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Maize kernel size and texture: production parameters, quality of eggs of the laying hens and electricity intake

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ABSTRACT. The influence of maize corn size and texture on the performance parameters of laying hens and power consumption required for grinding maize corn were evaluated. The experiment was carried out on 384 Isa Brown hens, 36 weeks old, penned in a conventional aviary with 562.5 cm^2 $bird^{-1}$ stocking rate. The treatments were distributed in a completely randomized 2 x 3 factorial design (maize textures: flint and dent; and milling degree: fine, medium and coarse) with eight replicates of eight birds per plot. Data were evaluated with SISVAR and means were compared by Tukey's test at 5% probability. Difference was reported for the variable texture and flint increased the variables feed intake and egg weight. Significant difference in the characteristics of egg quality occurred only for the colorof the yolk. Larger corn sizes consumed less electricity during grinding. The maize flint cultivar had a lower 31.7% power consumption when compared to that of the dent cultivar.

Keywords: feed consumption, energy efficiency, processing, production of eggs.

Granulometria e textura do milho: parâmetros produtivos, qualidade dos ovos de poedeiras comerciais e consumo de energia elétrica

RESUMO. O objetivo foi avaliar como os fatores granulometria e textura do milho podem alterar os parâmetros de desempenho produtivo de poedeiras comerciais, bem como o consumo de energia elétrica para moagem dos grãos. Foram utilizadas 384 poedeiras da linhagem Isa Brown com 36 semanas de idade, alojadas em aviário de produção convencional com taxa de lotação de 562,5 cm^2 ave^{-1}. Os tratamentos foram distribuídos em delineamento inteiramente ao acaso em esquema fatorial 2 x 3 (texturas de milho: duro e dentado e graus de moagem: fino, médio e grosso), com oito repetições de oito aves por parcela. Os dados foram avaliados com o auxílio do pacote estatístico SISVAR com médias comparadas pelo teste de Tukey a 5% de probabilidade. Foi constatada diferença para o fator textura, em que a textura dura apresentou aumento nas variáveis: consumo de ração e peso dos ovos. As características de qualidade dos ovos demonstraram diferença significativa apenas quanto à cor da gema. Maiores granulometrias consumiram menos energia elétrica durante a moagem. A cultivar de milho duro teve consumo de energia elétrica 31,66% menor comparativamente à cultivar dentado.

Palavras-chave: consumo de ração, eficiência energética, processamento, produção de ovos.

Introduction

Maize is the main energy source in poultry and represents 60 to 65% of its dietary composition. It is the main input in poultry diets with significant impact on costs. Its use requires storage room and processing equipment so that most production energy costs are related to corn processing.

Differences in the texture of maize cultivars are the result of the links between chemical constituents (mainly carbohydrates and proteins) with high molecular weight and glucose polymers that determine the type and ratio of endosperm in corn. These connections are directly related to corn hardness. In fact hard texture maize differs from flour maize due to the relative shares of vitreous and soft endosperms in the kernels.

Processing whould ensure the best feed nutrient usage but the overall efficiency is affected by several factors. Maize hardness directly affects the time and energy consumed in grinding, as well as product digestibility since vitreous endosperms offer resistance to the activity of digestive enzymes (Silva et al., 2006).

The choice of suitable corn size in the manufacture of diets optimizes energy consumption during corn processing and determines the change in poultry nutrient use since larger particle sizes provide greater retention of diet in the gizzard and promote digestion associated with the mechanical work done by the organ.

Tailoring the processing of raw materials to the equipment found in a feed mill causes greater efficiency in the manufacturing process of feed by reducing waste and particularly by decreasing in power consumption. It also provides the desired changes in feed through maintenance or improvement of animal performance. Card and Nesheim (1968) reported that laying hens have higher feed intake when fed on milled coarse cereals, without compromising performance or quality of eggs.

Current research evaluated the corn size and texture of maize on the performance parameters of commercial laying hens and on the, electricity consumption in corn grinding.

Material and methods

Performance data of 384 semi-heavy Isa Brown lineage hens, 36 weeks old, were collected at the experimental facilities of the laying poultry center of the School of Veterinary Medicine and Animal Science – FMVZ of UNESP, Botucatu, São Paulo State, Brazil. The treatments were distributed in a completely randomized 2 x 3 factorial design with two maize textures (dent and flint), milled to three grain sizes (fine, medium and coarse) with eight replicates of eight birds per experimental plot.

The birds were housed in a conventional poultry house with 48 cages 100 cm long and 45 cm deep each, at a stocking rate of 562.5 cm^2 per bird. The cages were arranged in two double rows with a service corridor. Each cage had an independent feeder in its front side. The feed was delivered twice a day and water provided ad libitum via nipple waters with cups. A lighting schedule of 16 hours of daylight was adopted as recommended by the lineage handbook.

The preparation of the experimental diets and the electricity consumption tests were performed in the feed mill at FMVZ, UNESP in Botucatu. The maize cultivars adopted in the experiment were 177 DKB flint and AG 4051 dent both cultivated at the School of Agronomical Sciences (School of Agricultural Science - FCA), UNESP, Botucatu, São Paulo State, Brazil, on the same soil type and with identical correction, fertilization and cultivation. The chemical composition of a sample of each cultivar was analyzed and its percentage of crude protein, ether extract and crude fiber evaluated. Gross, digestible and metabolizable energy was computed according to the equation proposed by Rostagno et al. (2011), as shown in Table 1.

Table 1. Rates of dry matter (DM), crude protein (CP), ether extract (EE), crude fiber (CF), gross (GE), digestible (DE) and metabolizable (ME) energy and mineral matter (MM) of the cultivars used in the experiment.

Cultivar	DM (%)	CP (%)	EE (%)	CF (%)	GE (kcal kg^{-1})	DE (kcal kg^{-1})	ME (kcal kg^{-1})	MM (%)
Flint corn (cultivar DKB 177)	86.97	8.61	4.25	3.32	3925.4	3449.5	3358.0	0.97
Dent corn (cultivar AG 4051)	87.02	9.48	5.08	3.99	3967.9	3459.4	3358.7	1.24

Maize samples were ground in a saw mill through sieves of different mesh diameters (3, 6, and 9 mm). Average Geometric Diameter (AGD) required the use of vibrating sieves number 5, 10, 16, 30, 50 and 100 mm and bottom, corresponding to the following mesh openings: 4; 2; 1.20; 0.60; 0.30; 0.15 and 0 mm. AGD was calculated according to the equation by Handerson and Perry (1955).

The following performance parameters were evaluated during the 112-day experiment: feed intake (g $bird^{-1}$ day^{-1}), egg production (% egg production $bird^{-1}$), egg weight in grams; egg mass in grams plus feed conversion per dozen and per kilogram of eggs. Data were collected daily and recorded in a spreadsheet.

The full period of data collection was divided into four periods of 28 days to assess the internal and external quality of eggs. At the end of each experimental period two whole eggs per plot were collected randomly for three consecutive days. All analyzes were performed at the egg laboratory of the School of Veterinary Medicine and Animal Science at UNESP, Botucatu, Brazil.

The following parameters for egg quality were assessed: specific gravity, performed by immersing the eggs in salt solutions with densities ranging between 1,060 and 1,100 g cm^{-3}, following Moreng and Avens (1990).

Shell breaking strength: measured with a TA.XT plus - Texture Analyser equipped with a 75 mm probe (p/2) at a test speed of 1 mm s^{-1}. Percentages of yolk, albumen and shell: determined by dividing their respective weights by the egg weight and results given percentages. Haugh unit: determined by formula proposed by Card and Nesheim (1968)

(Equation 1), from the data of egg weight and albumen height:

$$HU = 100 \log (H + 7.57 \text{ to } 1.7 W^{0.37}) \quad (1)$$

where:

H = albumen height in (mm);

W = egg weight in (g).

Yolk color was measured using a Roche yolk color fan with color scores from 1 to 15.

Taking into account the characterization of maize varieties and AGD determination diets were balanced according to the lineage nutritional requirements. Table 2 shows the percentage compositions and nutritional levels of the experimental diets.

Table 2. Composition and nutritional rates calculated from experimental diets formulated from flint and dent maize cultivars.

Ingredients (%)	Flint corn (cultivar DKB 177)	Dent corn (cultivar AG 4051)
Maize	64.772	65.253
Soybean meal 45%	24.918	23.107
Limestone	7.955	7.966
Dicalcium Phosphate	1.476	1.468
DL - Methionine	0.191	0.204
Wheat Bran	0.109	1.422
Salt	0.380	0.380
Mineral Supplement 1	0.100	0.100
Vitamin Supplement 1	0.100	0.100
Total	100.00	100.00
Calculated rates		
Metabolizable Energy (kcal kg^{-1})	2750	2750
Crude Protein (%)	17.000	17.000
Calcium (%)	3.500	3.500
Available phosphorus (%)	0.370	0.370
Digestible methionine (%)	0.400	0.400
Digestible lysine (%)	0.780	0.780
Digestible methionine + cystine (%)	0.680	0.680
Digestible threonine (%)	0.570	0.570
Digestible tryptophan (%)	0.170	0.170

[1]Nutritional levels of vitamin and mineral supplement for laying hens (per kg of diet): Vitamin A: 7.000 IU; Vitamin D3: 2.000 IU; Vitamin E: 50 UI; Vitamin K3: 1.6 mg; Vitamin B2: 3 mg; Vitamin B12: 8 mg; Niacin: 20 mg; Pantothenic acid: 5 mg; Choline: 234.36 mg; Copper: 8 mg; Iron: 50 mg; Manganese 70 mg; Zinc: 50 mg; Iodine 1.2 mg; Selenium 0.2 mg; Bacitracin zinc: 20 mg.

The isonutrient diets, differed only in maize cultivar and grain size of maize milling. The treatments were: Treatment 1 – Feed from flint maize cultivar (DKB 177) ground into fine particle size (602.08 μm); Treatment 2 - Feed from flint maize cultivar (DKB 177) ground into an average particle size (784.86 μm); Treatment 3 - Feed from flint maize cultivar (DKB 177) ground into coarse particle size (1166.19 μm); Treatment 4 – Feed from dent maize cultivar (AG 4051) ground into fine particle size (612.95 μm); Treatment 5 – Feed from dent maize cultivar (AG 4051) ground into average particle size (831.23 μm); Treatment 6 – Feed from dent maize cultivar (AG 4051) ground into coarse particle size (1230.05 μm).

The measurement of electrical power consumption required for milling the maize cultivars was made with a silver brand saw-type grind mill, powered by a three-phase induction 25 horsepower electrical motor. The maize was weighed before entering the mill, for a total of 160 kg per treatment. Power, voltage, current and power factor of the mill were measured during milling and grinding time was clocked.

The electrical behavior of the mill at different situations (texture of maize and corn size) was recorded SAGA 4000 electronic single or three-phase electrical balanced/unbalanced electrical systems analyzer with internal mass memory, allowing data to be recorded at intervals of measurement with no need to be transferred to a personal computer or portable reader. Data and time to grind the predetermined volume (160 kg of maize/treatment) were recorded for posterior analysis.

During the grinding process the following parameters were measured: power, voltage, current and power factor, at given intervals (every 10 seconds for flint corn and every 30 seconds for dent corn). As milling time was different between treatments, each treatment had a different number of data records.

The electricity consumption in kWh was obtained with Equation 2 for flint corn and with Equation 3 for dent corn from the sum of rates recorded by the device during the grinding of each treatment:

$$C = \Sigma Pt \quad (2)$$

$$C = \Sigma Pt \quad (3)$$

where:

C (kWh) = power consumption in (kWh);

Pt = instantaneous power of the engine measured at predetermined time intervals in (W).

The specific consumption of electric power (SC) in kWh kg^{-1} of ground maize for each treatment was determined by Equation 4:

$$SC = C/p \quad (4)$$

where:

SC: specific energy consumption per kilogram of maize in [kWh kg^{-1}];

p: quantity of maize in kg ground for each treatment, 160 kg.

For the statistical analysis of the rates of specific consumption of electricity in each treatment, there were a different number of repetitions, obtained as a function of grinding time. Thus, the number of records and replicates per treatment were: Treatment 1 - grinding time of 22 min. 40 s and 133 records and repetitions; Treatment 2 - grinding time of 21 min. 50 s and 131 records and repetitions; Treatment 3 - milling time of 22 min. 40 s and 128 records and repetitions; Treatment 4 - grinding time of 36 min. and 00 s and 72 records and repetitions; Treatment 5 - grinding time of 31 min. 30 s and 67 records and repetitions; Treatment 6 - grinding time of 36 min. 30 s and 73 records and repetitions.

Data were subjected to analysis of variance with SISVAR (Ferreira, 2000) and means compared by Tukey's test at 5% probability.

Results and discussion

Table 3 shows the results of productive performance of laying hens fed on diets composed of flint or dent maize processed to fine, medium or coarse particle sizes. There was no interaction ($p > 0.05$) among the factors evaluated, or rather, corn size and texture.

Table 3. Feed intake (FI), laying percentage (P), egg weight (Wegg), egg mass (EM), feed conversion dz^{-1} (FC dz) and feed conversion kg^{-1} (FC kg) of laying hens fed on diets composed of flint and dent maize ground to fine, medium or coarse particle sizes.

Variables		FI (g)	P (%)	W egg (g)	EM (g)	FC (dz)	FC (kg)
Kernel size	Fine[1]	115.87	87.42	64.16	56.10	1.59	2.08
	Medium[2]	115.91	88.17	65.28	57.57	1.58	2.03
	Coarse[3]	113.14	86.00	64.52	55.52	1.59	2.05
Texture	Flint*	116.30^A	87.49	65.14^A	57.00	1.60	2.05
	Dent**	113.64^B	86.90	64.17^B	55.79	1.58	2.06
CV (%)		3.62	4.71	2.26	5.21	4.17	4.14
Kernel size (K)		ns	ns	ns	ns	ns	ns
Texture (T)		< 0.05	ns	< 0.05	ns	ns	ns
Kernel size x Texture (K x T)		ns	ns	ns	ns	ns	ns

[1] (602.08 to 612.95 μm), [2] (784.86 to 831.26 μm), [3] (1166.19 to 1230.05 μm.) * Cultivar DKB 117; **cultivar AG 4051. [A, B] Means followed by different capital letters in the column differ ($p < 0.05$) by Tukey Test, ns (not significant at 5% significance level).

There was no effect ($p > 0.05$) of the particle size on the performance of the variables analyzed. Results revealed that the particle size did not alter significantly the digestion process and nutrient absorption, and may be used in the preparation of diets for laying hens. The physical form and particle size of the diet are among the factors that interfere with the morphological and physiological characteristics of the digestive tract of birds, damaging the villi or favoring microbial growth (Engberg et al., 2004; Frikha et al., 2011; Yegani & Korver, 2008).

The results of this experiment differ from those by Card and Nesheim (1968), who evaluated the effect on maize and wheat in diets for Lohmann Brown lineage laying hens fed on fine, medium and coarse particle sizes from grinding sieves of 6, 8 and 10 mm in hammer mills. These authors concluded that increasing particle size increased food intake but had no influence on the other performance characteristics.

The results demonstrate that particle size for laying hens has their productive performance somewhat modified by changing the particle size, within the range studied. This result indicates that the digestive organs, particularly intestine and gizzard, maintain their functionality without any impairment to nutrient assimilation and conversion of food products. Consequently, larger particle sizes may be administered.

Although several studies have shown that decrease in the particle size of food results in greater surface contact with digestive enzymes, Amerah et al. (2007) reported that coarse particles are more effective during processing and stimulate the development of the gizzard, providing increased intestinal motility and consequently greater digestion of nutrients.

There were significant differences ($p < 0.05$) of maize texture on feed intake in birds fed on flint corn obtaining higher food intake when compared to birds fed on dent corn. Result shows that diets based on flint corn provide higher food transportation rates and demonstrate increased consumption of food.

According to Ramos et al. (2009), the hardness of the corn was directly correlated with the amount of amylopectin and indicated that hard texture maize had a higher content of the polymer in its constitution when compared to the dent corn cultivar. Thus, differences in the structure and composition of the corn, coupled with higher feed intake, may have resulted in heavier eggs obtained from hens fed on hard maize corn.

Table 4 gives the results concerning the characteristics of egg quality.

No interaction was registered ($p > 0.05$) between corn size and texture characteristics of egg quality, except for yolk color. It fact, larger particle sizes determined best colorations, possibly because more slowly and gradually supplied pigments were better utilized by birds in yolk formation.

Although causing a change in yolk color, the size of particle tested was unable to alter the proportions of the constituents of eggs. The above indicated that the digestive tract was capable of processing food so that the supply of nutrients for the formation of yolk, albumen and shell was similar for all particle sizes. The retention of food in the gizzard for a longer time allowed the body to perform mechanical activities on the food and to expose it to the action of several digestive enzymes (Amerah et al., 2007).

Table 4. Specific gravity (SG), shell strength (Resis), yolk percentage (Y), percentage of albumen (A), percentage of shell (S), Haugh unit (HU) and yolk color (Color) of eggs from laying hens fed on diets with two textures of maize and fine, medium and coarse corn sizes.

Variables		SG (g cm^{-3})	Resis (kg)	Y (%)	A (%)	C (%)	HU	Color
Kernel size	Fine[1]	1,090	4.01	25.30	64.92	9.76	77.42	5.88^{B}
	Medium[2]	1,090	3.89	25.43	64.88	9.68	78.99	6.13^{A}
	Coarse[3]	1,090	3.94	25.59	64.75	9.65	79.25	6.13^{A}
Texture	Flint*	1,090	3.95	25.41	64.84	9.73	78.15	5.90^{B}
	Dent**	1,090	3.95	25.46	64.86	9.66	78.96	6.19^{A}
CV (%)		0.80	7.08	3.70	1.58	2.87	5.97	5.49
Kernel size (K)		ns	ns	ns	ns	ns	ns	<0.05
Texture (T)		ns	ns	ns	ns	ns	ns	<0.05
Kernel size x Texture (KxT)		ns	ns	ns	ns	ns	ns	ns

[1](602.08 to 612.95 μm), [2](784.86 to 831.26 μm) [3](1166.19 to 1230.05 μm.) *Cultivar DKB 117; **cultivar AG 4051. $^{A, B}$Means followed by different capital letters in the column differ ($p < 0.05$) by Tukey Test, ns (not significant at 5% significance level).

Differences were reported ($p < 0.05$) for texture while, dent cultivars showed better yolk color when compared to that of the flint cultivars. This difference may have been determined by the corn structure since the pigments in flint corn may form complexes with other components of the vitreous endosperm (starch and protein), making them less available when compared to the dent corn. Even if there were structural differences between the two maize textures under analysis, they had not been sufficient so that the percentages of yolk, albumen and shell could be changed, which indicated that the two maize cultivars showed similarities with regard to corn nutritional content.

According to Cotta (1997), the egg yolk is composed of lipoproteins, proteins, vitamins, minerals and pigments, which are substances synthesized by the liver and transported by the blood to the ovary. The above author further reported that liver function and dietary changes may interfere with the content of some constituents of the yolk, corroborating the results of current research.

Table 5 gives the results for the specific consumption of electric energy in kWh kg^{-1} during the milling of flint and dent maize cultivars into fine, medium and coarse particle sizes.

Table 5. Specific consumption of electricity (SCE) for grinding flint and dent maize cultivars through 3, 6 and 9 mm mesh sieves.

Variables		SCE (kWh kg^{-1})
Kernel size	Fine[1]	16.08
	Medium[2]	12.09
	Coarse[3]	11.83
Texture	Flint*	12.09
	Dent**	15.76
CV (%)		3.62
corn size (K)		< 0.05
Texture (T)		< 0.05
Particle size x Texture (K x T)		< 0.05

[1](602.08 to 612.95 μm), [2](784.86 to 831.26 μm), [3](1166.19 to 1230.05 μm.) *Cultivar DKB 117; **cultivar AG 4051. $p < 0.05$ (difference at 5% significance level).

There was an interaction ($p < 0.05$) among the factors evaluated. It may be noted that fine corn demanded greater milling machine work and, consequently, a higher energy consumption for grinding. Zanatta et al. (2006), compared the energy consumption of hammer mills using 4 and 8 mm mesh sieves, and reported, that reduction in energy demand is around 31% when working with 8 mm mesh sieves, or rather, a 6.4% higher maize meal production when compared to the 4 mm mesh sieve.

The results from the interaction between particle size and texture are shown in Table 6.

Table 6. Interaction between textures and degrees of grinding on the specific consumption of electricity (kWh kg^{-1}).

Kernel size	Texture		Average (kWh kg^{-1})
	Flint*	Dent**	
Fine[1]	14,80 ^{aA}	18.49 ^{bA}	16.08
Medium[2]	11,12 ^{aB}	13.96 ^{bC}	12.09
Coarse[3]	10.14 ^{aC}	14.72 ^{bB}	11.83
Average	12.09	15.76	

[1](602.08 to 612.95 μm), [2](784.86 to 831.26 μm) [3](1166.19 to 1230.05 μm.) *Cultivar DKB 117; **cultivar AG 4051. $^{A, B, C}$Means followed by different capital letters in the column differ significantly by Tukey's test ($p < 0.05$). $^{a, b}$Means followed by lower case letters in the row differ significantly by Tukey's test ($p < 0.05$).

The specific consumption of electricity (kWh kg^{-1} of ground maize) in milling dent cultivars was higher for all particle sizes, which may be due to the fact that dent maize offers more resistance to milling, probably because of its greater plasticity. Furthermore, flint maize corn shatters more easily into smaller particles in saw-type mills when compared to dent maize. In fact, they require less grinding work and cause a greater ground material flow, corroborated by the smaller particle sizes for flint when compared to dent maize.

Since dent maize cultivars requires more grinding time and greater process energy consumption, a lower milling rate is generated when compared to that of flint corn. Based on these results, the fine corn size resulted in energy consumption between 33 and 35% higher when compared to medium and coarse particle sizes, respectively. This increase in energy demand is a result of increased machine work for processing maize into smaller particles.

According to the results in Table 6, power consumption was 31.66% higher for dent maize cultivars than for flint cultivars. This result suggests that, due to its constitution and structure, dent corn is less efficient when ground in a saw mill. These results actually differ from those by Factori et al. (2008) who evaluated flint and dent maize milled to 865 and 570 μm geometric diameters, respectively fine and coarse sizes, and observed 14% higher energy consumption for grinding the flint maize cultivar to fine corn size when compared to that employed in dent maize cultivar.

It may be noted that decrease in electricity intake occurs parallel to increase in particle size and the relative power consumption/AGD is higher for the flint cultivar. The increase in milling time is a consequence of larger particle sizes obtained with the dent maize cultivar when compared to hard maize corn. The latter, requires greater machine work for maintaining the flow of grinding and consequently cause an increase in energy demand and reduction in the processing efficiency.

The type of equipment used may also change yield during processing. Pozza et al. (2005) reported that differences in equipment, both with reference to mill specification and to its proper design may induce variations in the grinding rate and power consumption. In fact, data collected during grinding showed that the saw mill seemed more efficient when used for processing flint maize corns, to produce medium or coarse corn sizes.

Conclusion

The maize flint cultivar ground into coarse (1166.19 μm) particle size is the treatment that combines productivity, efficiency and energy saving during milling.

The factors did not affect the external and internal characteristics of the eggs, except that the color yolk showed improvement with increasing particle size.

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