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Maize particle size with the addition of wheat on zootechnical parameters in chickens

Tamaño de partícula de maíz con la adición de trigo sobre parámetros zootécnicos en pollos

José Arce-Menocal[1], **Ernesto Avila-González**[2], **Carlos López-Coello**[2], **Arturo Cortes-Cuevas**[2], **José Herrera-Camacho**[3*]

[1]Facultad de Medicina Veterinaria y Zootecnia, Universidad Michoacana de San Nicolás de Hidalgo.
[2]Centro de Enseñanza, Investigación y Extensión en Producción Avícola, Facultad de Medicina Veterinaria y Zootecnia, Universidad Nacional Autónoma de México.
[3]Instituto de Investigaciones Agropecuarias y Forestales. Universidad Michoacana de San Nicolás de Hidalgo.

[*]Corresponding author: josheca@hotmail.com

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ABSTRACT. An experiment was performed to compare in the meal diets different particle sizes of corn, with and without the addition of whole wheat, on the performance of chicken broilers. 2 800 broilers, four particle sizes was compared; T1) 1175 μm, T2) 740 μm, T3) 541 μm, and T4) 398 μm, with and without the addition of whole wheat (5, 10 and 15%). Body weight (kg), feed consumption (kg), feed conversion ratio (kg/kg), and mortality percentage were evaluated at 7, 14, 21, 28, 35, 42 and 45 days. The gizzard total weight and relative weight was recorded at end of the study. The data recorded in each variable was analyzed by general lineal model for factorial design 4 x 2. At 45 days of age, T2 showed the highest body weight ($p < 0.01$), maintaining a similar conversion feed rate than T3 and T4, without effects ($p > 0.05$) in mortality rate; while the size of the gizzard was lower ($p < 0.01$) as the particle size decreased. The diets with the addition of whole wheat, showed higher body weights ($p < 0.01$), in relation to diets without addition, non significative effect ($p > 0.05$), was observed in the other parameters evaluated. A significative effect ($p < 0.01$) of the interaction of particle size 740 μm with the addition of the whole wheat was observed on the body weight at the end of the study, suggesting that this can be alternative for obtain best performance and save money by feed.
Key words: Broilers, corn particle size, coarse wheat, performance.

RESUMEN. Se compararon dietas en harina con diferentes tamaños de partículas de maíz, con y sin la adición de trigo entero, sobre parámetros zootécnicos en pollo de engorda. En 2 800 pollos de engorda, se compararon cuatro tamaños de partícula; T1) 1175 μm, T2) 740 μm, T3) 541 μm y T4) 398 μm, con y sin la adición de trigo entero (5, 10 y 15%). El peso corporal (kg), consumo de alimento (kg), tasa de conversión alimenticia (kg/kg) y porcentaje de mortalidad fueron evaluados a 7, 14, 21, 28, 35, 42 y 45 días. El peso total y relativo de la molleja fue evaluado al final del estudio. Los datos de cada variable fueron analizados por el proc GLM en un diseño factorial 4 x 2. A los 45 días de edad, el tratamiento T2 mostró el mayor peso corporal ($p < 0.01$), manteniendo conversión similar que T3 y T4, sin afectar ($p > 0.05$) la mortalidad; mientras que el tamaño de la molleja fue menor ($p < 0.01$) a medida que el tamaño de partícula disminuía. Las dietas con la adición de trigo entero, mostraron peso corporal más alto ($p < 0.01$), con relación a las dietas en las que no se adiciono, sin mostrar efectos ($p > 0.05$), en los demás parámetros evaluados. Se observo efecto de interacción de la granulometría 740 μm con la adición de trigo entero en el alimento, sobre la ganancia de peso corporal, al final del estudio, por lo que es una alternativa para eficientar parámetros zootécnicos y costos en alimentación.
Palabras clave: Pollo de engorda, tamaño de partícula del maíz, trigo entero, productividad.

INTRODUCTION

The physical form of the diet, is a tool to improve broiler live performance, especially feed efficiency. However coarse feed particles enhance gizzard function, which was referred to as the pacemarker of gut motility (Xu *et al*. 2015a, Xu *et al*. 2015b, Kheravi *et al*. 2017). Studies respect to particle size impact on health, digestive efficiency and broiler performance were developed more than 60 years ago (Pacheco *et al*. 2014, Xu *et al*. 2015a, Xu *et al*. 2015b). Several authors include the impact on production performance based on particle size on broiler chickens and layers for grains (Amerah *et al*. 2007a, Safaa *et al*. 2009), with soybean meal (Kilburn and Edwards 2004) and minerals which include Ca, P and NaCl sources (McNaughton 1981, Anderson *et al*. 1984). Several authors of older references report an important effect on particle size showing that higher grain sizes have negative impact on feed intake (Dilworth *et al*. 1970), Currently, Xu *et al*. (2015a) founded similar effects. Other trials, shown a positive effect on feed intake for medium to high particle size in young broilers (Nir *et al*. 1994a, Nir *et al*. 1994b, Kilburn and Edwards 2004), and older broilers (Nir *et al*. 1995). Therefore, broiler chickens are reducing the days to achieve market weight, it is important to understand the relationship between particle size and its impact in broiler on performance and gizzard and pancreas weight (Pacheco *et al*. 2013, Pacheco *et al*. 2014, Xu *et al*. 2015). Recently, Kheravii *et al*. (2017) employed sugarcane bagasse with coarse corn indicated enhanced gizzard development, growth performance and feed efficiency on broilers. Further, sugarcane bagasse increased ilial Bacillus spp. Suggesting is a promising prebiotic. Therefore, the objective of this study was to evaluate different corn particle sizes and the inclusion of coarse wheat in the diets on zootechnical parameters in a commercial feeding program for broiler chickens.

MATERIALS AND METHODS

Animals and diets

This experiment was conducted in Michoacán, México. Two thousand eight hundred, Ross 308 one-day-old mixed sex chickens were used. Broilers were vaccinated for Marek's disease at the hatchery. Two vaccinations against Newcastle Disease (La Sota strain) were applied via the drinking water at 8 and 25 days of age. All broilers were reared in floor pens with fresh wood shavings, exposed to natural daylight. Chickens were assigned to one of 28 floor pens (2 x 2.5 m) equipped with one automatic drinker (bell-type) and two feeders (45 cm in diameter). Th2e control and experimental diets were formulated using a commercially available feed formulation program, Nutrion Pro (Nutrion 10.21. Jalisco, Mexico). Diets used for this experiment were corn-soybean meal based formulated following Ross 308 nutritional guides as a basis to resemble typical Mexican industry feeds. Corn was obtained from a local supplier and grinded using a hammer mill (Molino Azteca 015320, Mexico). Corn meal was separated with the aid of screen mesh sieves into four different particle-size ranges: 1) 1175 micrometers (μm) of geometrical mean diameter (GMD); 2) 740 GMD; 3) 571 GMD and 4) 398 GMD. Eight different screen mesh sieves (Table 1) were used ranging from 37 μ, 300 μ, 420 μ, 600 μ, 840 μ, 1200 μ, 1700 μ and 2400 μ to determine the GMD of corn meal. 50 g samples were placed in a Ro-Tap sieve shaker for 10 min.

Table 1. Geometrical mean diameter (GMD) of the corn utilized in the feed formulation.

Microns	Percentage (%)			
	T1	T2	T3	T4
2 400	16.70	4.05	0.00	0.00
1 700	19.75	12.95	3.75	0.25
1 200	20.70	21.25	20.30	4.75
840	3.10	3.45	4.55	3.00
600	18.90	26.40	32.54	34.55
420	3.30	5.75	6.25	9.20
300	5.35	6.00	8.55	12.30
37	12.20	20.15	23.95	35.95
GMD (μm)	1175	740	571	398

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Treatment feed formulation

All chickens were feed mash diets in three phases (Table 2): Starter (from 1 to 21 days), Grower (from 22 to 35 d) and Finisher (from 36 to 45 days). In total, 8 different diets were produced (Table 3). Treatment 1 (T1) was formulated with a GMD of 1175 microns for corn meal. Treatment 2 (T2) was formulated with a GMD of 740 microns. Treatment 3 (T3) was formulated with a GMD of 571 microns. Treatment 4 (T4) was formulated with a GMD of 398 GMD. Treatment 5 (T5) was equal to T1 plus the addition of whole wheat “On Top”. Treatment 6 (T6) was equal to T2 plus the addition of whole wheat “On Top”. Treatment 7 (T7) was equal to T3 plus the addition of whole wheat “On Top”and Treatment 8 (T8) was equal to T4 plus the addition of whole wheat “On Top”. Whole wheat added “On Top”for starter feed was of 5%, for grower 10% and for finisher of 15%.

Experimental design and statistical analysis

This experiment was performed using a factorial 4 x 2 randomized block design. A total of 2800 one-day-old Ross 308 broiler mixed-sexed chickens were used for this experiment. Chickens were randomly distributed into eight treatments with seven replicates per treatment. Each replicate consisted of 50 chickens per pen (25 males and 25 females).

Data were analyzed by ANOVA with general lineal model procedures for a completely randomized design using the Statistical package SPSS version 17. Differences between treatments were determined using the Fisher LSD Test. A probability level of $p < 0.05$ was considered to be statistically significant.

Body weight (kg), feed consumption (kg), feed conversion ratio (kg kg^{-1}), and mortality percentage were evaluated at 7, 14, 21, 28, 35, 42 and 45 d. Feed consumption was measured on a daily basis and recorded by weighing residual feed for each replicate pen. Feed conversion ratio was obtained by dividing feed intake by body weight and corrected for mortality. Three males per pen were randomly selected at the end of the trial in order to evaluate gizzard total weight and relative weight.

RESULTS

Body weight

No significant differences ($p > 0.05$) were detected at 7 and 14 days of age broiler chickens for particle size, inclusion of coarse wheat and interaction between particle size and inclusion of coarse wheat on the body weight of chickens broilers (Table 4). At 21 days of age, chickens consuming the diet with 740 μm particle size were significantly heavier ($p < 0.01$) compared to chickens consuming the 1175 μm particle size diet (0.711 *vs* 0.671 kg). A positive interaction ($p < 0.01$) between particle size and inclusion of coarse wheat was detected on chickens consuming the 740 μm the particle size when compared to chickens consuming 1175 μm without it (0.726 *vs* 0.652 kg). At 28 days of age broilers consuming the 740 μm particle size diet were significantly heavier ($p < 0.01$) than broilers consuming the highest or lowest particle size diets (1.310 vs 1.233 and 1.245 kg). Broilers consuming the 571 μm particle size diet were heavier ($p < 0.01$) than the 1175 μ chickens (1.275 *vs* 1.233 kg). Broilers consuming coarse wheat were heavier ($p < 0.01$) than without it (1.279 *vs* 1.253 kg). Broilers consuming the 740 μm particle size diets plus the addition of coarse wheat had significantly ($p < 0.01$) the highest weight compared to the other treatments showing a positive interaction at this age. Broilers consuming the biggest particle size of 1175 μm were significantly ($p < 0.01$) the lightest among all treatments but when fed coarse wheat re-established its body weight to the level of the other treatments with the exception of chickens consuming the 740 μm particle size diet plus the addition of coarse wheat. At 35 days of age, broilers consuming the 740 μ particle size diet presented the highest ($p < 0.01$) body weight (1.962 kg) followed by the 571 μm diet (1.908 kg) and the 1175 μm diet (1.864 kg) with the lowest ($p < 0.01$) weight on the 398 μm diet (1.818 kg). No differences ($p > 0.05$) were detected at this age with the addition of coarse wheat. Broilers consuming the 740 μ particle size diet plus the addition of coarse wheat had significantly ($p < 0.01$) the highest weight at this age (1.973 kg). The lowest ($p < 0.01$) body weights were for the 398 μm particle size diets with

Table 2. Diets and nutritional specifications for experimental feed (kg).

	Starter (1 - 21 days)	Grower (22 - 35 days)	Finisher (36 - 45 days)
Ingredient			
Corn	52.12	54.94	59.90
Soybean meal	38.60	34.10	29.60
Vegetable Oil	4.20	6.30	6.00
Mono-dicalcium phosphate	1.99	1.72	1.54
Calcium Carbonate	1.58	1.38	1.32
Salt	0.31	0.28	0.27
DL-Methionine 99%	0.34	0.31	0.26
L-Lysine HCl 99%	0.25	0.16	0.22
Sodium Bicarbonate	0.22	0.20	0.20
Choline Chloride 60%	0.10	0.10	0.07
Mineral Premix[2]	0.06	0.06	0.06
Virginiamycine	0.05	0.05	0.05
Vitamin Premix[3]	0.05	0.05	0.05
Nicarbazine	0.05	0.00	0.00
Salinomycine 12%[4]	0.00	0.05	0.05
L-Threonine HCL 98%	0.07	0.04	0.04
Antioxidant	0.015	0.015	0.015
Natural Pigmentant[5]	0.00	0.22	0.22
Cantaxantin 1%[6]	0.00	0.025	0.025
Total	100.0	100.0	100.0
Nutrient[1]			
Met. Energy (Kcal kg^{-1})	3 025	3 190	3 225
Crude Protein	22.00	20.00	18.50
Dig. Lysine	1.25	1.10	1.03
Dig. Met+Cis	0.93	0.85	0.75
Dig. Threonine	0.80	0.72	0.67
Fat	5.40	7.60	7.50
Total Calcium	1.09	0.95	0.88
Av. Phosphorus	0.50	0.44	0.40

[1]Percent (%) of the diet unless otherwise indicated. [2]Mineral Premix provided per kg of product: iron, 50 mg; zinc, 50 mg; manganese, 110 mg; copper, 12 mg; iodine, 0.30 mg; selenium, 0.2 mg. [3]Vitamin Premix contains (per kg of product): vitamin A, 11 000 IU; vitamin D_3 2 500 IU; vitamin E, 15 IU; menadione, 2.5 mg; vitamin B_{12}, 20 ug; thiamine 2 mg; riboflavin, 7.5mg; pyridoxine, 4 mg; niacin, 45 mg; pantothenic acid, 15.7 mg; folic acid, 0.6 mg; biotin 0.15 mg. [4]Coccidiostat: Salinomycin 12%. [5]Avelut 30: powder product containing 30 active grams/kg of xanthophylls. [6]Contains 1% of Carophil Red cantaxantin.

Table 3. Treatments includes in the experiment the whole was include on top.

Treatment	Granulometry (μ)	With whole wheat	Without whole wheat
1	1 175	+	
2	740	+	
3	571	+	
4	398	+	
5	1 175	-	
6	740		-
7	571		-
8	398		-

or without the addition of coarse wheat (1.816 and 1.820 kg) showing a significant ($p < 0.01$) negative effect on body weight on the smallest particle size diet. At 42 days of age the 740 μm particle size diet presented significantly ($p < 0.01$) the highest body weight when compared to the other three treatments (2.604 *vs* 2.489, 2.479 and 2.408 kg). Broilers consuming the 398 μ diet had significantly ($p < 0.01$) the lowest weight with no differences between the 1175 and 571 μm diets. No differences ($p > 0.05$) were detected on the inclusion of coarse wheat. A positive interaction ($p < 0.01$) on the addition of coarse wheat was detected on chickens consuming the 1175 μm diet (2.531 *vs* 2.448 kg). At 45 days of age, broilers

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Table 4. Average results of weight (kg) in broiler chickens from 1 to 45 days of age.

Days of age		7	14	21	28	35	42	45
GMD (microns)								
1175		0.135	0.324	0.67^{b}	1.233^{c}	1.864^{c}	2.489^{b}	2.709^{c}
740		0.143	0.352	0.711^{a}	1.310^{a}	1.962^{a}	2.604^{a}	2.808^{a}
571		0.139	0.348	0.704^{ab}	1.275^{ab}	1.908^{b}	2.479^{b}	2.768^{b}
398		0.137	0.354	0.697^{ab}	1.245^{bc}	1.818^{d}	2.408^{c}	2.668^{d}
Probability		p > 0.05	p > 0.05	p < 0.01	p < 0.01	p < 0.01	p < 0.01	p < 0.01
With wheat		0.140	0.349	0.703	1.279^{a}	1.890	2.507	2.758^{a}
Without wheat		0.137	0.340	0.689	1.253^{b}	1.886	2.483	2.719^{b}
Probability		p > 0.05	p > 0.05	p > 0.05	p < 0.01	p > 0.05	p > 0.05	p < 0.01
GMD	(wheat)							
1175	+	0.140	0.334	0.690^{ab}	1.259^{b}	1.877^{cd}	2.531^{b}	2.747^{b}
	-	0.130	0.313	0.652^{b}	1.207^{c}	1.851^{de}	2.448^{cd}	2.672^{c}
740	+	0.145	0.359	0.762^{a}	1.339^{a}	1.973^{a}	2.619^{a}	2.845^{a}
	-	0.141	0.344	0.696^{ab}	1.281^{b}	1.950^{ab}	2.588^{a}	2.770^{b}
571	+	0.138	0.346	0.697^{ab}	1.274^{b}	1.894^{cd}	2.474^{c}	2.778^{c}
	-	0.140	0.351	0.710^{a}	1.277^{b}	1.851^{de}	2.448^{cd}	2.672^{c}
398	+	0.138	0.358	0.697^{ab}	1.244^{bc}	1.816^{e}	2.405^{d}	2.661^{c}
	-	0.137	0.351	0.697^{ab}	1.246^{bc}	1.820^{e}	2.411^{d}	2.676^{c}
Probability		p > 0.05	p > 0.05	p < 0.01	p < 0.01	p < 0.01	p < 0.01	p < 0.01
MSE		0.001	0.002	0.004	0.006	0.008	0.011	0.009

GMD = Geometrical mean diameter; ^{abcd}Values with different letter are statistically different (p < 0.01); MSE = Mean Standard Error.

consuming the 740 μm particle size diet presented significantly (p < 0.01) the highest body weight when compared to the other three treatments (2.808 *vs* 2.709, 2.768 and 2.668 kg). Broilers consuming the 571 μm diets were significantly (p < 0.01) heavier than the chickens consuming the 1175 μm diet (2.768 *vs* 2.709 kg) and chickens consuming the 398 μ diet were significantly (p < 0.01) the lightest (2.668 kg) of all treatments. Broilers consuming coarse wheat were significantly (p < 0.01) heavier at this age (2.758 *vs* 2.719 kg) with a positive interaction (p < 0.01) for the addition of coarse wheat at 740 and 1175 μm diets compared to the diets that did not contained coarse wheat.

Feed Intake

No significant differences (p > 0.05) were detected at 7 and 14 days of age broiler chickens for particle size, inclusion of coarse wheat and interaction between particle size and inclusion of coarse wheat (Table 5). At 21 days of age, chickens consuming the diet with 1175 μ had significantly (p < 0.01) higher feed intake when compared to the other three diets (1.147 *vs* 1.083, 1.013 and 1.004 kg). Chickens consuming mid-size particle size 740 μ diet had significantly (p < 0.01) higher feed intake than the 571 and 398 μ diets (1.083 *vs* 1.013 and 1.004 kg). No differences (p > 0.05) on feed intake were detected with the inclusion of coarse wheat in the diets. At this age, a positive interaction (p < 0.01) for feed intake on large particle size 1175 μ and the inclusion of coarse wheat was detected with significantly (p < 0.01) the highest feed intake among all treatments. A negative interaction (p < 0.01) was determined for chickens consuming the 571 and 398 μ diets and coarse wheat with the lowest feed intakes. At 28 days of age the chickens consuming the 1175 μ particle size diet had significantly (p < 0.01) the highest feed intake followed by the 740 μ diet. No differences (p > 0.05) on feed intake were detected between the 571 and 398 μ particle size diets. Chickens consuming added coarse wheat presented significantly (p < 0.01) lower feed intake than the chickens that did not consume it (1.921 *vs* 1.982). A positive interaction (p < 0.01) between the use of coarse wheat and coarse particle size 1175 μ was detected. A negative interaction (p < 0.01) on chickens consuming the 571 and 398 μ diets and coarse wheat with the lowest feed intakes trend con-

Table 5. Average results of feed intake (kg) in broiler chickens from 1 to 45 days of age.

Days of age		7	14	21	28	35	42	45
GMD (microns)								
1 175		0.119	0.478	1.147^{a}	2.071^{a}	3.186^{a}	4.468^{a}	5.060^{a}
740		0.135	0.489	1.083^{b}	1.988^{b}	3.102^{b}	4.409^{a}	5.002^{a}
571		0.128	0.448	1.013^{c}	1.883^{c}	2.995^{c}	4.248^{b}	4.853^{b}
398		0.126	0.450	1.004^{c}	1.864^{b}	2.912^{d}	4.159^{c}	4.809^{b}
Probability		p > 0.05	p > 0.05	p < 0.01	p < 0.01	p < 0.01	p < 0.01	p < 0.01
With wheat		0.129	0.471	1.057	1.921^{b}	3.029	4.310	4.924
Without wheat		0.126	0.462	1.066	1.982^{a}	3.068	4.332	4.939
Probability		p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05
GMD	(wheat)							
1 175	+	0.125	0.510	1.180^{a}	2.111^{a}	3.241^{a}	4.516^{a}	5.122^{a}
	-	0.113	0.446	1.114^{ab}	2.031^{ab}	3.130^{b}	4.420^{b}	4.998^{b}
740	+	0.135	0.489	1.080^{bc}	1.967^{bc}	3.096^{b}	4.413^{b}	5.021^{b}
	-	0.135	0.488	1.086^{bc}	2.009^{bc}	3.108^{b}	4.406^{b}	4.984^{b}
571	+	0.126	0.438	0.986^{d}	1.811^{d}	2.911^{c}	4.160^{c}	4.769^{c}
	-	0.130	0.458	1.039^{bc}	1.955^{bc}	3.079^{b}	4.337^{b}	4.938^{b}
398	+	0.127	0.446	0.982^{d}	1.796^{d}	2.869^{c}	4.152^{c}	4.784^{c}
	-	0.124	0.454	1.025^{cd}	1.932^{c}	2.956^{c}	4.166^{c}	4.835^{c}
Probability		p > 0.05	p > 0.05	p < 0.01	p < 0.01	p < 0.01	p < 0.01	p < 0.01
MSE		0.001	0.004	0.009	0.015	0.017	0.019	0.017

GMD = Geometrical mean diameter; ^{abcd}Values with different letter are statistically different (p < 0.01). MSE = Mean standard error.

tinued. At 35 days of age chickens consuming the 1175 μ had significantly (p < 0.01) the highest feed intake (3.186 kg) followed by the 740 μ (3.102 kg), 571 μ (2.995 kg) and 398 μ (2.912 kg) particle size diets. No differences (p > 0.05) were detected at this age for the inclusion of whole wheat. A positive interaction (p < 0.01) for coarse particle size (1175 μ) and inclusion of coarse wheat was detected at this age. A negative interaction (p > 0.05) was detected on broilers fed the 571μ particle size diet plus the coarse wheat. At 42 days of age chickens consuming the 1175 and 740 μ particle size diets had the highest (p < 0.01) feed intake compared to the 571 and 398 μ particle size diets (4.468 and 4.409 *vs* 4.248 and 4.159 kg). The significantly (p < 0.01) lowest feed intake was achieved with the 398 μ particle size diet. No differences (p > 0.05) were detected at this age for the inclusion of whole wheat. A positive interaction (p < 0.01) was detected for the 1175 μ and coarse wheat. A negative interaction (p < 0.01) was detected for the inclusion of whole wheat and 571 μ particle size diet. At 45 days of age broilers consuming the 1175 and 740 μ diets had significantly (p < 0.01) higher feed intake compared to the smaller particle size diets (5.060 and 5.002 *vs* 4.853 and 4.809 kg). No differences (p > 0.05) were detected at this age for the inclusion of whole wheat. A positive interaction (p < 0.01) was detected for the 1175 μ and coarse wheat with the highest feed intake (5.122 kg). A negative interaction (p < 0.01) was detected for the inclusion of whole wheat and 571 μ particle size diet with the lowest feed intake (4.769 kg) among all treatments.

Feed Conversion Ratio (FCR)

No differences (p > 0.05) were detected at 7 days of age. At 14 days of age, FCR was significantly (p < 0.01) lower on 571 and 398 μ particle sizes when compared to 1175 and 740 μ particle sizes (1.454 and 1.435 *vs* 1.682 and 1.569) were 1175 μ had significantly (p < 0.01) the highest FCR (Table 6). At 21 days of age broilers consuming the 1175 μ particle size diet had significantly (p < 0.01) the highest FCR (1.819) followed by the 740 μ diet (1.615) with the lowest FCR for the 571 and 398 μ particle sizes (1.526 and 1.530). At 28 days of age the 1175 μ particle size diet had significantly (p < 0.01) the highest FCR when compared to the other diets (1.736 *vs* 1.567, 1.525 and 1.547). At 35 days of age a similar trend continued were the

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Table 6. Average results of feed conversion ratio (kg/kg) in broiler chickens from 1 to 45 days of age

Days of age		7	14	21	28	35	42	45
GMD (microns)								
1 175		1.253	1.682^{c}	1.819^{c}	1.736^{b}	1.747^{b}	1.825^{b}	1.896^{b}
740		1.313	1.569^{b}	1.615^{b}	1.567^{a}	1.614^{a}	1.721^{a}	1.808^{a}
571		1.299	1.454^{a}	1.526^{a}	1.525^{a}	1.603^{a}	1.742^{a}	1.780^{a}
398		1.300	1.435^{a}	1.530^{a}	1.547^{a}	1.639^{a}	1.757^{ab}	1.830^{ab}
Probability		p > 0.05	p < 0.01	p < 0.01	p < 0.01	p < 0.01	p < 0.01	p < 0.01
With wheat		1.285	1.525	1.597^{a}	1.552^{a}	1.638	1.747	1.813
Without wheat		1.297	1.545	1.648^{b}	1.636^{b}	1.663	1.775	1.844
probability		p > 0.05	p > 0.05	p < 0.01	p < 0.01	p > 0.05	p > 0.05	p > 0.05
GMD	(wheat)							
1 175	+	1.254	1.730	1.815	1.733	1.765	1.813	1.893
	-	1.252	1.635	1.822	1.740	1.729	1.836	1.900
740	+	1.289	1.532	1.574	1.514	1.602	1.711	1.790
	-	1.337	1.605	1.656	1.619	1.627	1.730	1.825
571	+	1.288	1.431	1.502	1.469	1.570	1.709	1.743
	-	1.310	1.478	1.551	1.581	1.636	1.775	1.816
398	+	1.310	1.408	1.497	1.492	1.617	1.756	1.825
	-	1.290	1.462	1.562	1.602	1.661	1.757	1.835
Probability		p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05
MSE		0.014	0.017	0.018	0.014	0.009	0.007	0.008

GMD = Geometrical mean diameter; ^{abcd}Values with different letter are statistically different (p < 0.01); MSE = Mean Standard Error.

1175 μ particle size diet had significantly (p < 0.01) the highest FCR of all treatments. However, at 42 and 45 days of age the 1175 μ particle size had a significantly (p < 0.01) higher FCR than the 740 and 571 μ particle size diets but not different than the 398 μm particle size diet. At 21 and 28 days of age, FCR was significantly (p < 0.01) lower with the addition of whole wheat on the diets but no differences (p > 0.05) were detected on other ages. Finally, no interaction for FCR was detected at any age between particle size and inclusion of whole wheat (Table 6).

Mortality rate

No differences were detected (p > 0.05), in the general mortality (%), during the development of the study between the evaluated treatments (granulometries 1175, 740, 571 and 398 μm), also with or without the addition "on top"of different percentages of whole wheat (5, 10 and 15%), in the different feeding phases, also in the interaction of both factors, as shown in Table 7.

Gizzard total weight and relative weight

The results obtained in the present study indicated that both the total weight and the relative weight of the gizzard increased (p < 0.01), from 571 to 1175 μm of particle size. Without showing effect (p > 0.05), with or without the inclusion of whole wheat "on top", or with the interaction of both factors (Table 8).

DISCUSSION

Body weight

Previous studies about body weight conducted by Benedetti *et al*. (2011) showed that the inclusion of corn with a grain size of 460, 730 and 870 μm do not had significant effect on the weight gain of Cobb chickens at 7 and 42 days of age, but did affect (p < 0.05) the gain of weight at 21 days of age, observing greater body weight gain in chickens exposed to corn of 460 μm compared to 870 μm (929 g *vs* 913 g, respectively), while chickens exposed to corn with grain size of 730 μm had a similar behavior (p > 0.05) to the previous treatments (914 g). In the study conducted by Mingbin *et al*. (2015), with Ross 308 line chickens, a smaller (p < 0.05) weight gain was observed in the growth stage (1-21 days) when a fine

Table 7. Average results of mortality (%) in broiler chickens from 1 to 45 days of age.

Days of age		7	14	21	28	35	42	45
GMD (microns)								
1 175		1.36	2.50	3.29	3.79	4.50	5.07	5.36
740		1.00	2.14	2.64	2.79	3.43	4.21	4.57
571		1.14	1.86	2.43	2.64	2.86	2.93	3.14
398		1.71	2.64	3.14	3.50	3.64	4.07	4.14
Probability		p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05
With wheat		1.57	2.39	3.21	3.50	4.14	4.79	5.04
Without wheat		1.04	2.18	2.54	2.86	3.07	3.36	3.57
Probability		p > 0.05	p > 0.05	p > 0.05	p > 0.01	p > 0.05	p > 0.05	p > 0.05
GMD	(wheat)							
1 175	+	1.14	2.00	3.00	3.43	4.57	5.14	5.29
	-	1.57	3.00	3.57	4.14	4.43	5.00	5.43
740	+	1.14	1.86	2.71	2.86	3.71	4.71	5.29
	-	0.86	2.43	2.57	2.71	3.14	3.71	3.86
571	+	1.43	2.14	3.00	3.14	3.43	3.57	3.71
	-	0.86	1.57	1.86	2.14	2.29	2.29	2.57
398	+	2.57	3.57	4.14	4.57	4.86	5.71	5.86
	-	0.86	1.71	2.14	2.43	2.43	2.43	2.43
Probability	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05	
MSE	0.22	0.35	0.35	0.37	0.39 60.42	0.42		

GMD = Geometrical mean diameter; MSE = Mean standard error.

Table 8. Gizzard total weight and relative weight on broiler fed with different particle size and coarse wheat at 45 days of age.

GMD (microns)		Gizzard total weight (g)	Gizzard relative weight (%)
1 175		44.3^{a}	1.37^{a}
740		42.9^{a}	1.27^{ab}
571		36.8^{ab}	1.17^{ab}
398		32.2^{b}	1.07^{b}
Probability		p < 0.01	p < 0.01
With wheat		38.5	1.22
Without wheat		38.6	1.22
Probability		p > 0.05	p > 0.05
SEM	1.258	0.032	
GMD	(wheat)		
1 175	+	44.4	1.37
	-	44.3	1.37
740	+	42.4	1.27
	-	43.0	1.27
571	+	36.9	1.17
	-	36.8	1.17
398	+	32.2	1.07
	-	32.2	1.07
Probability		p > 0.05	p > 0.05
MSE		2.86	0.079

GMD = Geometrical mean diameter; abValues with different letter are statistically different (p < 0.01); MSE = Mean Standard Error.

particle food was offered, with respect to the medium particles and thick (38.6, 39.9 and 39.7 g days^{-1} respectively), while in the growth stages (d 22-32) and finalization stage (days 33-40) the weight gain per day was similar when a fine particle size was offered, medium or thick (85.2, 84.8, 84.8 and 84.4, 85.5 and 86.7 g days^{-1}, respectively).

In another recent study, Shirani *et al*. (2018) did not observe a significant effect of particle size (500, 1000 and 1500 μm) on the weight gain of Ross 308

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chickens at 10 d of age. In the same sense, Selle *et al*. (2019), did not observe a significant effect ($p > 0.05$) on the size of the Tiger variety sorghum particle (783, 1 055, 1 354 and 1 402 μm) and Block I (805, 1 173, 1 370 and 1 408 μm) included in the diet, on the weight gain of broilers Ross 308, at 28 days of age, registering a weight per bird that oscillated between 1 519 and 1 592 g. Another study by Siegert *et al*. (2018), showed that the addition of corn or soybean particles of 2 000 and 3 000 μm in diameter improved, in fattening chickens the weight gain at 21 days of age.

In the present study, the body weight gain at 21 days of age was better ($p < 0.01$) with granulometries below 740 μm according with that reported previously by Benedetti *et al*. (2011). However, the birds that were eating food with granulometries of 740 μm showed from 21 to 45 days of age, the highest body weights, an effect that helped the addition of whole wheat “on top” to the food, which showed effects ($p < 0.01$), at 28 and 45 days of age on a greater gain in body weight, finding effects of interaction between granulometries and the “on top” addition of whole wheat from 21 days of age, mainly due to the granulometry of 740 μm with the addition of wheat, showing a greater body weight, from 35 days of age, unlike the rest of the treatments with and without the addition of whole wheat. Effect that could be due to digestive physiological changes that favor the development and motility of the gastro-intestinal tract (TGI), with changes in the behavior of food consumption, and reduction in the pH of the proximal TGI, which serves as a barrier against pathogens and increase the retention time of the digesta in the gizzard (Abdollahi *et al*. 2018).

Feed Intake

The results of studies examining the effects of particle size on feed consumption in broilers fed on flour diets have been inconsistent. It is likely that the difference in the results obtained is related to a complex series of factors, such as the type and variety of grain, hardness of the endosperm, particle characteristics (shape, size, uniformity and distribution), as well as the components of feeding, type of grinding and age of the birds (Abdollahi *et al*. 2018). Amerah *et al*. (2007b) suggested that feeding broilers with a diet with more uniform grain particles, which corresponds to diameter (GMD) and geometric standard deviation (GSD), can have beneficial effects on growth and yield through the reduction of time, and possibly, the energy expenditure used to search and choose the desired particles.

In the present study, feed intake was higher when granulometries greater than 740 μm were used, contrary to what was reported by Benedetti *et al*. (2011), probably due to the addition of different percentages "on top" of whole wheat in the diet, which modified the consumption in the present work. It is important to note that the differences ($p < 0.01$) found were as of 21 days of age in the greatest grain size studied (1175 μm); however, it was until the final stages (35 days of age) when the granulometry of 740 μm was similar to that of greater granulometry. The addition of whole wheat or the interaction between granulometries or the addition of whole wheat affected ($p > 0.05$) food consumption during the study. While the positive effects of high grain size on food consumption and intestinal health are evident in wheat-based foods, these effects are not as obvious, or even opposite, when corn is used as the main cereal. The lower capacity to grind the largest particles of corn in relation to wheat, especially in young birds, in the gizzard, and the greater energy expenditure of the operation of the gizzard with larger granulometries may be possible causes of this difference in the final effect (Abdollahi *et al*. 2018).

Previous studies have shown that as particle size increases, feed intake in broilers decreases, this effect was previously observed by Benedetti *et al*. (2011), who found a trend ($p < 0.05$) where the larger the particle size of corn, the lower the food consumption in chickens aged 7 and 42 days exposed to granulometry of 870 μ with respect to the particle sizes of 730 μ and 460 μ (141, 140 and 137 g, and 5 045, 5 049, and 5030 g, respectively), while significant differences were observed in food consumption at 21 d of age, reporting food consumption values of 1 275, 1 279 and 1 230 g for particle sizes of 870, 730 and 460 μ, respectively. In the same way, Shirani *et al*. (2018), observed a higher feed consumption when the particle size was smaller (500 μm) than with a particle of 1000 or 1 500 μm (287 and 283 g days^{-1}) on day 10, without the differences observed being significant (p > 0.05). In recent studies (Selle *et al*. 2019), they demonstrated a higher feed intake in broilers Ross 308 at 28 days of age subjected to a feeding with an intermediate granulometry (1055 and 1 354 μm) of Tiger variety sorghum than with granulometries of smaller (783 μm) or larger (1402 μm) size, although the differences found between treatments were not significant. In the same study, the granulometry of 1173 μm of the sorghum variety Block I, showed a greater consumption of food (2 452 g) than the granulometries of 805, 1 370 and 1 408 μm (2 452, 2 426 and 2 499 g), respectively, although the differences observed were not statistically significant (p > 0.05).

Feed Conversion Ratio (FCR)

Previous studies has presented by Benedetti *et al*. (2011), showed a significant effect (p < 0.05) on feed conversion rate at 21 d of age, similar to what was observed in the present study, that as the diameter of the corn incorporated in the diet increases the feed conversion it also increases. Shirani *et al*. (2018), reported that the particle size (500, 1 000 and 1 500 μm) of corn-soybeans in the diet, did not significantly affect (p > 0.05) food conversion in Ross 308 line chickens at 10 d of age observing a food conversion rate (g g^{-1}) of 1.28, 1.21 and 1.20, respectively.

Another study conducted by Mingbin *et al*. (2015), they did not find significant differences (p > 0.05), in the feed conversion rate at age 21 and 40 d of Ross 308 line chickens, but they observed a lower feed consumption (p < 0.05), improving the feed conversion ratio in birds that consumed fine particle size, with respect to medium and coarse (1 680, 1 712 and 1 736 g, respectively). In the same way, the results reported by Selle *et al*. (2019), regarding the feed conversion of Ross 308 broilers, which were given sorghum of two varieties (Tiger and Block I) and different geometric particle size (783, 1 055, 1 354, 1 402 and 805, 1 173, 1 370 and 1 408 μm, respectively), showed no significant differences (p > 0.05) observing a conversion of 1 500 to 1 600 g of food to produce a kilogram of meat.

In the present study, the lowest granulometries (571 and 398 μm), showed better feed conversion rate after 14 days of age, an effect that remained until the end of the study. From 28 days of age, the granulometry of 740 μm showed in birds the benefit of conversion as well as low particle sizes. The greatest granulometry (1 175 μm), showed the highest conversions from the beginning to the end of the test in relation to the rest of the granulometry used. Without showing effect (p > 0.05) with and without the addition of whole wheat, or in the interaction of both factors studied, on the index of the food conversion. Similar effects were reported by (Chewning *et al*. 2012) using corn-based diets, they reported that the increase in particle size increased the feed intake of broiler chickens compromising food efficiency. The different body weights and food consumptions recorded in the present study were decisive to establish differences (p < 0.01), in the feed conversion rate between treatments, mainly to changes in the behavior of food consumption with its consequences within the digestive system such as changes in pH, increases in retention time of the digesta in the gizzard as well as energy expenditure to search and choose the desired particles (Abdollahi *et al*. 2018).

Mortality rate

In previous studies, an effect similar to those obtained in the present study has been demonstrated, in this regard Bennedeti *et al*. (2011), mentioned that the particle size in the diet did not affect the mortality rate of broilers. More recently (Mingbin *et al*. 2015) also did not observe a significant effect (p > 0.05) on the mortality rate in broilers when fine, medium and coarse particle sizes were included in the diet, finding a survival of 97.9, 97.1 and 98.2%, respectively. Similarly, Selle *et al*. (2019), also didn't observe differences in the 28-day mortality rate, when two varieties of sorghum (Tiger and Black I) at different geometric particle size were included in the diet.

Gizzard total weight and relative weight

The gizzard development is essential to ob-

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tain favorable zootechnical results improving the digestibility of nutrients and the health of the gastrointestinal tract, being the directive organ of peristaltic movements and reflux of the digestive system (Jacobs *et al*. 2010). In contrast to what was observed in the present study, Shirani *et al*. (2018), reported a significant effect ($p < 0.05$), of particle size (500, 1 000 and 1 500 μm) on the relative gizzard weight (g BW^{-1}) of 2.77, 3.19 and 3.51, even higher than observed in our study In the same sense, Selle *et al*. (2019), observed that sorghum-based diets with a smaller average geometric particle size (783 or 805 μm) generated significantly 4.94% lighter gizzards. The grain and food granulometry stimulate gizzard development and allow it to perform its digestive functions; however, it is not always a linear effect (at greater granulometry, greater development, size and functionality), in the present study the granulometry of 740 μm, showed the greatest body weight and better feed conversion than the greatest granulometry (1175 μm) , used, without the differences being significant ($p > 0.05$), in the total weight and relative weight of the gizzard at the end of the study. In another study, Amerah *et al*. (2007b) suggested that gizzard stimulation was due to the time that the mainly thick particles remained in the gizzard, favoring the solubility of the particles and subsequent enzymatic access, improving digestive peristalsis and nutrient utilization.

CONCLUSIONS

The meal in flour with the granulometry of 740 μm registered greater body weight which distinguishes it from the rest of the treatments, at the end of the study. The meal in flour with the addition of whole wheat "on top" (5, 10 and 15%), in the different phases of food, improved body weight, which distinguishes it from non-addition, at the end of the study. Granulometry interaction effect was shown 740 μm with the addition of whole wheat "on top" in the feed, on the best weight gain of the broilers at the end of the study. The flour meal with the granulometry of 398 μm, showed the lowest values of the gizzard, showing no effects, with or without whole wheat, or in the interaction.

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