** At 49 wk of age, after the corresponding performance control, 2 hens per replicate were randomly selected, weighed individually, and euthanized by CO\( _2 \) inhalation. The digestive tract, from the post-crop esophagus to the cloaca, including the digesta content and the annex organs (liver, pancreas, and spleen) was
removed and weighed. Then, the proventriculus, gizzard, and the liver were excised and weighed and the weight expressed relative to BW. In addition, the gizzard was emptied from any digesta content, cleaned, dried with desiccant paper, and weighed again. The weight of the digesta content of the gizzard was expressed relative to the full organ weight (%). Gizzard pH was measured in situ in all these hens in duplicate using a digital pH meter fitted with a fine tip glass electrode (model 507, Crison Instruments S.A., Barcelona, Spain) as indicated by Jiménez-Moreno et al. (2009a). The length of the duodenum (from the gizzard to the pancreo-biliary ducts), jejunum (from the pancreo-biliary ducts to the Meckel’s diverticulum), ileum (from the Meckel’s diverticulum to the ileocecal valve), and the two ceca (from the ostium to the tip of the right and left ceca) were measured on a glass surface using a flexible tape with a precision of 1 mm. The length of the small intestine was determined by adding that of the duodenum, jejunum, and ileum. In addition, hen length, from the tip of the beak to the end of the longest phalanx, was measured in extended birds as indicated for the small intestine and body mass index (BMI) was estimated. Also, the length and diameter of the tarsus of these hens were measured with the aid of a digital caliper and expressed relative to BW. The average value of the 2 hens was used for further statistical analysis.

Statistical Analysis

Data were analyzed as a completely randomized design with 10 treatments arranged as a $2 \times 5$ factorial with main cereal of the diet and screen size used as main effects using the MIXED procedure of SAS (SAS Institute, 2004). In addition, treatment sum of squares of the effects of screen size on all variables studied was partitioned into the linear and quadratic components. Also, a non-orthogonal contrast comparing the effects of the average of the 2 diets based on corn or barley ground through a 4-mm screen and the average of all the other diets (ground through a 6- to 12-mm screen size) was included in the statistical analysis. The Pearson correlation analyses (SAS Institute, 2004) was used to study the effect of diet on the relation between BW and BMI, body length, tarsus length, and tarsus diameter of the hens at 49 wk of age. Results in tables are presented as means and differences were considered significant at $P < 0.05$.

RESULTS

The GMD was higher for the barley than for the corn diets and increased as the screen size used to grind the cereals increased (Table 2). The GSD, however, was higher for the corn than for the barley diets and increased with the size of the screen used.

**Hen Productivity and Egg Quality.**

Mortality was 0.6% and was not related to any treatment (data not shown). No interactions between main cereal of the diets and the screen size used were observed for any of the traits studied and therefore, only main effects are discussed.

**Main Cereal of the Diet.** For the entire experimental period, none of the production traits studied, except egg weight that tended ($P = 0.092$) to increase with barley, were affected by the main cereal of the diet (Table 3). In fact, egg production, ADFI, and BW gain were not affected by the main cereal in any of the periods studied. Egg mass, however, increased with barley feeding in some of the periods considered (Figure 2). The main cereal of the diet did not affect any of the egg quality traits studied (dirty, broken, and shell-less eggs, Haugh units, and strength, thickness, and color of the shell) (Table 3).

**Screen Size.** From 17 to 49 wk of age, the screen size used to grind the cereal did not affect any of the production or egg quality traits studied, except for FCR that tended ($P = 0.081$) to be higher in hens fed the 4-mm screen ground diet as compared with the average of hens fed the 6- to 12-mm screen ground diets (Table 3). Egg production, egg mass, and FCR were affected by the screen size used to grind the cereal in some of the periods considered (Figure 3). The screen size used to grind the cereal did not affect any of the egg quality traits studied.

**Gastrointestinal Tract Traits and Body Measurements**

**Main Cereal of the Diet.** At the end of the experiment, the GIT (126 vs. 122 g/kg BW; $P < 0.05$) and the gizzard (29.1 vs. 27.7 g/kg BW; $P < 0.05$) were heavier in hens fed barley than in hens fed corn. Gizzard pH, gizzard content, and body measurements traits, however, were not affected by the main cereal of the diet (Tables 4 and 5).

**Screen Size.** The relative weight of the full gizzard ($P < 0.01$), GIT ($P = 0.089$), and liver ($P = 0.056$) increased linearly as the screen size used increased (Table 4). Body measurements, however, were not affected by the screen size (Table 5).

A significant positive relation between BW of the hens and BMI ($P < 0.001$), body length ($P < 0.05$), and tarsus length and diameter ($P < 0.01$) were observed at 49 wk of age (Table 6).

**DISCUSSION**

The chemical composition of the experimental diets was close to expected values, confirming that the ingredients were mixed correctly. The GMD was greater for the barley than for the corn diets, in agreement with data of Pérez-Bonilla et al. (2011). The glumes
of the barley grains are coarse and flexible and barley has a higher NDF content than corn. Consequently, the chances of the fiber fraction of barley passing intact through the screen increase, resulting in an increase in the GMD of the diet. In contrast, the GSD was higher for the corn than for the barley diets, in agreement with data of Pérez-Bonilla et al. (2014) comparing different types of grinding in diets for laying hens. The data suggest that the structure of the feed (mean particle size and uniformity) depends not only on the size of the screen but also on the characteristics of the grain used. As expected, the GMD of the diets increased as the screen size increased. In fact, the GMD of the diet (average of the corn and barley diet) increased by 42.3%
(1,003 to 1,427 μm) as the size of the screen increased from 4 to 12 mm. The GSD tended to increase with increases in screen size.

**Hen Productivity and Egg Quality**

**Main Cereal of the Diet.** For the entire experimental period, the main cereal of the diet did not affect egg production, ADFI, FCR, or egg quality traits, results that agree with previous studies (Safaa et al., 2009; Pérez-Bonilla et al., 2011). In contrast, Coon et al. (1988) reported higher ADFI but reduced feed efficiency in hens fed barley than in hens fed corn but in this research the diets were not supplemented with enzymes. Yu et al. (1998) reported also better growth performance of broilers when fed a corn diet than when fed a barley diet supplemented with enzymes. The chemical

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*Table 4. Influence of the main cereal of the diet and the screen size used to grind the cereal on the relative weight (g/kg full BW) and length (cm/kg full BW) of the gastrointestinal tract (GIT) traits and gizzard content (% organ weight) and pH of the hens at 49 wk of age.*

<table>
<thead>
<tr>
<th>Cereal</th>
<th>Screen size (mm)</th>
<th>SD²</th>
<th>Probability³,⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td></td>
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<td>10</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full proventriculus</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full gizzard</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIT relative length</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jejunum</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ileum</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small intestine</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cecum</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gizzard content</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Gizzard pH</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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³Within a row, means without a common superscript differ significantly.
²Average of 2 hens per replicate chosen at random.
²5 replicates for the main cereal and 10 replicates for the screen size.
1) Effect of the main cereal; 2) linear effect of the screen size; 3) comparison between the average of the 2 diets ground at 4 mm vs. the average of all the other diets (ground at 6 to 12 mm).
The interactions between main effects, and the quadratic effect of the screen size were not significant for all variables (P > 0.1).
⁴From the post-crop esophagus to the cloaca, including the digesta content and the annex organs (liver, pancreas, and spleen).
composition and nutritive value of barley is less uniform than that of corn because of its higher content in NSP (Jacob and Pescatore, 2012). Consequently, the use of corn favors poultry performance as compared with the use of barley. However, the potential differences in nutritive value among the two cereals might be reduced and even disappear when the barley diets are supplemented with adequate exogenous enzymes (Lázaro et al., 2003; Gracia et al., 2003; Pérez-Bonilla et al., 2011), as occurred in the current experiment. On the other hand, moisture content is more variable in corn than in barley (FEDNA, 2010). Consequently, FCR could increase in those flocks fed diets based on corn with a higher moisture content.

Eggs tended to be heavier in hens fed barley than in hens fed corn. The information available on the effects of the main cereal of the diet on egg weight is limited and conflicting, with reports showing higher (Nahashon et al., 1994; Lázaro et al., 2003), similar (Brufau et al., 1994; Pérez-Bonilla et al., 2011), or reduced (Coon et al., 1988) egg weight with barley. Total sulfur AA, LNL, and supplemental fat are the main dietary factors affecting egg weight in commercial layer operations (Grobas et al., 1999b; Safaa et al., 2008). In the current research, the contents in TSAA and all others indispensable AA of the 2 diets was above recommendations (FEDNA, 2008; Lohmann, 2014) and the LNL content was also in excess of hen requirements for optimal hen productivity (Grobas et al., 1999a). Consequently, no effect of an excess of TSAA or LNL on egg production was expected. On the other hand, the level of supplemental fat was higher for the barley than for the corn diet (5.3 vs. 4.7%) which might have resulted in the small increase in egg weight observed (Pérez-Bonilla et al., 2011).

**Screen Size.** In the current research, FCR was not affected by the screen size used to grind the cereal. Most published research, however, showed that hens had a preference for larger feed particles and that fine grinding reduced voluntary FCR in laying hens (Safaa et al., 2009). In this respect, Safaa et al. (2009) observed a 2.5% greater FCR in hens fed corn or wheat ground with a 10-mm screen than in hens fed the same cereals ground with a 6-mm screen. Moreover, many laying hens management guides (i.e., Lohmann, 2014) recommend the use of coarse texture diets when the objective is to maximize FCR. In this respect, Nir et al. (1994b) indicated that coarse particles are better adapted to the size of the beak than fine particles. The lack of effect of the screen size used to grind the cereal on FCR in the hens observed in the current experiment is not consistent with most published research and we do not have a clear explanation for the difference in behavior observed. In our research, the proportion of very fine particles (<315 μm) was low in all the diets (between 7.9% for the 4-mm screen diet and 4.0% for the 12-mm screen diet) which might have reduced the negative impact of fine grinding on FCR. In addition, all diets included extra amounts of supplemental fat (4.7 to 5.3%) which could have reduce dust formation and hen selection. The data suggest that laying hens adapt well their voluntary FCR to diets varying widely in particle size, provided that the proportion of very fine particles is limited and that some extra supplemental fat is included in the diet.

In the current research, FCR from 17 to 49 wk of age tended to be reduced in hens fed the 4-mm screen ground diets as compared with the average of the hens fed the other diets. Also, a reduction in egg production and egg mass was observed in hens fed the 4-mm screen ground diet in some of the feeding periods. The available data on the effects of coarse particle size on nutrient digestibility and feed efficiency in poultry are contradictory with some research showing an improvement (Nir et al., 1994a,b; Röhe et al., 2014; Ruhnke et al., 2015) and some research showing no effects (Mackasac and Anderson, 2007; Safaa et al., 2009). Coarsely ground diets have a stimulating effects of the development of the GIT, improving gizzard and

### Table 5. Influence of the main cereal of the diet and the screen size used to grind the cereal on the body mass index (BMI, g/body length$^2$) and the relative length$^1$ (cm/kg full BW) of the hens and tarsus at 49 wk of age.

<table>
<thead>
<tr>
<th>Cereal</th>
<th>Screen size (mm)</th>
<th>BMI</th>
<th>Hen length</th>
<th>Tarsus length</th>
<th>Tarsus diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Corn</td>
<td>0.400</td>
<td>0.407</td>
<td>0.399</td>
<td>0.417</td>
<td>0.499</td>
</tr>
<tr>
<td>Barley</td>
<td>37.6</td>
<td>37.4</td>
<td>37.8</td>
<td>36.7</td>
<td>37.4</td>
</tr>
<tr>
<td>Cereal</td>
<td>4.70</td>
<td>4.73</td>
<td>4.71</td>
<td>4.69</td>
<td>4.65</td>
</tr>
<tr>
<td></td>
<td>0.720</td>
<td>0.739</td>
<td>0.721</td>
<td>0.730</td>
<td>0.734</td>
</tr>
<tr>
<td></td>
<td>0.186</td>
<td>0.311</td>
<td>0.238</td>
<td>0.271</td>
<td>0.304</td>
</tr>
</tbody>
</table>

1. Average of 2 hens per replicate chosen at random (BW are shown in Table 4).
2. Probability

### Table 6. Correlations between BW of the hens$^1$ at 49 wk of age and BMI$^2$, body length, and tarsus length and diameter.

<table>
<thead>
<tr>
<th></th>
<th>BMI (g/cm$^2$)</th>
<th>Body length (cm)</th>
<th>Tarsus length (cm)</th>
<th>Tarsus diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hen length</td>
<td>0.6829</td>
<td>0.2449</td>
<td>0.3624</td>
<td>0.3602</td>
</tr>
<tr>
<td>Probability</td>
<td>&lt;0.001</td>
<td>0.048</td>
<td>0.010</td>
<td>0.010</td>
</tr>
</tbody>
</table>

1. Average of 2 hens per replicate chosen at random (BW are shown in Table 4).
2. Body mass index.
pancreas weight (Röhe et al., 2014) and starch digestibility (Ruhnke et al., 2015). Fine particles, however, are not retained for long in the gizzard, which reduce gizzard activity and nutrient digestibility in poultry (Nir et al., 1994a; Mateos et al., 2012). In this respect, Amerah et al. (2007) suggested that coarse particles increase the antiperistaltic movements in the GIT of the birds, leading to better mixing and utilization of the nutrients. Also, a reduction in particle size increases the surface of contact between nutrients and endogenous enzymes which might favor nutrient digestibility (Amerah et al., 2007). On the other hand, the vitamins, minerals, and crystalline AA might concentrate in the fine fraction of the diet. Consequently, a preference for coarse particles affects the balance of nutrients ingested, which eventually might reduce egg weight and hen production. These opposite effects of particle size on feed efficiency might counteract each other, and the final outcome might depend on factors such as ingrediant composition of the diet and age, management, and health status of the birds.

The screen size used to grind the cereal did not affect any of the egg quality traits studied. Most published data (Saldaña et al., 2009) do not show any influence of particle size on egg traits, including different measurements of shell and albumen quality. Moreover, Hafeez et al. (2015) indicated that differences in albumen weight and shell quality due to particle size were of little practical interest. Also, these authors recorded that the proportion of shell, yolk, and albumen of the eggs were not affected by particle size. Consequently, the screen size used to grind the cereal can be modified according to specific requirements without any effect on egg quality.

Gastrointestinal Tract Traits and Body Measurements

Main Cereal of the Diet. None of the GIT traits studied was affected by the main cereal of the diet, except the gizzard that was heavier in hens fed barley. The GMD of the diets was greater for the barley than for the corn diets and coarser particles are associated with greater development of the gizzard in broilers (Nir et al., 1994a) and pullets (Saldaña et al., 2015). Also, the NDF content was higher (11.3 vs. 10.4%) in the barley than in the corn diets and consequently, barley feeding might stimulate more gizzard and GIT development than corn feeding (González-Alvarado et al., 2007; Mateos et al., 2012; Sacranie et al., 2012).

Screen Size. None of the GIT traits studied were affected by the screen size, except gizzard weight that increased as the screen size used to grind the cereal increased, in agreement with the data of Röhe et al. (2014). Fine particles pass faster through the upper part of the GIT than coarse particles (Hetland et al., 2002) and consequently, gizzard size and function will increase with coarse grinding (Jiménez-Moreno et al., 2009b; Mateos et al., 2012).

Body mass index, body length, and tarsus length and diameter are used to estimate the BW and size of broilers (Van Roovert-Reijrink, 2013), pullets (Saldaña et al., 2015), and laying hens (Guzmán et al., 2016). In the current research, none of these traits was affected by the main cereal of the diet or the screen size used to grind the cereal, results that are consistent with the lack of effect of the characteristics of the diets on BW gain. On the other hand, the significant positive relation detected between BW and BMI, body length, and tarsus length and diameter, confirm that these traits can be used as good estimators of BW in hens.

In summary, barley can substitute up to 45% of the corn in diets for laying hens provided that the feed is supplemented with adequate enzymes. The size of the screen used to grind the cereal had no impact on hen productivity or egg quality provided that the proportion of very fine particles (<160 μm) remains low and that the diets are supplemented with fat. Gizzard development, however, improves as the screen size increases. The data suggest that corn and barley ground through a 6 to 10-mm screen can be used indistinctly in diets for laying hens, without any effect on hen performance.

REFERENCES


