South African Journal of Animal Science 2020, 50 (No. 6)

Effects of feed particle size on energy values for broiler chickens at various ages

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(Submitted 16 April 2020; Accepted 28 July 2020; Published 7 December 2020)

Abstract

The objective of this study was to evaluate the effects of various geometric mean diameters (GMDs) of particles of corn, pelleted soybean meal and a corn-soy mixture in the proportion of 70% and 30%, respectively, on the nutritional value of the feeds. The study evaluated energy consumption, the contents of apparent metabolizable energy (AME) and AME corrected for nitrogen balance (AME_n) and the metabolizability coefficients for broiler chickens at various ages. A total of 540 Cobb 500 male broilers were housed in metabolic cages (experimental units). Trials were performed separately with each feed. A completely randomized design was used with four treatments, namely corn with 573, 636, 851, and 1012 µm GMDs; pelleted soybean meal with 538, 550, 665, and 741 µm GMDs; and the corn-soy mixture with 627, 658, 893, and 1040 µm GMDs. Birds were evaluated on days 1 - 10, 11 - 20, 21 - 30, and 31 - 40. Larger GMDs resulted in lower energy consumption. From 1 to 10 days, birds consumed less metabolizable energy than older birds. Birds fed corn from days 1 to 10 had higher metabolizable energy (P <0.05) with increasing GMD up to 1042 µm. However, the results varied, depending on the feed and its combinations. The use of coarse particles could reduce the costs of grinding, and would have few effects on the metabolizable energy of broiler chickens.

Keywords: feed cost, metabolizable energy, rearing phases
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Introduction

The metabolizable energy content of feedstuffs is important in meeting the nutritional requirements of broiler chickens. This content can be determined with various methods. It can also be influenced by factors such as age, sex, the amount of feed provided, and the methodology used in the metabolism trials (Kunrath *et al*., 2010).

Apparent metabolizable energy increases from 0 to 14 days old, and then remains constant (Batal & Parsons, 2002). A diet based on corn and soybean meal probably increased AME with age owing to the enhanced utilization of starch, fat and protein. The absorptive capacity of the birds could also have been affected by the feed ingredients and the age of the birds (Adeola *et al*., 2018).

The importance of the physical structure of the diet as a means of improving feed efficiency and live performance has been recognized (Xu *et al*., 2015). A reduced particle size allows greater interaction of the feed with the digestive enzymes owing to its increased surface area (Chewning *et al*., 2012). However, a finer particle size could decrease gut peristalsis and increase feed consumption and the rate of passage, thus reducing feed digestibility (Svihus *et al*., 2002; Pacheco *et al*., 2013). A coarser feed structure was demonstrated to influence nutrient digestibility and animal live performance positively (Xu *et al*., 2015). Any reduction in the power used in grinding to reduce the particle size would lower the cost of feed manufacture significantly (Amerah *et al*., 2008). Thus, information about the relationship of particle size and energy utilization by the birds would make it possible to reduce production costs (Benedetti *et al*., 2011; Vukmirović *et al*., 2016).

A very fine GMD of corn – that is, less than 400 µm in mash and crumbled feeds – may impair feed intake owing to the presence of dust, which may cause respiratory disorders, contaminate drinking water

URL: http://www.sasas.co.za
ISSN 0375-1589 (print), ISSN 2221-4062 (online)
Publisher: South African Society for Animal Science
http://dx.doi.org/10.4314/sajas.v50i6.9

with the feed and increase the water intake and the moisture content of the litter (Brum *et al*., 1998). However, an optimum particle size has not been well established in the literature. Amerah *et al*. (2007) concluded a feed particle size between 600 and 900 µm was optimal for broiler diets based on maize and sorghum. Parsons *et al*. (2006) evaluated various particle sizes for corn and found AME_n was maximized with a particle size of 1042 um. Because a coarser particle size could reduce grinding costs and might increase the AME and AME_n values for broiler chickens, the objective of this study was to evaluate the effects of various particle sizes of corn, pelleted soybean meal, and a mixture of these ingredients for broiler chickens of different ages.

Material and Methods

The study was conducted at the Poultry Research Centre of the Experimental Station of Western Parana State University. All procedures that involved birds were approved by the Animal Care and Use Committee of the university (Protocol 027/09).

Three trials were performed to evaluate feeds and their combinations. In the first trial corn was evaluated. In the second trial pelleted soybean meal was assessed, and in the third a mixture of 70% corn and 30% pelleted soybean meal was estimated. These ingredients were milled in four batches of 50 kg and ground through 2-, 4-, 6-, and 8-mm sieves. The hammer mill had a 7.5 horsepower motor, which required three-phase 254 volt electricity. The flow rate of the mill hopper was controlled to maintain the mill at a current intensity of 16 amps. At the end of each process, the total time of milling was recorded to calculate the amount of electrical energy used in the process.

The power consumption of the motor during milling was estimated according to this formula (Bhowmick & Bera, 2008):

$$C = \sqrt{3}\ x\ U\ x\ I\ x\ cos\varphi\ /\ 1000$$

where: C = energy consumption in kilowatt hours,
√ 3 = square root of three, because of the three-phase electricity motor,
U = input voltage,
I = average amperage,
cos φ = power factor, and
1000 = constant to convert watts to kilowatts.

The milling rate (T/h) was determined by dividing the amount milled (50 kg) by the time, converted from minutes to hours, which resulted in the milling capacity in one hour of working. After milling, an analysis of the GMDs of the feed particles was performed with a granulometric sieve shaker (SP Labor, SP-1100), with 4-, 2-, 1.2-, 0.6-, 0.3-, and 0.15-mm sieves, and a sieve-free compartment (Zanotto & Bellaver, 1996).

For the metabolic assay, 540 one-day-old male Cobb 500 broiler chickens were obtained from a commercial hatchery. They were raised in a concrete floor covered with pine wood shavings and received a common reference diet (Table 1) based on corn and soybean meal and water ad libitum. When the broiler chickens reached the ages for evaluation, they were transferred to metabolic cages, which were equipped with flow-through type feeders and drinkers. The room temperature was kept within the ideal comfort zone indicated for each phase, according to the values recommended for the strain. The lighting programme consisted of continuous 23 hours light and 1 hour of darkness (30 lux light intensity) throughout the period.

The study was performed in a completely randomized design, with four treatments consisting of the four GMDs. The trials were performed separately for each feed. In the first trial, ground corn with 573, 636, 851, and 1.012 µm GMDs was evaluated. In the second trial pelleted soybean meal with 538, 550, 665, and 741 µm GMDs was evaluated. Finally, a mixture of 70% corn and 30% pelleted soybean meal with 627, 658, 893, and 1040 µm GMDs was assessed. The effects were also evaluated for each particle size. For the pre-starter period, ten birds were allocated to each metabolic cage. For the starter period, there were eight birds per cage. For the grower period, there were five birds per cage and for finisher period, there were four birds per cage. The tested feeds replaced the reference diet (Rostagno *et al*., 2011) at rates of 10%, 20%, 30%, and 40%.

Each experimental period lasted ten days, with five days to adapt to the diets and cages, and five days to collect excreta (Sibbald & Slinger, 1963). A galvanized tray was placed under each cage, and the excreta were collected every 12 hours to minimize fermentation. It was then frozen and stored in plastic bags for five days at -20 °C until the end of the collection period, when feed intake and the total amount of excreta were measured. The excreta from each cage was defrosted in the plastic bags at room temperature (20 °C) for 12 hours, and homogenized manually, and an aliquot was taken. Each aliquot was weighed and dried in a forced-air oven at 55 °C for 72 hours. Subsequently, the dried excreta were ground in a Wiley-type mill (Star FT-80/2, Fortinox, Piracicaba, SP) using a 1-mm sieve screen and stored for later analysis.

Dry matter (DM) (method 934.01) and crude protein (CP) (method 981.10) were analysed according to AOAC (1990). Gross energy (GE) analysis was conducted using an oxygen calorimetric bomb (IKA C2000, with an accuracy of 0.001 ºC), and AME was corrected to zero N retention (AME_n) using a factor of 8.22 kcal/g (Hill & Anderson, 1958). The values of AME and AME_n were calculated according to Matterson *et al*. (1965).

Table 1 Composition of reference diets (% as fed) for broiler chickens in various phases of growth

Ingredient (g/kg)	Phase		
	Pre-starter	Starter	Grower and finisher
Corn grain	530.80	563.20	607.10
Soybean meal 45% CP	398.00	361.40	311.80
Soybean oil	26.80	35.20	42.10
Dicalcium phosphate	19.30	18.30	16.90
Limestone	9.30	9.00	8.60
Sodium chloride	5.20	5.00	4.80
DL-Methionine	3.50	2.60	2.50
L- Lysine HCl	3.00	1.90	2.50
L-Threonine	1.20	0.50	0.80
Vitamin premix[1]	1.00	1.00	1.00
Choline chloride 60%	0.60	0.60	0.60
Anticoccidial	0.50	0.50	0.50
Mineral premix[2]	0.50	0.50	0.50
Antioxidant	0.20	0.20	0.20
Avilamycin	0.10	0.10	0.10
Calculated composition (g/kg)			
Metabolizable energy (kJ/kg)	12 385	12 761	13 180
Crude protein	230.0	214.0	197.0
Digestible lysine	13.630	11.890	10.990
Digestible methionine	6.668	5.567	5.137
Digestible Met+Cis	9.680	8.440	7.910
Digestible tryptophan	2.547	2.362	2.110
Digestible threonine	8.860	7.730	7.140
Calcium	9.420	8.890	8.370
Available phosphorus	4.710	4.490	4.180
Sodium chloride	2.240	2.180	2.080

[1]Vitamin A: 3000 mg, vitamin D_3: 55 mg, vitamin E: 6000 IU, vitamin B_1: 1.4 g, vitamin B_2: 4.0 g, vitamin B_6: 1.8 g, vitamin B_{12}: 15,000 mcg, pantothenic acid: 8.5 g, vitamin K: 1.4, folic acid: 0.4 g, nicotinic acid: 25.0 g, selenium: 0.3 g
[2]Iron: 100 g/kg, copper: 6 g/kg, manganese: 150 g/kg, zinc: 100 g/kg, iodine: 1.5 g/kg

The data were tested for normality with the Shapiro-Wilk test and subjected to analysis of variance (SAS Institute, Inc., Cary, North Carolina, USA). To evaluate the effects of particle size, linear and quadratic orthogonal polynomials were evaluated. When a polynomial effect was significant, a regression equation was obtained. Tukey's test was used to compare the means for the phases. A probability level of 5% was regarded as indicating a significant difference. The mathematical model used was:

$$y_{ij} = \mu + t_i + e_{ij}$$

where: γ_{ij} = observation,
μ = overall mean,
t_i = effect of treatment, and
e_{ij} = random residual error.

Results and Discussion

The GMD values obtained after the grinding process for corn were 573, 636, 851 and 1012 µm for the 2-, 4-, 6-, and 8-mm sieves, respectively. For the soybean meal, the GMD values were 538, 550, 665 and 741 µm, and for the corn-soy mixture, the GMD values were 627, 658, 893 and 1040 µm (Table 2).

Table 2 Geometric mean diameter of feed particles and energy consumption during milling in various sieves

Feed	Sieve (mm)	GMD (µm)	Time	Consump-tion (kw)	Milling rate (t/h)	Consumption per ton (kw/T)
Corn	2	573	7’05”	0.723	0.424	14.46
	4	636	6’27”	0.658	0.465	13.17
	6	851	4’28”	0.456	0.672	9.12
	8	1012	3’31”	0.359	0.853	7.17
Mean		768	5’23”	0.594	0.604	10.98
Pelleted soybean meal	2	538	4'03"	0.413	0.741	8.27
	4	550	3'11"	0.324	0.942	6.50
	6	665	1'43"	0.175	1.748	3.50
	8	741	1'21"	0.138	2.222	2.76
Mean		624	2’45”	0.263	1.413	5.258
Mixture	2	627	6’29”	0.660	0.464	13.20
	4	658	6’02”	0.616	0.497	12.32
	6	893	3’32”	0.361	0.849	7.21
	8	1040	2’31”	0.257	1.192	5.14
Mean		805	4’49”	0.474	0.751	9.468

GMD: geometric mean diameter

Corn showed higher milling times, greater energy consumption, and a lower milling rate relative to the other feeds. In contrast, the soybean meal had a lower milling rate in the various sieves, and the corn-soy mixture showed intermediate values, tending to be closer to the corn owing to its composition. The consumption of electrical energy during the milling process ranged from 7.17 to 14.46 kWh/ton for corn, from 2.76 to 8.27 kWh/ton for pelleted soybean meal and from 5.14 to 13.20 kWh/ton for the corn-soy mixture.

For birds of all ages, the mean AME values from those that received corn were higher than AME_n (Table 3). This effect is usually obtained when the birds are fed ad libitum and nitrogen retention is positive (Kato *et al*., 2011).

Birds in the pre-starter phase that received corn processed to a GMD of 573 µm had smaller (P <0.05) AME and AME_n values relative to feed consumed (apparent metabolizable energy expressed relative to feed intake (CAME) and $CAME_n$ values, respectively) than older birds (Table 4). There were no differences (P >0.05) in the CAME and $CAME_n$ values between phases for the finely ground feed. The higher values with older birds may be related to the development of the gastrointestinal tract as a function of increased secretion of bile salts and increased activity of the lipase enzyme, in addition to the more expressive fermentation of structural carbohydrates in the caecum, which improved energy efficiency (Queiroz *et al*., 2015).

Table 4 Apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen balance expressed relative to amount of corn consumed as a function of particle size and broiler age

Coefficient	Age, days	Geometric mean diameter, µm				SE	*P*-value	
		573	636	851	1012		Linear	Quadratic
CAME, %								
	1 - 10	75.33[b]	78.47[c]	78.53[b]	78.69[b]	0.485	0.021	0.097
	11 - 20	81.98[a]	84.83[a]	81.79[ab]	81.84[ab]	0.551	0.237	0.629
	21 - 30	81.84[a]	81.14[bc]	81.01[ab]	80.54[ab]	0.394	0.339	0.902
	31 - 40	84.58[a]	84.25[ab]	82.95[a]	82.81[a]	0.322	0.103	0.505
$CAME_n$, %								
	1 - 10	74.19[b]	77.13[b]	77.02[b]	77.59[b]	0.463	0.015	0.184
	11 - 20	80.53[a]	83.12[a]	80.12[ab]	80.64[a]	0.567	0.365	0.893
	21 - 30	80.75[a]	80.86[a]	80.10[ab]	79.87[ab]	0.362	0.315	0.977
	31 - 40	82.83[a]	82.24[a]	81.29[a]	81.10[a]	0.236	0.100	0.599

CAME: apparent metabolizable energy expressed relative to feed intake, $CAME_n$: apparent metabolizable energy corrected for nitrogen balance expressed relative to feed intake
[a,b,c] Within a column, means with a common superscript were not different at *P* =0.05

In general the values of CAME and $CAME_n$ for corn processed to 636, 851 and 1012 µm GMD were lower in the pre-starter phase than in the finisher phase, with the starter and grower phases being intermediate. Similar results were obtained by Kato *et al.* (2011), who evaluated corn hybrids and found lower AME and AME_n values in the pre-starter phase compared with other phases. In the light of this, Freitas *et al*. (2006) recommended using AME_n in the formulation of starter diets for broiler chicks.

Regression analysis of CAME and $CAME_n$ values on corn GMDs indicated linear increases (*P* <0.05) with greater particle size for starter chicks.

$$CAME = 74.10618 + 0.00488GMD\ (R^2 = 0.56)$$
$$CAMEn = 72.78208 + 0.00494GMD\ (R^2 = 0.56)$$

This result may be related to enhanced gizzard activity and improved gastrointestinal tract function with increased particle size (Xu *et al*., 2015). Feeding coarse particles during the pre-starter phase is important to stimulate the mechanical action of the gizzard when coarser particles are fed subsequently (Rubio *et al*., 2020). Feeding coarse particles may improve the digestibility of nutrients owing to the lower pH of the digesta, enhanced peptic digestion, and increased enzyme-substrate interaction from greater retention time (Xu *et al*., 2015). Similar results were obtained by Amerah *et al*. (2008), who showed that coarsely ground maize (7-mm hammer mill screen) had positive effects on broiler performance compared with fine grinding (1-mm screen) of pelleted diets.

The results of this study demonstrated that particle sizes up to 1012 µm improved energy utilization for birds in the pre-starter phase. However, Jacobs *et al.* (2010) reported a reduction in metabolizable energy in seven-day old birds fed a particle size of 1387 µm compared with smaller particle sizes. Parsons *et al*. (2006) evaluated the metabolizable energy of corn with various particle sizes They observed a quadratic relationship between particle size and metabolizable energy values, with an intermediate optimum predicted at a particle size of 1042 µm. Parsons *et al*. (2006) found greater nitrogen and lysine retention with increases in particle size, and suggested coarse diets. Naderinejad *et al*. (2016) found improved starch digestibility and AME with greater particle size in pelleted diets, and related these results to increased gizzard weight and reduced gizzard content pH. However, they did not obtain a similar effect of particle size in mash diets.

Particle size had no effect on CAME and $CAME_n$ values for corn in the present study in the starter, grower, and finisher phases. Eyng *et al*. (2009) evaluated eight cultivars of corn with 656 and 743 µm GMDs in broilers from 22 to 32 days old, and obtained CAME of between 72.5% and 78.49% and $CAME_n$ between 70.68% and 76.84%. These values are lower than those found at comparable ages in the present study.

The mean values of AME of the pelleted soybean meals were 11.54%, 7.65%, 9% and 10.63% greater than AME_n in the pre-starter, starter, grower and finisher phases, respectively (Table 5). The smaller difference in the starter phase may have resulted from the higher nitrogen retention of growing birds (Calderano *et al*., 2010).

Table 5 Apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen balance of pelleted soybean meal as a function of particle size and broiler age

Values, kj/kg	Age (days)	Geometric mean diameter (µm)				Average
		538	550	665	741	
AME						
	1 - 10	9,728	9,757	9,644	9,431	9,640
	11 - 20	10,774	10,322	10,799	10,564	10,615
	21 - 30	11,393	9,966	10,092	10,748	10,550
	31 - 40	12,481	12,192	12,046	10,828	11,887
	Average	11,094	10,559	10,645	10,393	
AME_n						
	1 - 10	8,678	8,598	8,473	8,360	8,527
	11 - 20	10,213	9,452	10,083	9,460	9,802
	21 - 30	10,213	9,251	9,314	9,615	9,598
	31 - 40	11,150	11,025	10,648	9,673	10,624
	Average	10,064	9,582	9,630	9,277	

AME: apparent metabolizable energy, AME_n: apparent metabolizable energy corrected for nitrogen balance

Birds that received pelleted soybean meal with 538, 550, and 665 µm GMDs had higher values for CAME in the finisher phase (Table 6). In the starter phase, birds fed pelleted soybean meal with a 741 µm GMD showed a smaller CAME value, whereas no effects of GMD were found among the other phases. The lower coefficients of digestibility in younger birds might be related to lower enzymatic activity. Digestive capacity was not fully developed in the younger birds and this might limit their utilization of nutrients (Mello *et al*., 2009). Similar results were obtained by Bertechini *et al*. (2019), who found greater metabolizable energy values in older birds, which was related to their more developed digestive tracts. Schneiders *et al*. (2017) evaluated soybean meal (563 µm GMD) for broiler chickens in various phases (1 - 8, 11 - 18, 31 - 38, and 41 - 48 days) and found a linear decrease in CAME with age, with values varying from 56.2% to 51.4%. These authors also evaluated deactivated whole soybean (1588 µm GMD) and obtained increased values with greater age of broilers. Apparent metabolizable energy expressed relative to feed intake varied from 56.8% to 74.2%, demonstrating differences arising from processing methods.

Regression analysis of CAME and $CAME_n$ values on the GMD of the pelleted soybean meal detected a quadratic effect (P <0.05) for CAME in the grower phase with a minimum value (54.73%) estimated at 640 µm.

$$CAME = 262.53280 - 0.64919GMD + 0.00050702GMD^2 \ (R^2 = 0.90)$$

There were also decreasing linear effects on CAME and $CAME_n$ with the increased particle size (P <0.05) in the finisher phase.

$$CAME = 89.17612 - 0.03740\,x \ (R^2 = 0.68)$$
$$CAME_n = 81.53266 - 0.03637\,x \ (R^2 = 0.78)$$

These results were unexpected. However, the surface area available for enzymatic activity was possibly reduced with a larger particle size (Daveby *et al*., 1998).

The AME values of the corn-soy mixture were 4.6% greater relative to AME_n at all ages (Table 7). This may have resulted from greater nitrogen retention for deposition in tissues (Generoso *et al*., 2008). Zang *et al*. (2009) evaluated diet particle sizes of 953 and 597 µm and found greater AME values for a finer particle size compared with a coarser one (12,510 kJ/kg as opposed to 12,138 kJ/kg, respectively) in birds at 19 to 21 days old and in birds at 42 days old (12,154 as opposed to 12,456 kJ/kg). However, the difference between the AME values at 42 days old was not detected.

Table 6 Apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen balance expressed relative to the amount of pelleted soybean meal consumed as a function of particle size and broiler age

Values, %	Age, days	Geometric mean diameter (µm) (GMD)				SE	*P*-value	
		538	550	665	741		Linear	Quadratic
CAME								
	1 - 10	53.89[c]	54.06[b]	53.44[c]	52.25[b]	0.380	0.099	0.549
	11 - 20	59.68[b]	57.18[b]	59.83[b]	58.51[a]	0.554	0.773	0.505
	21 - 30	63.13[b]	55.21[b]	55.90[c]	59.55[a]	0.862	0.202	0.001
	31 - 40	69.14[a]	67.55[a]	66.74[a]	60.00[a]	0.971	<0.001	0.006
$CAME_n$								
	1 - 10	48.08[b]	47.63[b]	46.94[c]	46.31[b]	0.423	0.153	0.977
	11 - 20	56.59[a]	52.36[b]	55.85[a]	52.41[a]	0.922	0.483	0.384
	21 - 30	56.57[a]	51.25[b]	51.60[b]	53.25[a]	0.740	0.299	0.064
	31 - 40	61.77[a]	61.08[a]	58.99[a]	53.58[a]	0.941	<0.001	0.080

CAME: apparent metabolizable energy expressed relative to feed intake, $CAME_n$: apparent metabolizable energy corrected for nitrogen balance and expressed relative to feed intake
[a,b,c] Within a column, means with a common superscript were not different at *P* =0.05

Table 7 Apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen balance in a feed composed of 70% corn and 30% soybean meal as a function of particle size and broiler age

Values, kJ/kg	Age, days	Geometric mean diameter, µm				Average
		627	658	893	1040	
AME						
	1 - 10	12,280	12,293	12,615	12,811	12,500
	11 - 20	13,075	13,221	13,372	13,631	13,325
	21 - 30	12,380	12,711	12,811	13,100	12,751
	31 - 40	14,435	14,163	14,100	13,602	14,075
	Average	13,043	13,097	13,225	13,286	
AME_n						
	1 - 10	11,657	11,807	11,979	12,142	11,896
	11 - 20	12,473	12,644	12,849	13,083	12,762
	21 - 30	11,950	12,347	12,318	12,682	12,324
	31 - 40	13,615	13,426	13,380	12,958	13,345
	Average	12,424	12,556	12,632	12,716	

AME: apparent metabolizable energy, AME_n: apparent metabolizable energy corrected for nitrogen balance

Birds in the starter phase had lower CAME and $CAME_n$ (P <0.05) values at all GMDs of the corn-soy mixture than those in the finisher phase (Table 8). Likewise, at 627, 658, and 893 µm GMD, CAME values (P <0.05) for birds in the grower phase were lower than those in the finisher phase. These effects carried over to the $CAME_n$ values at 627 and 658 µm GMD . Thomas *et al*. (2008) evaluated various cereal grains, including corn, for birds of various ages and observed that AME_n values at three days old decreased through nine days old and then increased. They posited that these observations were based on the early availability of energy from the yolk sac, changes in the microflora, digestive enzyme availability, endogenous secretions, and inefficiency in mixing of the digesta.

Table 8 Apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen balance and expressed relative to the amount of 70% of corn and 30% of soybean meal mixture consumed as a function of particle size and broiler age

Age (days)	Geometric mean diameter (µm) (GMD)				SE	*P*-value	
	627	658	893	1040		Linear	Quadratic
CAME (%)							
1 - 10	70.29^{c}	70.35^{c}	72.20^{c}	73.32^{c}	0.392	<0.001	0.932
11 - 20	74.83^{b}	75.67^{b}	76.52^{b}	77.18^{a}	0.475	0.109	0.861
21 - 30	70.87^{c}	72.76^{c}	73.33^{bc}	74.97^{bc}	0.467	0.134	0.605
31 - 40	82.62^{a}	81.06^{a}	80.70^{a}	77.84^{ab}	0.513	<0.001	0.149
$CAME_n$ (%)							
1 - 10	66.72^{c}	67.58^{c}	68.58^{c}	69.49^{b}	0.386	0.007	0.924
11 - 20	71.38^{b}	72.37^{b}	73.53^{ab}	74.87^{a}	0.650	0.063	0.973
21 - 30	68.38^{bc}	70.68^{b}	$70.49b^{c}$	72.60^{ab}	0.432	0.079	0.287
31 - 40	77.93^{a}	76.85^{a}	76.60^{a}	74.17^{a}	0.464	0.003	0.234

[a,b,c] Within a column, means with a common superscript were not different at *P* =0.05

The regression of CAME and $CAME_n$ values on GMD of the mixed ration indicated a linear increase for birds in the pre-starter phase:

$$CAME = 65.93050 + 0.00720GMD \ (R2 = 0.71)$$
$$CAME_n = 64.44134 + 0.00459GMD \ (R2 = 0.48)$$

There was no effect (*P* >0.05) of GMD on CAME and $CAME_n$ in the starter and grower phases. However, the birds in the final phase showed a linear decrease in CAME and $CAME_n$ with increased GMD:

$$CAME = 87.30396 - 0.00868\,x \ (R2 = 0.76)$$
$$CAMEn = 81.70721 - 0.00688\,x \ (R2 = 0.59)$$

Particle sizes greater than 1000 µm could adversely influence the performance of younger birds because they have lower gizzard capacity to break the larger particles (Amerah *et al*. 2007). In the present study, and contrary to Amerah *et al*. (2007), the corn-soy mixture with GMD of 1040 µm improved the CAME and $CAME_n$ values in birds from 1 to 10 days old. Similar results were obtained by Parsons *et al*. (2006), who evaluated various particle sizes in broiler chickens at 28 days old, and obtained a linear increase in nitrogen and nutrient retention with increasing particle size. However, they observed reduced bird performance and energy metabolism when the particle size exceeded 1042 µm.

Conclusion

The larger particle sizes evaluated in this study resulted in benefits because of the lower energy cost of grinding. However, when one considers all phases and feeds, few differences occurred in the metabolizable energy values. Metabolizable energy was generally higher for older birds.

Authors' Contributions

RF, CS and RAS collected the data for this study. ASA, PLO, CE, JB and RF conducted the statistical analyses, collaborated in interpretation of the results, wrote the initial draft of this manuscript, and finalized the manuscript. RVN and PCP developed the original hypothesis, designed the experiments, and collaborated in interpreting the results. The authors have read and approved the finalized manuscript.

Conflict of Interest Declaration

The authors declare there is no conflict of interest.

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