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# Influence of the main cereal in the diet and particle size of the cereal on productive performance and digestive traits of brown-egg laying pullets☆

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ABSTRACT

A total of 864 brown-egg laying pullets was used to study the effects of the main cereal of the diet (500 g maize or wheat/kg) and particle size of the cereal (hammer milled to pass through a 6-, 8-, and 10-mm screen) on growth performance and digestive traits from 1 to 120 d of age. Each of the six treatments was replicated six times (24 pullets per replicate). Type of cereal did not affect pullet performance at any age. From 1 to 45 d of age, body weight (BW) gain was increased ($P<0.001$) and feed conversion ratio was improved ($P<0.05$) as the particle size of the cereal was reduced, but no effects were observed after this age. At 45 d of age, pullets fed maize tended ($P<0.10$) to have a heavier relative weight (RW, g/kg BW) of the total digestive tract and proventriculi and a higher relative length (RL, cm/kg BW) of the small intestines (SI) than pullets fed wheat. Also at this age, the RW of the digestive tract increased ($P<0.05$) with increases in the particle size of the cereal. At 120 d of age, dietary treatment did not affect the RW of any of the organs studied or gizzard pH but the RL of the SI was higher ($P<0.05$) for pullets fed wheat than for pullets fed maize. Also, the RL of the SI was reduced ($P<0.05$) as the particle size of the cereal increased. We conclude that 500 g wheat/kg can be included in pullet feeds from 1 to 120 d of age, and that particle size of the cereal affects pullet performance during the first 45 d of life but not thereafter. Therefore, it is recommended to grind the cereal used in this period with a screen size of no more than 8 mm.

## 1. Introduction

Maize and wheat are the main energy sources used in poultry diets worldwide. Wheat has more protein but also more fibre and less apparent metabolizable energy nitrogen corrected (AMEn) than maize. The chemical composition of maize is quite uniform but that of wheat varies with cultivar, agronomic practices, weather conditions and length of storage

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*Abbreviations:* ADFI, average daily feed intake; AMEn, apparent metabolizable energy nitrogen corrected; BW, body weight; BWG, body weight gain; Ca, calcium; DM, dry mater; FCR, feed conversion ratio; GIT, gastrointestinal tract; GMD, geometric mean diameter; PSI, particle size index; P, phosphorus; RL, relative length; RW, relative weight; SCWL, Single Comb White Leghorn; SI, small intestine; WHC, water holding capacity.

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(Pirgozliev et al., 2003; Gutiérrez del Alamo et al., 2008). In addition, the nutritional value of the wheat depends on factors such as hardness of the endosperm, water holding capacity (WHC) and composition of the carbohydrate fraction (Carré et al., 2002; Pirgozliev et al., 2006; Péron et al., 2007). The effects of using wheat in substitution of maize in poultry diets have been studied in detail in broilers (Ruiz et al., 1987; Mathlouthi et al., 2002; Amerah et al., 2008), turkeys (Crouch et al., 1997; Persia et al., 2002) and laying hens (Lázaro et al., 2003; Safaa et al., 2009). In general, the data indicate that wheat can be used in substitution of maize in poultry diets without any significant impact on productive performance. However, the information available comparing wheat and maize in pullet diets is very scarce.

Grinding of the cereal facilitates particle prehension by the bird and might improve feed intake (Picard et al., 1997). Huang and De Beer (2010) indicated that young broilers (1–10 d of age) showed preference for feed particles between 860 μm and 2000 μm and that they rejected particles smaller than 860 μm and bigger than 3180 μm. Nir et al. (1994) reported that the best performance of broilers fed mash diets was obtained when the geometric mean diameter (GMD) of the particles of the grain was between the 1130 and 1230 μm independent of the cereal used (maize, wheat or sorghum). These authors found lower feed intake with particles smaller than 570 μm or larger than 2100 μm. Rodgers et al. (2009) observed better performance in broilers from 11 to 35 d of age when the sorghum used as the main ingredient of the diet was ground through a 3-mm screen than when fed as whole grain or ground to pass through a 1-mm screen. However, Amerah et al. (2008) reported higher average daily feed intake (ADFI), although poorer feed conversion ratio (FCR), in 21-d-old broilers fed pelleted diets based on fine maize (1-mm screen) than in those fed coarse maize (7-mm screen). In brown-egg laying hens, Safaa et al. (2009) reported similar productive performance in hens fed diets based on 10-mm ground maize or wheat (GMD of 1165 μm and 1250 μm, respectively) than in hens fed 6-mm ground cereals (GMD of 774 μm and 922 μm, respectively). Similarly, Deaton et al. (1989) did not observe any difference in productive performance when Single Comb White Leghorn (SCWL) hens were fed maize based diets with a GMD varying between 873 and 1501 μm. However, the information available about the influence of particle size of the cereal on performance of pullets is very limited.

Diet composition, feed form and particle size affect the development of the gastrointestinal tract (GIT) in poultry (Zang et al., 2009; González-Alvarado et al., 2010). For example, Nir et al. (1994) observed a heavier relative weight (RW, g/kg of body weight) of the gizzard in 21-d-old broilers fed maize than in those fed wheat. In 45-d-old pullets fed diets based on maize or wheat, Frikha et al. (2009) observed a higher RW of the gizzard with mash than with pellets. With respect to particle size, Amerah et al. (2008) reported heavier gizzards in 21-d-old broilers fed coarse maize (7-mm screen) than in those fed fine maize (1-mm screen). However, no differences were detected between coarse and fine grinding when the diets were based on wheat.

The hypothesis of this research was that 500 g maize could be substituted by 500 g wheat/kg as the main cereal in pullets diets without any loss in performance, and that coarse grinding of the cereal could reduce ADFI and productive performance of pullets during the first wk of life. Also, it was hypothesized that the development of the GIT, especially that of the gizzard, could benefit from coarse grinding of the cereal.

The aim of this study, therefore, was to determine the influence of the main cereal (maize *vs.* wheat) of the diet when ground to pass through a 6-, 8- or 10-mm screen on growth performance and GIT development of brown-egg laying pullets from 1 to 120 d of age.

## 2. Materials and methods

### *2.1. Husbandry and experimental design*

All the experimental procedures described in this research were approved by the Animal Ethics Committee of Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals for scientific purposes (Boletín Oficial del Estado, 2005).

A total of 864 one-day-old Hy-Line Brown pullets with an initial body weight (BW) of 37.1 ± 2.3 g was obtained from a commercial hatchery (Avigan Terralta, Tarragona, Spain) and used in this trial. The pullets were placed in a windowless environmentally controlled room with free access to feed and water. Room temperature was maintained at 32 °C during the first three days of life and then reduced gradually until reaching 21 °C at 5 wk of age. Birds were debeaked at 10 d of age and vaccinated against main diseases (Infectious bronchitis disease, Infectious bursal disease, Newcastle disease, Laryngotracheitis, *Mycoplasma* and *Salmonella* spp.) according to commercial practices. The pullets were kept on a 23 h/day light program for the first wk of life and then, light was decreased 2 h/wk until reaching 11 h at 7 wk of age. At arrival to the research farm, the birds were weighed individually and stratified by BW into three groups of 288 pullets each. Thirty-six uniform groups of 24 pullets each (eight from each BW group) were formed and two adjacent cages (12 pullets per cage) formed the experimental unit. Each cage (Zucami, Pamplona, Spain; 0.50 m × 0.76 m) was provided with an open trough feeder and two low pressure nipple drinkers. Six replicates (24 pullets each) were randomly assigned to each of the six experimental diets.

### *2.2. Feeding program and experimental diets*

The feeding program consisted of three feeds that were supplied in mash form from 1 to 45 d, 46 to 85 d and 86 to 120 d of age. Within each age period, diets were formulated to have similar nutrient content (Fundación Española para el Desarrollo

**Table 1**
Ingredient composition and calculated analysis of the experimental diets (g/kg, as-fed basis unless otherwise indicated).

| Item | 1–45 d | | 46–85 d | | 86–120 d | |
|---|---|---|---|---|---|---|
| | Maize | Wheat | Maize | Wheat | Maize | Wheat |
| Ingredient | | | | | | |
| Maize[a] | 500.0 | – | 500.0 | – | 500.0 | – |
| Wheat[b] | – | 500.0 | – | 500.0 | – | 500.0 |
| Barley | 132.7 | 195.2 | 170.6 | 233.7 | 145.8 | 206.6 |
| Rice bran | – | – | – | – | 60.0 | 60.0 |
| Soybean meal, 440 g/kg CP[c] | 312.0 | 253.5 | 179.7 | 121.2 | 136.7 | 80.9 |
| Sunflower meal, 320 g/kg CP | – | – | 100.0 | 100.0 | 103.6 | 103.1 |
| Soybean oil | 18.7 | 13.4 | 14.0 | 8.8 | 7.4 | 1.9 |
| Dicalcium phosphate | 7.7 | 6.5 | 5.2 | 3.7 | 3.7 | 2.5 |
| Calcium carbonate | 18.3 | 19.2 | 20.0 | 21.0 | 25.2 | 26.1 |
| Sodium chloride | 3.5 | 3.5 | 3.3 | 3.3 | 3.2 | 3.2 |
| Vitamin and mineral premix[d] | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Methionine hydroxy analogue, 880 g/kg | 2.0 | 2.2 | 1.7 | 1.5 | 0.3 | 0.5 |
| L-Lysine–HCl, 780 g/kg | 0.8 | 1.7 | 1.5 | 2.3 | 0.1 | 0.8 |
| L-Threonine, 980 g/kg | 0.3 | 0.8 | – | 0.5 | – | 0.4 |
| Sepiolite[e] | – | – | – | – | 10.0 | 10.0 |
| Calculated analysis | | | | | | |
| ME (MJ/kg) | 12.1 | 12.1 | 11.7 | 11.7 | 11.4 | 11.4 |
| Crude fibre | 36.0 | 37.1 | 52.8 | 53.9 | 54.0 | 54.9 |
| Digestible lysine | 9.3 | 9.3 | 7.6 | 7.6 | 5.8 | 5.8 |
| Digestible methionine | 4.5 | 4.5 | 4.1 | 3.8 | 2.8 | 2.8 |
| Digestible methionine + cystine | 7.2 | 7.5 | 6.6 | 6.6 | 5.1 | 5.4 |
| Digestible threonine | 6.3 | 6.3 | 5.1 | 5.1 | 4.7 | 4.7 |
| Digestible tryptophan | 1.9 | 2.0 | 1.6 | 1.7 | 1.5 | 1.6 |

[a] Determined chemical composition ($n = 3$): 875 g dry matter, 73 g crude protein, 38 g ether extract and 13 g total ash/kg of diet. The water holding capacity was 2.05 L/kg DM and the particle size index was 2.0%.

[b] Determined chemical composition ($n = 3$): 896 g dry matter, 112 g crude protein, 23 g ether extract and 15 g total ash/kg of diet. The water holding capacity was 2.75 L/kg DM and the particle size index was 14.5%.

[c] Crude protein.

[d] Provided the following (per kg of diet): vitamin A (trans-retinyl acetate), 9000 IU; vitamin D3 (cholecalciferol), 2600 IU; vitamin E (DL-α-tocopheryl acetate), 16 mg; vitamin B1, 1.6 mg; vitamin B2, 6.5 mg; vitamin B6, 2.2 mg; vitamin B12 (cyanocobalamin), 0.015 mg; vitamin $K_3$, 2.5 mg; choline (choline chloride), 300 mg; nicotinic acid, 30 mg; pantothenic acid (D-calcium pantothenate), 10 mg; folic acid, 0.6 mg; D-biotin, 0.07 mg; manganese (MnO), 70 mg; zinc (ZnO), 60 mg; iron ($FeSO_4 \cdot H_2O$), 40 mg; copper ($CuSO_4 \cdot 5H_2O$), 7 mg; iodine [$Ca(IO_3)_2$], 0.7 mg; selenium ($Na_2SeO_3$), 0.3 mg; Roxazyme (DSM S.A., Madrid, Spain), 200 mg [1600 U Endo-1.4-β-glucanase (EC 3.2.1.4); 3600 U Endo-1.3(4)-β-glucanase (EC 3.2.1.6), and 5200 U Endo-1.4-β-xylanase (EC 3.2.1.8)]; Natuphos 5000 (BASF Española S.A., Tarragona, Spain), 60 mg (400 FTU/kg).

[e] Complex magnesium silicate clay.

de la Nutrición Animal, 2003) and met or exceeded the nutritional recommendations of National Research Council (1994) for pullets (Table 1). A batch of local maize and of local wheat were obtained from a commercial trader, ground through a hammer mill (model CH-9240, Bühler AG. S.A., Uzwil, Switzerland) provided with a 6-, 8- or 10-mm screen depending on treatment, and used to manufacture the diets. Within each feeding period, the main difference among diets was the cereal (maize *vs.* wheat) and the diameter of the screen (6-, 8- and 10 mm) used to grind the cereal. All the diets, including those based on maize, incorporated an exogenous phytase (Natuphos, BASF Española S.A., Tarragona, Spain) and a mixture of β-glucanases and xylanases (Roxazyme, DSM S.A., Madrid, Spain) at the levels recommended by the supplier. The carbohydrase enzymes mixture was included in the maize diets to give merit to the potential beneficial effects of the xylanase on maize digestibility.

### *2.3. Laboratory analysis*

Representative samples of the feeds were ground in a laboratory mill (model Retsch ZM 200, Retsch GmbH 42781 Haan, Germany) fitted with a 1-mm screen and analysed in triplicate for moisture by oven-drying (method 930.01), total ash by muffle furnace (method 942.05), nitrogen by combustion (method 990.03) using a LECO analyser (Model FP-528, LECO, St. Joseph, MI) and calcium (Ca) and phosphorus (P) by spectrophotometry (methods 968.08 and 965.17, respectively) as described by the Association of Official Analysis Chemists International (2000). Ether extract was determined by Soxhlet fat analysis (method 4.b) after 3 N HCl acid hydrolysis (Boletín Oficial del Estado, 1995) and gross energy was determined using an isoperibol bomb calorimeter (Model 1356, Parr Instrument Company, Moline, IL). The calculated and determined analyses of the experimental diets are shown in Tables 1 and 2, respectively.

The GMD of the cereals was determined in 100 g samples using a Retsch shaker (Retsch, Stuttgart, Germany) provided with eight sieves ranging in mesh from 5000 to 40 μm according to the methodology outlined by American Society of Agriculture Engineers (1995). Wheat and maize hardness was determined using the particle size index (PSI) method as indicated by Amerah et al. (2009). Briefly, 35 g sample of the two cereals was ground using a laboratory mill (model ZM 200, Retsch, Haan, Germany) fitted with 1-mm screen size. Relative hardness (%) was determined by sieving 10 g sample of the ground cereal

**Table 2**
Determined analysis[a] (g/kg, as-fed basis unless otherwise indicated) of the diets and geometric main diameter (GMD ± GSD[b], μm) of the ground cereals.

| | From 1 to 45 d | | | | | | From 46 to 85 d | | | | | | From 86 to 120 d | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Maize | | | Wheat | | | Maize | | | Wheat | | | Maize | | | Wheat | | |
| | 6 | 8 | 10 | 6 | 8 | 10 | 6 | 8 | 10 | 6 | 8 | 10 | 6 | 8 | 10 | 6 | 8 | 10 |
| Gross energy (MJ/kg) | 16.7 | 16.4 | 16.5 | 16.7 | 16.8 | 16.6 | 16.6 | 16.6 | 16.3 | 16.6 | 16.5 | 16.8 | 16.1 | 16.4 | 16.2 | 16.3 | 16.2 | 16.1 |
| Dry matter | 883 | 888 | 887 | 898 | 908 | 894 | 892 | 894 | 890 | 911 | 910 | 910 | 890 | 890 | 889 | 904 | 904 | 906 |
| Crude protein | 191 | 185 | 183 | 193 | 181 | 190 | 172 | 171 | 173 | 173 | 171 | 172 | 153 | 155 | 153 | 161 | 151 | 162 |
| Ether extract | 49 | 47 | 52 | 44 | 53 | 53 | 49 | 51 | 48 | 45 | 52 | 52 | 47 | 48 | 46 | 39 | 43 | 40 |
| Total ash | 56 | 59 | 51 | 48 | 53 | 50 | 51 | 51 | 53 | 48 | 48 | 43 | 61 | 58 | 58 | 59 | 56 | 64 |
| Calcium | 10 | 11 | 11 | 10 | 11 | 10 | 12 | 12 | 11 | 13 | 13 | 12 | 12 | 12 | 12 | 12 | 11 | 13 |
| Phosphorus | 6 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 6 | 5 | 5 | 5 | 5 | 6 | 5 | 6 |
| GMD[c] (μm) | 929 | 991 | 1042 | 967 | 1119 | 1216 | 760 | 803 | 825 | 813 | 921 | 993 | 733 | 798 | 829 | 691 | 850 | 953 |
| GSD | ±2.14 | ±2.22 | ±2.28 | ±2.19 | ±2.26 | ±2.37 | ±2.50 | ±2.73 | ±2.70 | ±2.43 | ±2.68 | ±2.50 | ±2.28 | ±2.24 | ±2.43 | ±2.42 | ±2.44 | ±2.40 |

[a] Analysed in triplicate samples.

[b] Geometric standard deviation = log normal SD.

[c] Data correspond to particle size of the main cereal used in the corresponding diet.

through a 75 μm sieve. The % PSI was calculated as (weight of particles passed the through sieve/sample weight) × 100. In addition, the WHC of the two cereals was determined as indicated by González-Alvarado et al. (2008). Briefly, a subsample (1 g DM) of ground cereal was left to soak for 24 h in excess of distilled water (100 mL). The sample was filtered using a fritted glass crucible (porosity 2) and the walls of the breaker were carefully rinsed. The wet sample was weighed after letting the water drain for 10 min, and the WHC was calculated as the amount of water retained and expressed as L/kg DM. All these determinations were conducted in triplicate.

### 2.4. *Productive performance*

Body weight and feed consumption were recorded by replicate at 45, 85 and 120 d of age, and mortality was recorded daily. Feed wastage was observed to be negligible and was not measured. From these data, BW gain (BWG), ADFI and FCR corrected for mortality were determined by period and cumulatively. In addition, all the pullets of one of the two cages that formed the experimental units (12 birds at 45 d and 10 birds at 85 d and 120 d of age) were weighed individually and the uniformity of BW was assessed by calculating the percentage of pullets of each replicate that were within ±1.25 SD of the mean average BW (Frikha et al., 2009). The 1.25 SD range was selected to fit commercial target (Hy-Line International, 2009) for BW homogeneity of the flock (80% of pullets within ±10% of the average BW).

### 2.5. *Gastrointestinal tract development*

Details on the methodology used to measure the relative weight (RW, g/kg BW) and the relative length (RL, cm/kg BW) of the different organs of the GIT at 45 d and 120 d of age, and on the pH of the gizzard at 120 d of age have been described elsewhere (Frikha et al., 2009).

### 2.6. *Statistical analysis*

The experimental design was completely randomized with six treatments arranged factorially with two main cereals and three GMD of the cereal. Main effects and the interaction were studied. The experimental unit consisted of a group of 24 pullets for all traits except for uniformity in which only 12 pullets at 45 d of age and 10 pullets at 120 d of age were used. For digestive traits, the experimental unit consisted of two birds chosen at random from each replicate. Data were analysed using the GLM Procedure of SAS software (SAS Institute, 1990). When the model was significant, Tukey's test was used to separate treatment means. Differences between treatment means were considered significant at $P<0.05$ and $P<0.10$ were considered as a trend. Results in tables are presented as means.

## 3. Results

The determined chemical composition of the experimental diets was similar to expected values, except for total P that were slightly lower and Ca that were higher than expected for all diets (Table 2). The GMD of both cereals increased as the size of the screen increased but the differences were higher for the wheat than for the maize. The PSI and the WHC of the cereals were 14.5% and 2.75 L/kg DM for wheat and 2.0% and 2.05 L/kg DM for maize.

### 3.1. *Productive performance*

Mortality was low (2.5%) and not related to treatment. Most of the mortality (87%) occurred during the first wk of life (data not shown). From 1 to 45 d of age, pullets fed the finer diet (6-mm screen) had a higher BWG ($P<0.001$) and a better FCR ($P<0.05$) than those fed the medium and the coarser diets (8- and 10-mm screen, Table 3). From 46 to 120 d of age, no differences in productive performance were observed among diets. Cumulatively (from hatching to 120 d of age), neither the main cereal of the diet nor the GMD of the cereal affected pullet performance. Body weight uniformity was not affected by diet at any age (Table 4).

### 3.2. *Gastrointestinal tract development*

At 45 d of age, pullets fed maize tended to have heavier digestive tracts ($P=0.07$) and proventriculi ($P=0.06$) and longer small intestines (SI, $P=0.07$) than pullets fed wheat (Table 5). At 120 d of age, pullets fed maize had shorter ($P<0.05$) SI, jejuna and ceca and tended ($P=0.07$) to have shorter ilea than pullets fed wheat (Table 6). No other effects of the main cereal on GIT traits were observed. At 45 d of age the digestive tract was heavier and the jejunum was longer ($P<0.05$) in pullets fed the coarser diets than in pullets fed the finer diets with pullets fed the medium ground diets being intermediate. At 120 d of age, no differences in RW were observed because of the GMD of the cereal but the SI were longer ($P<0.05$) in pullets fed the finer diets than in pullets fed the medium and the coarser diets. Dietary treatment did not affect gizzard pH at 120 d of age (Table 6).

**Table 3**
Influence of the main cereal of the diet and screen size of the cereal on growth performance of pullets from 1 to 120 d of age.

| | From 1 to 45 d | | | From 46 to 85 d | | | From 86 to 120 d | | | From 1 to 120 d | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BWG[a] | ADFI[b] | FCR[c] | BWG | ADFI | FCR | BWG | ADFI | FCR | BWG | ADFI | FCR |
| Cereal | | | | | | | | | | | | |
| Maize | 9.9 | 25.6 | 2.58 | 16.6 | 65.2 | 3.92 | 9.4 | 73.9 | 7.85 | 12.0 | 53.0 | 4.42 |
| Wheat | 10.0 | 25.4 | 2.54 | 16.5 | 64.7 | 3.91 | 9.2 | 72.7 | 7.87 | 11.9 | 52.4 | 4.39 |
| S.E.M.[d] ($n = 18$) | 0.061 | 0.25 | 0.02 | 0.14 | 0.86 | 0.033 | 0.14 | 0.83 | 0.101 | 0.06 | 0.56 | 0.032 |
| Screen size (mm) | | | | | | | | | | | | |
| 6 | 10.3ab | 25.7 | 2.50b | 16.5 | 64.8 | 3.92 | 9.2 | 72.7 | 7.87 | 12.0 | 52.6 | 4.36 |
| 8 | 9.9b | 25.6 | 2.58a | 16.4 | 65.3 | 3.97 | 9.5 | 73.9 | 7.77 | 12.0 | 53.0 | 4.43 |
| 10 | 9.7b | 25.2 | 2.60a | 16.7 | 64.7 | 3.86 | 9.3 | 73.4 | 7.94 | 11.9 | 52.6 | 4.42 |
| S.E.M.[e] ($n = 12$) | 0.08 | 0.31 | 0.023 | 0.17 | 1.06 | 0.040 | 0.17 | 1.02 | 0.123 | 0.07 | 0.68 | 0.039 |
| Effect[f] | | | | | | | | | | | | |
| Cereal | 0.718 | 0.456 | 0.065 | 0.716 | 0.699 | 0.776 | 0.318 | 0.297 | 0.907 | 0.380 | 0.435 | 0.557 |
| Screen size | *** | 0.588 | * | 0.453 | 0.932 | 0.218 | 0.390 | 0.736 | 0.596 | 0.330 | 0.874 | 0.454 |

Means within a column and main effects not sharing a common alphabet are different ($P<0.05$).

[a] Body weight gain (g/day).

[b] Average daily feed intake (g).

[c] Feed conversion ratio (g/g).

[d] Standard error mean:18 replicates of 24 pullets each.

[e] Standard error mean: 12 replicates of 24 pullets each.

[f] The interaction between main cereal of the diet and screen size used to grind the cereal was not significant ($P>0.05$).

[*] $P \leq 0.05$.

[***] $P \leq 0.001$.

**Table 4**
Effect of the main cereal of the diet and screen size of the cereal on body weight uniformity[a] of pullets at 45, 85 and 120 d of age.

| | 45 d | 85 d | 120 d |
|---|---|---|---|
| Cereal | | | |
| Maize | 82.4 | 81.1 | 81.1 |
| Wheat | 81.0 | 80.6 | 80.6 |
| S.E.M.[b] ($n = 18$) | 2.13 | 2.74 | 2.38 |
| Screen size (mm) | | | |
| 6 | 82.6 | 80.8 | 80.8 |
| 8 | 81.2 | 81.7 | 80.8 |
| 10 | 81.2 | 80.0 | 80.8 |
| S.E.M.[c] ($n = 12$) | 2.60 | 3.35 | 2.91 |
| Effect[d] | | | |
| Cereal | 0.647 | 0.887 | 0.869 |
| Screen size | 0.909 | 0.940 | 1.000 |

[a] Percentage of pullets with a BW within the average ± 1.25 SD.

[b] Standard error mean (18 replicates of 12 pullets at 45 d of age and of 10 pullets at 85 d and 120 d of age per main effect).

[c] Standard error mean (12 replicates of 12 pullets at 45 d of age and of 10 pullets at 85 d and 120 d of age per main effect).

[d] The interaction between main cereal of the diet and screen size used to grind the cereal was not significant ($P>0.05$).

## 4. Discussion

The GMD of the cereals increased as the screen size used increased but the increase was higher for wheat than for maize, probably because the endosperm of maize was harder but easier to break when hammer milled, than the endosperm of wheat (Mestres and Matencio, 1996; Dobraszczyk et al., 2002). Also, a small amount of wheat grains passed intact through the higher screen size increasing the GMD of this diet. Nir et al. (1995) reported a higher GMD for wheat than for sorghum when both cereals were ground through a 3.5-mm screen. However, the authors have not found any research comparing the GMD of maize and wheat when ground through different screens to compare with the current data.

### 4.1. *Productive performance*

Type of cereal did not affect productive performance of the pullets in any of the periods considered. In broilers fed mash diets, Mathlouthi et al. (2002) reported that growth performance was not affected when 600 g maize/kg diet was substituted by a combination of 400 g wheat and 200 g barley. In brown-egg laying hens, Liebert et al. (2005) and Safaa et al. (2009) did not observe any effect on ADFI, FCR or egg production when 500 g maize/kg diet was substituted by the same amount of wheat. Similar results have been reported by Lázaro et al. (2003) in SCWL hens from 20 to 44 wk of age. However, Amerah et al. (2008) using pelleted feeds, reported higher ADFI and BWG but impaired FCR in 1–21-d-old broilers fed wheat than in those fed maize. Also, Frikha et al. (2009) reported that BWG from 1 to 120 d of age was significantly greater in pullets fed maize than in pullets fed wheat although FCR was not affected. The reasons for the discrepancies in BWG among trials between

**Table 5**
Influence of the main cereal of the diet and screen size of the cereal on the relative weight (g/kg BW) and relative length (cm/kg BW) of several digestive organs of the gastrointestinal tract of pullets at 45 d of age.

| | Relative weight | | | Relative length | | | | |
|---|---|---|---|---|---|---|---|---|
| | Digestive tract[a] | Proventriculus | Gizzard | Small intestine | Duodenum | Jejunum | Ileum | Ceca |
| Cereal | | | | | | | | |
| Maize | 154 | 6 | 43 | 272 | 44 | 120 | 107 | 25 |
| Wheat | 150 | 6 | 42 | 263 | 43 | 117 | 103 | 25 |
| S.E.M.[b] ($n = 18$) | 1.7 | 0.1 | 0.6 | 3.3 | 0.9 | 1.7 | 1.4 | 0.9 |
| Screen size (mm) | | | | | | | | |
| 6 | 148b | 6 | 42 | 261 | 42 | 114b | 105 | 25 |
| 8 | 152ab | 6 | 42 | 269 | 44 | 120ab | 105 | 25 |
| 10 | 156a | 6 | 43 | 272 | 45 | 122a | 106 | 25 |
| S.E.M.[c] ($n = 12$) | 2.1 | 0.1 | 0.7 | 4.0 | 1.1 | 2.1 | 1.7 | 1.0 |
| Effect[d] | | | | | | | | |
| Cereal | 0.066 | 0.058 | 0.203 | 0.069 | 0.217 | 0.118 | 0.109 | 0.799 |
| Screen size | * | 0.256 | 0.356 | 0.145 | 0.382 | * | 0.908 | 0.937 |

Means within a column and main effects not sharing a common alphabet are different ($P<0.05$).

[a] Includes the weight of the digestive tract (from the beginning of the proventriculus to cloaca, with digesta contents), the liver, and the pancreas.

[b] Standard error mean: 18 replicates of 24 pullets each.

[c] Standard error mean: 12 replicates of 24 pullets each.

[d] The interaction between main cereal of the diet and screen size used to grind the cereal was not significant ($P>0.05$).

* $P<0.05$.

**Table 6**
Influence of the main cereal of the diet and screen size of the cereal on the relative weight (g/kg BW) and relative length (cm/kg BW) of several digestive organs of the gastrointestinal tract and on gizzard pH of pullets at 120 d of age.

| | Relative weight | | | Relative length | | | | | Gizzard pH |
|---|---|---|---|---|---|---|---|---|---|
| | Digestive tract[a] | Proventriculus | Gizzard | Small intestine | Duodenum | Jejunum | Ileum | Ceca | |
| Cereal | | | | | | | | | |
| Maize | 119 | 3 | 23 | 105 | 18 | 45 | 42 | 17 | 3.43 |
| Wheat | 120 | 3 | 23 | 109 | 19 | 47 | 44 | 18 | 3.55 |
| S.E.M.[b] ($n = 18$) | 1.9 | 0.1 | 0.6 | 1.3 | 0.3 | 0.7 | 0.5 | 0.3 | 0.092 |
| Screen size (mm) | | | | | | | | | |
| 6 | 121 | 3 | 23 | 110a | 19 | 48 | 43 | 19 | 3.46 |
| 8 | 120 | 3 | 24 | 106b | 18 | 45 | 42 | 18 | 3.45 |
| 10 | 117 | 3 | 23 | 105b | 18 | 45 | 42 | 18 | 3.56 |
| S.E.M.[c] ($n = 12$) | 2.3 | 0.2 | 0.8 | 1.6 | 0.3 | 0.8 | 0.7 | 0.4 | 0.113 |
| Effect[d] | | | | | | | | | |
| Cereal | 0.664 | 0.628 | 0.706 | * | 0.122 | * | 0.065 | * | 0.384 |
| Screen size | 0.515 | 0.558 | 0.638 | * | 0.255 | 0.062 | 0.159 | 0.102 | 0.757 |

Means within a column and main effects not sharing a common alphabet are different ($P<0.05$).

[a] Includes the weight of the digestive tract (from the beginning of the proventriculus to cloaca, with digesta contents), the liver, and the pancreas.

[b] Standard error mean: 18 replicates of 24 pullets each.

[c] Standard error mean: 12 replicates of 24 pullets each.

[d] The interaction between main cereal of the diet and screen size used to grind the cereal was not significant ($P>0.05$).

* $P<0.05$.

birds fed maize or wheat are not known but age, diet form (pellets *vs.* mash) and the physico-chemical characteristics of the wheat used might explain part of these differences (Lentle et al., 2006; Gutiérrez del Alamo et al., 2009; Amerah et al., 2009). For example, the PSI was lower and the WHC was higher for the wheat used in the current trial than that used by Frikha et al. (2009) indicating differences in the hardness of the endosperm and the behavior of both wheats at the GIT levels. In this respect, Pirgozliev et al. (2003) reported in young broilers that the higher the hardness of the wheat, the higher was the BWG and the better was the FCR. Also, Pirgozliev et al. (2003) and Selle et al. (2009) reported that the WHC of the wheat was negatively correlated with the AMEn content. In addition, in the study of Frikha et al. (2009) the GMD was lower for the wheat than for the maize diets (963 *vs.* 1018 μm, respectively) whereas the opposite occurred in the present experiment (1100 *vs.* 987 μm, respectively). Thus, differences in the physico-chemical characteristics of the wheat used might explain, at least in part, the differences observed among trials.

The effects of particle size of the diet on poultry performance are a subject of debate. In the current trial, the GMD of the cereal affected productive performance of the birds from 1 to 45 d of age but not thereafter. In this period, pullets fed the finely ground cereals (6-mm screen) had higher BWG and better FCR than pullets fed the medium and the coarsely ground cereals. Probably, the particle size of coarser diets did not fit beak size and consequently feed intake was reduced (Picard et al., 2000). Amerah et al. (2008) observed in 1–21-d-old broilers fed pelleted diets that ADFI was higher and FCR was impaired with fine (1-mm screen) than with coarse (7-mm screen) grinding of maize and wheat. In contrast, Nir et al. (1990) fed mash diets based on sorghum with a GMD of 629, 762 or 829 μm to broilers from 7 to 21 d of age, and observed that ADFI and BWG increased as the GMD of the diet was increased. Also, Amerah et al. (2007) reported a better BWG and FCR when broilers were fed a coarsely ground wheat diet (7-mm screen size; GMD = 1164 μm) than when fed a finely ground wheat diet (3-mm screen size; GMD = 839 μm). Rate of feed passage increases as the GMD of the feed is reduced (Sibbald, 1979) and thus, fine grinding might increased ADFI. On the other hand, coarse particles are retained for longer in the gizzard than fine particles (Hetland et al., 2005) and consequently, the development of the muscular layers of the gizzard, the motility of the GIT and the secretion of HCl and pancreatic enzymes will benefit from coarse grinding (Duke, 1986; Hetland and Svihus, 2001). Thus both effects, that is a faster rate of feed passage because of the fine grinding and a better gizzard functioning and enzyme production because of coarse grinding, will counteract each other. Consequently, the final effect of the GMD of the diet on ADFI and FCR might vary depending on factors such as type and age of the birds and the physico-chemical characteristics of the basal diet.

At 120 d of age, performance of pullets was not affected by particle size of the diet consistent with the better ability of the older birds to consume feed particles of bigger size. In addition, the effects of particle size on the retention of the digesta in the gizzard and GIT motility might be more pronounced in younger birds than in more mature birds because the diameter of the orifice of exit of the digesta from the gizzard to the duodenum increases with age and therefore, less proportion of the digesta will be retained in this organ in more mature birds. Consequently, particle size should affect more feed intake and nutrient digestibility in younger than in older birds (González-Alvarado et al., 2008; Jiménez-Moreno et al., 2009a,b). This suggestion is consistent with results of Yasar (2003) who reported a better performance from 1 to 21-d-old broilers when fed coarse (7-mm screen) than when fed fine (4-mm screen) wheat diets, but no effects were observed from 21 to 42 d of age.

Average BW and BW uniformity at the onset of egg production are useful criteria to evaluate future productive performance of pullets (ISA, 2007; Hy-Line International, 2009). In this respect, Leeson et al. (1997) reported that heavier pullets at 18 wk of age consumed more feed, matured faster and produced more egg mass to 70 wk of age than lighter pullets. In the current experiment, uniformity and BW at 120 d of age were not affected by the cereal nor by the GMD of the cereal used and thus, no differences in productive performance during the laying cycle should be expected. Frikha et al. (2009) compared wheat and maize based diets in similar type of pullets and reported no differences in BW uniformity. However, in broilers, Brickett et al. (2007) reported better flock uniformity at 35 d of age when pelleted diets (lower GMD) rather than mash diets (higher GMD) were used.

### *4.2. Gastrointestinal tract development*

At 45 d of age, the RW of the gizzard was not affected by the main cereal of the diet, in agreement with data of Thomas and Ravindran (2008) in 14-d-old broilers fed maize or wheat based diets. In contrast, Frikha et al. (2009) observed heavier gizzards in pullets fed maize than in pullets fed wheat at this age. The reason for this discrepancy is not known but it might be related, at least in part, with differences in the physico-chemical characteristics of the wheat used. For example, in the current experiment, the GMD was 967 μm for the wheat and 929 μm for the maize, whereas in the research of Frikha et al. (2009) the values were 798 μm and 870 μm, respectively.

The RL of the different segments of the SI was not affected by the main cereal of the diet, in agreement with previous results of Frikha et al. (2009) in pullets fed mash diets. Similar results have been reported by Thomas and Ravindran (2008) in 14-d-old broilers fed pelleted diets based on wheat, sorghum or maize. In contrast, Amerah et al. (2008) reported shorter RL of all the organs of the GIT in broilers fed wheat than in those fed maize. Again, differences in the physico-chemical characteristics of the wheat used might explain, at least in part, the discrepancies observed.

At 45 d of age, the RW of the digestive tract and the RL of the jejunum increased with increases in GMD of the cereals. Also, the RW of the gizzard increased from 42.0 *vs.* 43.4 g/kg BW with an increase in the GMD of the cereal but in this case, the difference was not significant. Nir et al. (1994) and Santos et al. (2006) observed in young broilers that an increase in particle size of the diet increased the size of the gizzard.

At 120 d of age, dietary treatment did not affect the RW of the different organs of the GIT but the SI was longer with the wheat than with the maize diets. The observed increase in the RL of the SI with wheat as compared with maize agrees with data of Amerah et al. (2008) in 21-d-old broilers. However, Thomas and Ravindran (2008) did not observe any difference in the RL of the SI in 14-d-old chicks fed wheat, sorghum or maize based diets. Similarly, González-Alvarado et al. (2008) did not find any effect of the main cereal (maize or rice) of the diet on the RL of the GIT in 22-d-old broilers. The authors have not found any published research reporting the effects of particle size on the RL of the different organs of the GIT in pullets. In broilers, Amerah et al. (2008) reported shorter SI with coarse ground maize (7-mm screen) than with fine ground maize (1-mm screen) but no differences because of particle size were detected with wheat.

Gizzard pH was not affected by type of diet, in agreement with results of Frikha et al. (2009) in 120-d-old pullets fed maize and wheat diets and of Dahlke et al. (2003) in 42-d-old broilers fed diets based on maize varying in GMD from 340 μm to 1120 μm. The results of the current study and those of other authors conducted with broilers suggest that the GIT of young birds might be more sensitive to differences in particle size and diet composition than the GIT of more mature birds. Modern broilers are selected for higher ADFI and BWG whereas egg-laying pullets are selected for better FCR while maintaining a moderate BWG. Consequently, broilers and pullets might respond differently to diet changes.

## 5. Conclusion

The substitution of 500 g maize by wheat/kg of diet did not affect productive performance or BW uniformity of pullets at 120 d of age. Particle size of the cereal affects BWG and FCR from 1 to 45 d of age, but not thereafter. Consequently, both maize and wheat can be used indistinctly in pullet feeds but it is recommended to grind the main cereal of the diet (either maize or wheat) during the first 45 d of life with a screen of no more than 8-mm.

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