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ANIMAL SCIENCE

Effect of different levels of whole corn germ on energy values and ileal digestibility in broilers

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Abstract: This study evaluated the effects of broiler age (A) and levels of replacement (L) of control diet (CD) on the utilization of energy and nutrients of whole corn germ. 720 one-day-old broilers (b) were allocated at completely randomized design to six treatments and six replicates, in three assays: pre-starter (1-8 days, 10 b/cage), starter (15-22 days, 6 b/cage), and grower (28-35 days, 4 b/cage) phases. The treatments were: CD and four test diets (L): 100, 150, 200, 250, or 300 g kg^{-1} of the CD replaced by WCG levels. The data were adjusted to the response surface model. The stationary points for apparent energy metabolizable (AME) and AME corrected for nitrogen balance (AME_n) were: 4173 and 3591 kcal kg^{-1}, respectively, and coefficients of gross energy (AMCGE), crude protein (AMCCP), dry matter (AMCDM), and ether extract (AMCEE) were: 49.3, 40.4, 72.6, and 61.3%, respectively; and Ileal digestibility coefficient of crude protein (IDCCP), dry matter (IDCDM), digestibility crude protein values (DCP), and digestibility dry matter value (DDM) were: 78.0, 57.96, 8.50, and 56.17%, respectively. The EP for AMEn was at 18 days of age, 28 g kg-1 WCG. There was a correlation between A and L on digestibility and metabolisability of nutrient's WCG.

Key words: corn by-product, ether extract, ileal digestibility, metabolizable energy, stationary point.

INTRODUCTION

Some corn grain-processing industries are dedicated to the production of food starch and derivatives (e.g. gluten 60%, gluten 21%, defatted germ, whole germ, corn oil, among others). Wet milling is a more efficient process than dry milling in the separation of starch granules and the endosperm protein, generating a larger amount of by-product (Cardoso et al. 2011, Deepak & Jayadeep 2022).

In April 2023, according to the 7th CONAB survey, Brazil produced approximately 124.8 million tons of corn grain (CONAB 2023), and around 13.6% of this total were used by processing industries (CÉLERES 2023). Considering that the germ constitutes 11% of this grain (Paes 2006, Lopes et al. 2019), approximately 1.867 million tons of whole corn germ (WCG) were produced by the industries.

Whole corn germ is a by-product that can be obtained through the wet degermination of the corn grain without undergoing the lipid (corn oil) extraction process. It consists of the germ and the pericarp and contains high levels of ether extract, which range from 495 to 598 g kg^{-1} (Lima 2008, Lima et al. 2012, Albuquerque et al. 2014). Some companies extract the oil from WCG to produce another by-product, called 'defatted germ', which differs from WCG in its low ether extract content (101 g kg^{-1}) (Rochell et al. 2011, Rostagno et al. 2017). According to the literature, WCG contains 104 to 115 g kg^{-1}

crude protein (Lima 2008, Lima et al. 2012, Albuquerque et al. 2014), in addition to methionine, lysine, and threonine concentrations of 1.9, 4.8, and 4.0 g kg^{-1} (Albuquerque et al. 2014), which are higher than those found in corn (Lopes et al. 2019).

This by-product can be considered a high-energy feedstuff to be used in poultry diets, given its apparent metabolizable energy content of 4714 kcal kg^{-1} for 35-day-old broilers (Lima 2008). Few studies have been carried out to investigate the energy value of WCG obtained by wet processes, without the extraction of the corn oil, for broilers (Ciurescu 2008, Albuquerque et al. 2014, Ciurescu et al. 2014, Lopes et al. 2019). The majority of studies were conducted with defatted WCG (Kim et al. 2008, Stringhini et al. 2009, Brito et al. 2011, Rochell et al. 2011, Brunelli et al. 2012).

The age of poultry influences not only the metabolizable energy values, but also the metabolizability of nutrients from a diet. Nevertheless, none of the afore-mentioned studies took into consideration the effect of poultry age on the energy values of WGC or the interaction between age and the by-product inclusion levels. Matterson et al. (1965) analyzed different ingredients and reported changes in metabolizable energy according to the chemical composition of the tested ingredients. In addition, Sibbald & Price (1975) observed that the percentage of substitution of control diet with the test feedstuff also interferes with the metabolizable energy values. Silva et al. (2009) concluded that determining the metabolizable energy with poultry at different ages or of different categories (layers or broilers) can contribute to increasing the efficiency of diet formulations as it prevents overestimation caused by the inference of values determined in adult poultry for young poultry, or underestimation, in the opposite situation (results obtained in young poultry for adult poultry). Therefore, new studies should be conducted to investigate different levels of substitution of the test ingredients with poultry in different rearing phases to better define the metabolizable energy values.

Given this scenario, the present study proposes to evaluate the effect of poultry age and levels of substitution of control diet with WCG on the metabolizable energy values, metabolizability coefficients, and ileal digestibility coefficients of broilers, using the response surface model.

MATERIALS AND METHODS

The experiment was carried out in compliance with the ethical norms, after approval by the Ethics Committee on Animal Use (approval no. 083/2015) of the Universidade Federal Rural de Pernambuco (UFRPE).

Facilities and management of the poultry

A total of 720 one-day-old male broiler chicks (Cobb 500) with an average initial weight of 43 g were obtained from a commercial hatchery. The chicks were at completely randomized design to six treatments with six replicates. The experiment was divided into three assay, according to the birds age: pre-starter (1 to 8 days, 10 birds per replicate), starter (15 to 22 days, six birds per replicate), and grower (28 to 35 days, four birds per replicate).

The birds were housed in batteries of cages measuring 0.50 × 0.50 × 0.50 m in the pre-starter phase and 1.00 × 0.50 × 0.50 m in the starter and grower phases. Each cage was equipped with a trough feeder and a cup-type drinker. The room in which the cages were located had its ambient controlled, and the temperatures and air relative humidity values were recorded throughout the experimental period by a data logger (HOBOware U12-012). The temperature and humidity values recorded during the experiment were 30.79 °C and 64.11% in the pre-starter phase, 27.94 °C and 73.3% in the starter phase, and 26.86 °C and 76.55% in the grower phase, respectively.

The chicks were reared in a poultry facility where they received a diet and water *ad libitum*. The birds were managed according to recommendations to the lineage guideline. In each experimental phase, the poultry were selected based on their weight and transferred to the cages, with a new lot used for each phase.

Experimental diets and data collection

Experimental diets consisted of a control diet that was partially replaced with WCG in the proportions of 100, 150, 200, 250, and 300 g kg^{-1}. Control diet was formulated so as to meet the poultry nutritional requirements (Table I), in accordance with recommendations made by Rostagno et al. (2011). The WCG used consisted of germ and pericarp (Table II).

The partial excreta collection method (Matterson et al. 1965) was employed using 10 g kg^{-1} acid-insoluble ash, which was added to the diets (Scott & Boldaji 1997). Each experimental phase (1-8; 15-22 and 28-35 Days of life) lasted eight days, the first four of which were used as a period of adaptation, and the subsequent four were dedicated to the collection of excreta (which occurred twice daily).

The number of birds used for excreta collection followed according to each phase: pre-starter (1 to 8 days, 10 birds per replicate), starter (15 to 22 days, six birds per replicate), and grower (28 to 35 days, four birds per replicate).

At the end of each experimental phase, all birds were euthanized. Subsequently, their ileum was exposed by making an abdominal incision. A segment of 2.0 cm from Meckel's diverticulum ending at 2.0 cm from the ileocecal junction was then removed and its content was harvested.

Laboratory analyses

Samples of feed, excreta, and ileal content were analyzed for the concentrations of dry matter, nitrogen, and ether extract by the method described by AOAC (2006). Gross energy was determined using a bomb calorimeter standardized with benzoic acid and acid-insoluble ash was measured as proposed by Van Keulen & Young (1977).

For WCG, in addition to the above-described analyses, crude fiber (CF) and neutral detergent fiber (NDF) were also analyzed by the methodology described by AOAC (2006). Amino acids were determined by near-infrared reflectance spectroscopy.

Evaluated variables

Apparent metabolizable energy (AME) (Matterson et al. 1965), and nitrogen-corrected AME (AME_n) values, metabolisability coefficients of gross energy (AMCGE), crude protein (AMCCP), dry matter (AMCDM), and ether extract (AMCEE) in WCG were calculated using equations presented by Sakomura & Rostagno (2016). Based on the ileal content, we also determined the ileal digestibility coefficients of dry matter (IDC_{DM}) and crude protein (IDC_{CP}) and the digestible dry matter (DDM) and digestible crude protein (DCP) values (Sakomura & Rostagno 2016).

The coefficients were calculated as follows:

Table I. **Compositions of control diet according to broiler age (as-is basis).**

Centesimal composition	Age		
	1 to 8 days	15 to 22 days	28 to 35 days
Ground corn (78.8 g kg^{-1})	533.4	555.6	586.2
Soybean meal (450 g kg^{-1})	390.6	362.4	328.8
Soybean oil	32.4	43.0	49.2
Limestone	10.5	10.8	10.2
Dicalcium phosphate	19.2	15.4	13.2
Common salt	4.03	4.19	4.22
DL-methionine (990 g kg^{-1})	3.59	3.08	2.86
L-lysine HCl (788 g kg^{-1})	2.80	2.31	2.23
L-threonine (985 g kg^{-1})	1.06	0.73	0.61
Zinc bacitracin	0.50	0.50	0.50
Salinomycin sodium	0.50	0.50	0.50
Vitamin-supplement[1]	1.00	1.00	1.00
Mineral supplement[2]	0.50	0.50	0.50
Total	1000	1000	1000
Calculated nutritional composition, g kg^{-1}			
Metabolizable energy (kcal kg^{-1})	3000	3100	3180
Crude protein	224.0	212.0	199.0
Ether extract	58.1	69.1	75.6
Crude fiber	29.9	28.8	27.5
Calcium	9.20	8.41	7.58
Available phosphorus	4.75	4.01	3.54
Sodium	1.89	1.93	1.92
Potassium	8.71	8.26	7.74
Chlorine	3.50	3.50	3.50
Electrolytic balance	2247.6	2136.1	1983.3
Digestible amino acid, g kg^{-1}			
Methionine + cysteine	9.53	8.76	8.26
Methionine	6.52	5.88	5.53
Lysine	13.24	12.17	11.31
Threonine	8.61	7.91	7.35
Tryptophan	2.53	2.38	2.20
Arginine	14.20	13.37	12.41
Leucine	17.26	16.56	15.77
Isoleucine	8.88	8.29	7.72
Glycine + serine	18.70	17.72	16.57

[1]Guaranteed levels: vitamin A (min): 9,000,000 IU/kg, vitamin D3 (min): 1,600,000 IU/kg, vitamin E (min): 14,000 IU/kg, vitamin K3 (min): 1500 mg/kg, vitamin B1 (min): 1000 mg/kg, vitamin B2 (min): 4000 mg/kg, vitamin B6 (min): 1800 mg/kg, vitamin B12 (min): 12000 mcg/kg, folic acid (min): 300 mg/kg, pantothenic acid (min): 8280 mg/kg, biotin (min): 50 mg/kg, niacin (min): 30g/kg, and selenium (min): 250 mg/kg.
[2]Guaranteed levels: iron (min): 60 g/kg, copper (min): 18 g/kg, manganese (min): 120 g/kg, zinc (min):120 g/kg, and iodine (min): 2000 mg/kg.

$$\text{AME (kcal kg}^{-1}) = \text{Gross Energy - Gross Energy Excreted / Dry Matter Intake}$$

$$\text{AME}_n \text{ (kcal kg}^{-1}) = \text{(Gross Energy – (Gross Energy Excreted + 8.22 * Nitrogen Balance)) /dry matter intake}$$

$$\text{AMC}_{GE} = (\text{AME}_n \text{ / Gross Energy}) * 100$$

$$\text{AMC}_{DM} = \text{(DM ingested - DM excreted / DM ingested)} * 100$$

$$\text{AMC}_{CP} = \text{(CP ingested - CP excreted / CP ingested)} * 100$$

$$\text{AMC}_{EE} = \text{(EE ingested - EE excreted / EE ingested)} * 100$$

$$\text{DDM} = \text{(DM ingested - DM digesta) / DM ingested}$$

$$\text{DCP} = \text{(CP ingested - CP digesta) / CP ingested}$$

$$\text{IDCDM} = \text{(DDM Reference Diet + ((DDM Test Diet - DDM Reference Diet)/\% Inclusion of Feed)}$$

$$\text{IDCCP} = \text{(DCP Reference Diet + ((DCP Test Diet - DCP Reference Diet)/\% Inclusion of Feed)}$$

Statistical Analyses

The data were analyzed for the principles of error normality and variance homogeneity and were subjected to analysis of variance (ANOVA) to determine the difference between treatments ($P < 0.05$). The response surface model (RSM) was adjusted by using the RSREG procedure of SAS computer software version 9.0 (SAS Institute Cary - NC 2008) for the studied variables, considering the quadratic effects of poultry age, level of substitution of control diet with WCG, and the interaction between these two factors.

The system's behavior can be described as a quadratic model, according to the following equation:

$$\hat{Y} = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{14}x_1x_4 + a_{23}x_2x_3 + a_{24}x_2x_4 + a_{34}x_3x_4 + a_{11}x_1^2 + a_{22}x_2^2 + a_{33}x_3^2 + a_{44}x_4^2,$$

in which Y is the predicted response; a_0 is a constant coefficient (intercept); a_1, a_2, a_3, and a_4 are linear effects; a_{12}, a_{13}, a_{14}, a_{23}, a_{24}, and a_{34} are the interaction effects; a_{11}, a_{22}, a_{33}, and a_{44} are the quadratic effects; and x_1, x_2, x_3, and x_4 are independent variables, which are the levels of substitution of control diet with WCG (100, 150, 200, 250 and 300 g kg^{-1}) and broiler age (1 to 35 days of age). The critical points (a, b) of the z = f (x,y) function was obtained by solving the equation system formed by partial derivatives, which are described below:

$$\frac{\partial z}{\partial x} = 0$$

$$\frac{\partial z}{\partial y} = 0$$

Table II. Chemical, energy, and total amino acid compositions of whole corn germ (dry matter basis).

Nutrient, g kg^{-1}		Essential amino acid, g kg^{-1}	
Dry matter	974.0	Methionine	2.15
Crude protein	108.0	Lysine	5.44
Ether extract	565.2	Cystine	2.51
Crude fiber	235.2	Threonine	4.55
Neutral detergent fiber	302.8	Tryptophan	1.48
Gross energy (kcal kg^{-1})	7,183	Arginine	8.06
Mineral matter	16.0	Leucine	9.76
Non-essential amino acid, g kg^{-1}		Isoleucine	3.95
Glutamic acid	16.75	Valine	6.48
Aspartic acid	7.83	Phenylalanine	5.04
Glycine	6.52	Histidine	3.99
Serine	5.41		
Alanine	6.81		
Proline	7.66		

Table III. Averages of apparent metabolizable energy (AME), nitrogen-corrected AME (AME_n), and apparent metabolizability coefficients of gross energy (AMC_{GE}), crude protein (AMC_{CP}), dry matter (AMC_{DM}), and ether extract (AMC_{EE}) of whole corn germ (WCG), on a dry matter basis.

Substitution level (g kg^{-1})	Variable					
	AME	AME_n	AMC_{GE}	AMC_{CP}	AMC_{DM}	AMC_{EE}
	(kcal kg^{-1})		(%)			
	Age - 1 to 8 days					
100	3703	3508	48.03	63.20	45.47	28.03
150	3718	3530	47.79	63.39	44.98	31.73
200	4407	4243	57.44	67.33	70.74	36.76
250	4621	4435	60.05	68.91	65.58	43.95
300	4325	4179	56.58	67.87	58.52	37.34
Mean	4155	3979	53.98	66.14	57.06	35.56
	Age - 15 to 22 days					
100	4497	4414	59.76	72.00	75.96	43.01
150	4740	4624	62.60	73.16	66.50	45.05
200	5113	4977	67.39	75.10	80.94	69.31
250	4240	4221	57.14	69.12	50.58	44.84
300	4125	3981	53.90	71.94	50.29	44.30
Mean	4543	4443	60.16	72.26	64.85	49.30
	Age - 28 to 35 days					
100	4850	4831	65.40	77.92	61.47	46.12
150	5072	5007	67.79	77.93	68.85	55.51
200	5366	5199	70.40	80.44	77.12	64.65
250	4941	4791	64.86	77.69	60.38	59.26
300	4890	4789	64.84	74.19	53.71	50.08
Mean	5024	4923	66.66	77.63	64.31	55.12
SP	4173	3591	49.27	40.37	72.56	61.26
P value						
A	0.0008	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
$(A)^2$	0.4458	0.8922	0.8386	0.3231	0.0431	0.0124
$(L)^2$	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
L × A	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1331

SP = stationary point; A = bird age; L = level of substitution with WCG; $(A)^2$ = quadratic trend of age; $(L)^2$ = quadratic trend of level; L × A = interaction between level and age; P value = probability, significant when P<0.05.

RESULTS

Energy values and metabolisability coefficients of WCG

The metabolizable energy values and the metabolisability coefficients of the nutrients from WCG (Table III), revealed an interaction effect between the levels of substitution (L) with WCG and poultry age (A) on AME, AME_n, AMC_{GE}, AMC_{DM}, AMC_{CP}, and AMC_{EE}. The square of substitution level (L^2) showed a significant interaction with all analyzed variables, whereas the square of age (A^2) only showed an interaction with AMC_{DM} and AMC_{EE}. An interaction effect between level and age (L × A) was observed for AME, AME_n, AMC_{GE}, AMC_{DM}, and AMC_{CP}.

The stationary points for AME and AME_n were 4173 and 3591 kcal kg^{-1}, respectively (Table III). Table IV contains the RSM equations estimated for AME, AME_n, AMC_{GE}, AMC_{DM}, AMC_{CP}, and AMC_{EE} as well as the practical levels determined using the equations generated by the RSM. The minimum AME and AME_n values were 1781 and 1551 kcal kg^{-1}, respectively, and, as the broiler aged, these respective values rose by 52.5 and 68.4 kcal kg^{-1} per day.

The estimated point of optimum utilization of the energy from WCG considering the level × age interaction is represented by AME at 17.64 days of age with 280.5 g kg^{-1} WCG and by AME_n at 43 days of age with 357.3 g kg^{-1} WCG in the diet. The values given by the model estimated for AMC_{GE} were 40.12

Table IV. Equations of the RSM for apparent metabolizable energy (AME), nitrogen-corrected AME (AME_n), and apparent metabolizability coefficients of gross energy (AMC_{GE}), crude protein (AMC_{CP}), dry matter (AMC_{DM}), and ether extract (AMC_{EE}) of whole corn germ (WCG) for broilers from 1 to 35 days of age and practical levels.

Estimate	AME	AME_n	AMC_{GE}	AMC_{CP}	AMC_{DM}	AMC_{EE}
p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Intercept	1781.167	1551.255	22.019	48.399	-	–27.368
A	52.446	68.422	0.896	0.814	2.160	1.821
L	2034.550	1966.860	25.990	11.850	54.700	53.130
A × L	−1.570	−1.819	−0.024	−0.016	−0.050	-
A^2	-	-	-	-	−0.020	−0.0200
L^2	−41.190	-38.490	−00.510	−00.210	−01.200	−01.180
R^2	0.720	0.760	0.760	0.900	0.430	0.680
SP_A	17.640	43.040	40.120	11.680	31.160	38.200
SP_L	280.500	357.300	348.000	64.300	165.600	202.700

Practical levels

Age (days)	Optimum WCG level (g kg^{-1})	AME_n value (kcal/kg)
7	238	4228
14	2223	4413
21	206	4620
28	190	4846
35	1728	5095

RSM = response surface model; p = probability of the analysis; A = bird age; L = level of substitution with WCG; A × L = interaction between age and level; A^2 = quadratic trend of age; L^2 = quadratic trend of level; R^2 = determination coefficient; SP_A= stationary point for age; SP_L = stationary point for level.

days of age and 348.0 g kg^{-1} WCG; for AMC_{DM}, 31 days and 165.6 g kg^{-1}; and for AMC_{EE}, 38 days at the WCG level of 202.7 g kg^{-1}. There were daily increases of 0.89% in AMC_{GE}, 0.81% in AMC_{CP}, 2.16% in AMC_{DM}, and 1.82% in AMC_{EE}.

Every 10 g kg^{-1} of WCG added to the diet increased AME by 203.5 kcal kg^{-1} and AME_n by 196.7 kcal kg^{-1}. However, there was saturation of WCG; i.e. the energy utilization values decreased as the substitution levels were elevated ($L^2 = -42$ g kg^{-1}).

Based on the equations described by the mathematical model, we constructed the graphs presented in Figures 1a, b and 2a, b which show the behavior of the studied dependent variables in relation to the independent variables (level × age).

Ileal digestibility of WCG

The ileal digestibility coefficients of the nutrients from WCG obtained with broilers (Table V) revealed a significant effect of poultry age and substitution level on all studied variables (IDC_{CP}, IDC_{DM}, DCP, and DDM). However, there was no quadratic effect of age and level on IDC_{DM} or DDM. The following stationary points were estimated: IDC_{CP} = 78.88%, IDC_{DM} = 57.96, DCP = 8.50%, and DDM = 56.17%.

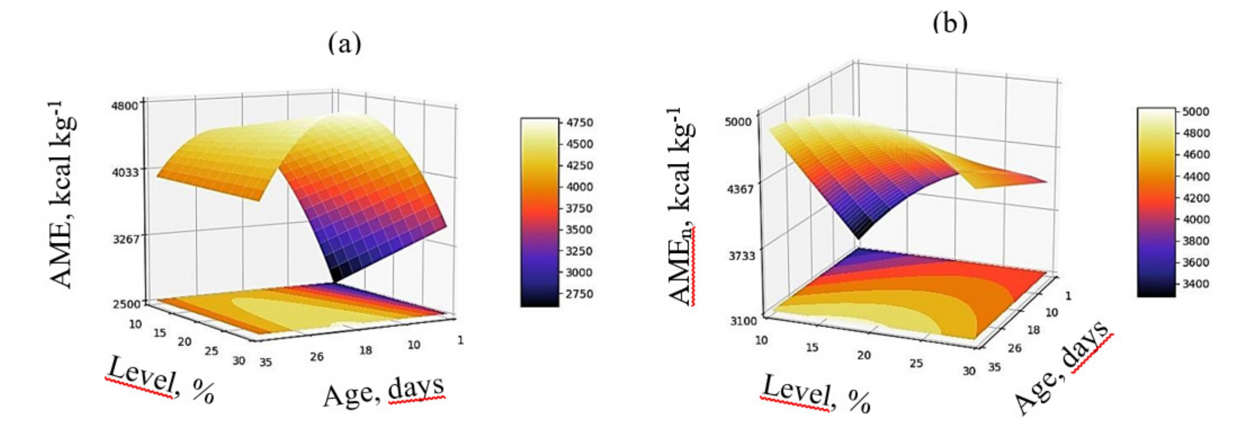

Figure 1. Result of response surface analysis illustrating the behavior of apparent metabolizable energy (AME; a) and nitrogen corrected AME (AME_n; b) of whole corn germ (WCG) at different substitution levels and poultry ages.

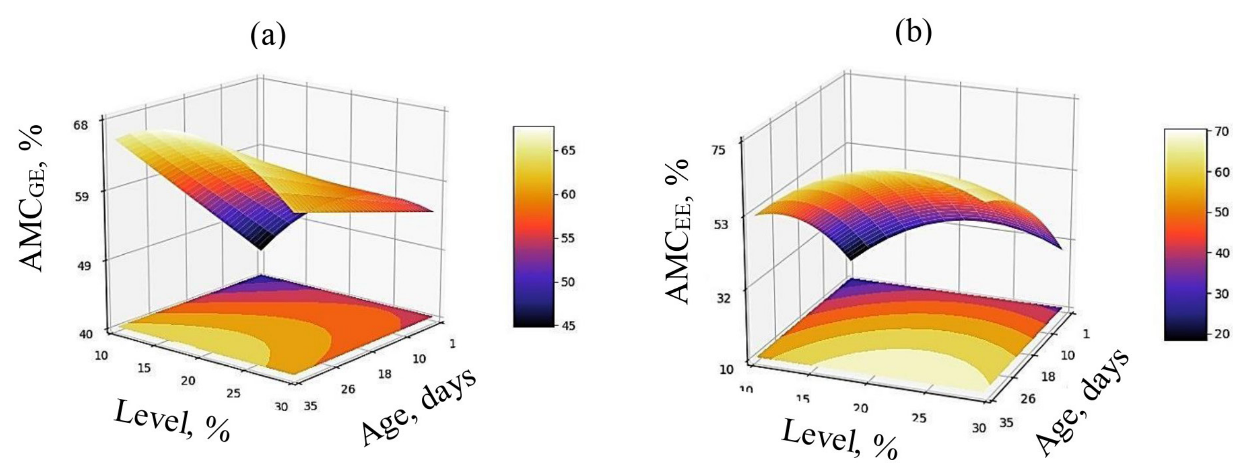

Figure 2. Result of response surface analysis illustrating the behavior of apparent metabolizability coefficient of gross energy (AMC_{GE}; a) and apparent metabolizability coefficient of ether extract (AMC_{EE}; b) of whole corn germ (WCG) at different substitution levels and poultry ages.

Table V. **Average of ileal digestibility coefficients of crude protein (IDC_{CP}) and dry matter (IDC_{DM}), digestible crude protein (DCP), and digestible dry matter (DDM) of whole corn germ (WCG) for broilers.**

Substitution level (g kg^{-1})	Variable			
	IDC_{CP} (%)	IDC_{DM} (%)	DCP (g kg^{-1})	DDM (g kg^{-1})
Age - 1 to 8 days				
100	86.91	45.51	9.36	44.26
150	87.83	44.60	9.46	43.37
200	91.13	70.23	9.81	68.30
250	91.15	62.74	9.82	61.02
300	82.98	57.80	8.94	56.21
Mean	88.00	56.18	9.48	54.63
Age - 15 to 22 days				
100	73.54	57.67	7.92	56.08
150	77.11	55.23	8.3	53.71
200	78.70	56.08	8.48	54.54
250	79.35	59.61	8.55	57.97
300	77.93	53.97	8.39	52.48
Mean	77.33	56.51	8.33	54.96
Age - 28 to 35 days				
100	73.47	74.09	7.91	72.05
150	81.05	67.22	8.73	65.37
200	80.58	59.69	8.68	58.05
250	76.84	48.75	8.28	47.41
300	75.29	46.87	8.11	45.58
Mean	77.45	59.32	8.34	57.69
SP	78.88	57.96	8.5	56.37
P value				
A	<0.0001	0.0010	<0.0001	0.0010
L	0.0014	0.0005	0.0014	0.0005
$(A)^2$	0.0002	0.4385	0.0002	0.4385
$(L)^2$	0.0007	0.0651	0.0007	0.0651
L × A	0.6647	<0.0001	0.6647	<0.0001

SP = stationary point; A = bird age; L = level of substitution with WCG; $(A)^2$ = quadratic trend of age; $(L)^2$ = quadratic trend of level; L × A = interaction between level and age; P value = probability, significant when P<0.05.

Table VI. Equations described by the RSM for the ileal digestibility coefficients of crude protein (IDC_{CP}) and dry matter (IDC_{DM}), digestible crude protein (DCP), and digestible dry matter (DDM) of whole corn germ (WCG) for broilers from 1 to 35 days of age.

Estimate	Variable			
	IDC_{CP}	IDC_{DM}	DCP	DDM
p	0.6590	0.1306	0.659	<0.0001
Intercept	79.592	-	8.572	-
A	–1.524	1.462	–0.164	1.422
L	20.220	29.890	02.180	29.070
A × L	-	–0.082	-	–0.079
A^2	0.026	-	0.003	-
L^2	–00.510	-	–00.060	-
R^2	0.490	0.490	0.490	0.490
SP_A	28.280	17.880	28.280	17.880
SP_L	206.100	208.400	206.100	208.400

RSM = response surface model; p = probability of the analysis; A = bird age; L = level of substitution with WCG; A^2 = quadratic trend of age; L^2 = quadratic trend of level; A × L = interaction between level and age; R^2 = determination coefficient; SP_A= stationary point for age; SP_L = stationary point for level.

The equations predicted by the RSM are described in Table VI. Significance was only detected for DDM, which rose by 1.42% per day and by 2.91% with every 10 g kg^{-1} of WCG added. It can be considered that the levels for optimum ileal digestibility of crude protein and dry matter were 206 g kg^{-1} at 28.2 days and 208 g kg^{-1} at 17.9 days of age, respectively.

DISCUSSION

Alternative energy feeds to corn tend to have high levels of ether extract and crude fiber (WCG), which can lead to a lower use of the feed in the initial phase of the poultry due to the low production of digestive enzymes, such as lipase and low microbial fermentation, that favor fiber digestion. These nutritional composition characteristics can also reduce the use of nutrients in the final phase, not due to the low production of digestive enzymes, but through saturation and stability in the processes of digestion and absorption of lipids, which lead to meeting the energy demand (Sakomura et al. 2014), and also by controlling satiety, increasing the passing rate through fiber content (Safaa et al. 2014).

In this study, it was possible to observe the effects of age and WCG level on metabolizable energy, metabolisability coefficients and ileal digestibility of broilers, whose advanced age was not enough to maintain maximum digestion and maximum absorption of WCG in the higher inclusion levels. Despite the use of nutrients increases with advancing age of broiler.

As a broiler grows older, it improve metabolizes the dietary nutrients. In this study, it was clear that, in the first days, with the use of low levels of WCG, AME increased linearly. However, after the stationary point, the AME values declined as the WCG inclusion levels were increased. A similar trend was seen for AME_n, which reached a saturation point at which the broiler body could not utilize all energy provided by the by-product despite its increasing digestibility with age.

The ileal digestibility of nutrients is expected to increase as broiler age. This was true up to approximately 28 days for IDC_{CP} and DCP and 18 days for IDC_{DM} and DDM. The model shows that, after those points, the ileal digestibility of WCG decreases. According to the RSM, the ideal WCG inclusion level to determine the ileal digestibility variables analyzed in this study is approximately 210 g kg^{-1}.

These phenomena can be explained by the lipid digestion process in poultry. Older broilers have a better nutrient digestibility than youngers due to the increased activity of the amylase, trypsin, and lipase enzymes (Schneiders et al. 2015, Ravindran & Abdollahi 2021); because duodenal activity doubles with age (between the 4th and 21st days of life); and also as a response to the consumed feed (Sklan 2001, Kato 2005). The concentrations of biliary salts rise linearly until their second week of life, because biliary secretion then is between 0.4 and 1 mL kg^{-1} per h (Macari et al. 2008). In this way, the reduction of the energy values in WCG might have been due to a possible saturation and stability in the processes of digestion and absorption of lipids in the gastrointestinal tract of the birds.

Lipid digestion in the intestinal lumen requires the participation of pancreatic and biliary secretions. The pancreatic lipase enzyme acts on triglycerides, degrading them to monoglycerides. Meanwhile, biliary secretions act on the emulsification of fats to facilitate enzymatic action (Nelson & Cox 2011). Hurwitz et al. (1973) estimated that 90% of bile salts are reabsorbed in the jejunum and ileum. Bile salts escaping intestinal absorption enter the hindgut, where they are deconjugated and dehydroxylated by bacteria (Zaefarian et al. 2019). In absence of biliary salts, lipid absorption is drastically diminished, increasing the presence of fat in the feces (Reece 2006). Increasing fatty acid intakes prompt an activation of cholecystokinin, which reduces the peristaltic movements of the intestine, thereby extending the residence time of the feed bolus in the digestive system and providing the sensation of satiety (Macari et al. 2008).

In addition to the impact of high ether extract contents, the fibers also influenced the utilization of the energy from the by-product. High levels of insoluble fiber in poultry diets are known to elevate the rate of passage of the feed through the small intestine. In this regard, Lima et al. (2016) reported an increase in the rate of passage of WCG added at the levels of 100 to 400 g kg^{-1} in layer diets. Hetland et al. (2003) stated that fiber is usually considered a diluent in poultry diets. Rochell et al. (2011) generated prediction equations for corn by-products and concluded that hemicellulose has an effect on the AME_n values and that it is a type of primary fiber present in corn by-products, composing a great part of NDF and CF.

The dietary fiber exerts metabolic and physiological effects on poultry, and it differs according to the fractions that constitute it, which can be soluble or insoluble. The physical stimulation of fibers on the wall of the gastrointestinal tract may reduce the action of digestive enzymes and consequently reduce nutrient digestibility (Sacranie et al. 2012). High levels of dietary soluble fiber may induce satiety and reduce feed intake in poultry (Mateos et al. 2014, Safaa et al. 2014). Additionally, they may accelerate fermentation in the small intestine, promoting a reduction in the digestibility of protein, starch, and lipids (Nian et al. 2011). However, the presence of a moderate quantity of insoluble fibers in the diet improves the digestibility of starch and lipids as a result of the greater activity of the gizzard, which may increase the reflux of digesta from the duodenum towards it, leading to an increase in the interaction between α-amylase and biliary acids and the substrates (Hetland et al. 2002, Jiménez-Moreno et al. 2016, Sacranie et al. 2017).

In this way, the energy values of ingredients are usually determined during the starter phase; however, the RSM gave accurate information about the poultry behavior during the rearing period through a simultaneous use of the correlation between birds age and the inclusion level of the test ingredient on the studied variables.

Broilers have a higher feed intake in the starter and grower phases, and when fed diets with high lipid contents, they may not fully utilize them due to the insufficient enzymatic production to metabolize the lipids available in the gastrointestinal tract. Lima (2008) reported a linear decrease in the feed intake of chickens fed diets containing WCG.

CONCLUSIONS

The level of replacement to the reference diet and broiler chickens' age influenced the determination of metabolizable energy and nutrient digestibility of whole corn germ. The age of the broiler chickens and the characteristics of the composition of the whole corn germ (lipids and fiber) must be considered to define the replacement level in digestibility studies with broiler chickens.

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REFERENCES

ALBUQUERQUE CS, RABELLO CBV, SANTOS MJB, LIMA MB, SILVA EP, LIMA TS, VENTURA DP & DUTRA JR WM. 2014. Chemical composition and metabolizable energy values of corn germ meal obtained by wet milling for layers. Braz Jour Poult Sci 16: 107-112. Doi: https://doi.org/10.1590/S1516-635X2014000100015.

AOAC INTERNATIONAL. 2006. Official Methods of Analysis of AOAC International. 18th ed. AOAC Int., Gaithersburg, MD.

BRITO AB, STRINGHINI JH, XAVIER SAG, GONZALES E, LEANDRO NSM & CAFÉ MB. 2011. Digestibilidade dos aminoácidos do milho, farelo de soja e gérmen integral de milho em galos e frangos de corte cecectomizados. Rev Bras Zootec 40(10): 2147-2151. Doi: https://doi.org/10.1590/S1516-35982011001000012.

BRUNELLI SR, PINHEIRO JW, FONSECA NAN & SILVA CA. 2012. Efeito de diferentes níveis de farelo de gérmen de milho desengordurado em dietas suplementadas com fitase para poedeiras comerciais. Semina: Ciênc Agr 33: 1991-2000. Doi: https://doi.org/10.5433/1679-0359.2012v33n5p1991.

CARDOSO WS, PINHEIRO FA, MACHADO FP, BORGES JTS & RIOS SA. 2011. Indústria do milho. In: Milho biofortificado. Ed. Suprema, p. 290, MG, Visconde do Rio Branco.

CÉLERES. 2023. Consultoria estratégica para o agronegócio. Disponível em: <https://celeres.com.br/>. Accessed 21 July 2023.

CIURESCU G. 2008. Chemical composition and effects the dietary corn by-products on broiler performance. Zootehnie si Biotehnologii 41: 491-497. Available at: https://spasb.ro/index.php/public_html/article/view/1814.

CIURESCU G, ROPOTA M & GHEORGHE A. 2014. Effect of various levels of corn germ on growth performance, carcass characteristics and fatty acids profile of thigh muscle in broiler chickens. Archivos Zootechnie 17: 77-91. Available at: https://www.ibna.ro/arhiva/AZ%2017-1/06_CiurescuG.pdf.

CONAB - COMPANHIA NACIONAL DE ABASTECIMENTO. 2023. Acompanhamento da Safra Brasileira de Grãos, Brasília, DF, v. 10, safra 2022/23, n. 7 sétimo levantamento, abril 2023. Available at: file:///C:/Users/apolo/Downloads/site_Boletim_de_Safras-7o-levantamento compactado.pdf.

DEEPAK TS & JAYADEEP PA. 2022. Prospects of Maize (Corn) Wet Milling By-Products as a Source of Functional Food Ingredients and Nutraceuticals. Food Technol

Biotechnol 60(1): 109-120. Doi: https://doi.org/10.17113/ftb.60.01.22.7340.

HETLAND H, SVIHUS B & KROGDAHL A. 2003. Effects of oat hulls and wood shavings on digestion in broilers and layers fed diets based on whole or ground wheat. Br Poult Sci 44: 275-282. https://doi.org/10.1080/000716603 1000124595.

HETLAND H, SVIHUS B & OLAISEN V. 2002. Effect of feeding whole cereals on performance, starch digestibility and duodenal particle size distribution in broiler chickens. Brit Poult Sci 43: 416-423. Doi: https://doi.org/10.1080/00071660120103693.

HURWITZ S, BAR A, KATZ M, SKLAN D & BUDOWSKI P. 1973. Absorption and secretion of fatty acids and bile acids in the intestine of the laying fowl. J Nutr 103: 543-547. Doi: https://doi.org/10.1093/jn/103.4.543.

JIMÉNEZ-MORENO E, COCA-SINOVA A, GONZÁLEZ-ALVARADO JM & MATEOS GG. 2016. Inclusion of insoluble fiber sources in mash or pellet diets for young broilers. 1. Effects on growth performance and water intake. Poult Sci 95: 41-52. Doi: https://doi.org/10.3382/ps/pev309. Epub 2015 Nov 14.

KATO RK. 2005. Energia metabolizável de alguns ingredientes para frangos de corte em diferentes idades. 95 p. Tese (Doutorado em Zootecnia), Universidade Federal de Lavras, Lavras.

KIM EJ, AMEZCUA CM, UTTERBACK PL & PARSONS M. 2008. Phosphorus Bioavailability, True Metabolizable Energy, and Amino Acid Digestibilities of High Protein Corn Distillers Dried Grains and Dehydrated Corn Germ. Poult Sci 87: 700-705. Doi: https://doi.org/10.3382/ps.2007-00302.

LIMA MB, RABELLO CBV & SILVA EP. 2016. Valores energéticos do gérmen integral de milho para aves de postura. R Ciênc Agron 47: 770-777. Doi: https://doi.org/10.5935/1806-6690.20160092.

LIMA MB, RABELLO CBV, SILVA EP, LIMA RB, ARRUDA EMF & ALBINO LFT. 2012. Effect of broiler chicken age on ileal digestibility of corn germ meal. Act Scient Anim Sci 34: 137-141. Doi: https://doi.org/10.4025/actascianimsci.v34i2.11812.

LIMA RB. 2008. Avaliação nutricional de derivados da moagem úmida do milho para frangos de corte industrial. 58 p. Dissertação (Mestrado em Zootecnia), Universidade Federal Rural de Pernambuco, Recife.

LOPES EC, RABELLO CBV, SANTOS MJB, LOPES CC, OLIVEIRA CRC, SILVA DA, OLIVEIRA DP & DUTRA JÚNIOR WM. 2019. Performance and carcass characteristics of broilers fed whole corn germ. R Bras Zootec 48: e20180247. Doi: https://doi.org/10.1590/rbz4820180247.

MACARI M, FURLAN RL & GONZALES E. 2008. Fisiologia aviária aplicada a frangos de corte. Ed. Funep. SP: Jaboticabal, 375 p.

MATEOS GG, JIMÉNEZ-MORENO E, GUZMÁN P, SALDANÃ B & LÁZARO R. 2014. Importance of fiber in pullet diets. Advancing Poultry Production, Proceedings of the Massey Technical Update Conference 16: 3-18.

MATTERSON LD, POTTER LM & STUTZ MW. 1965. The metabolizable energy of feed ingredients for chickens. Agricultural Experimental Station Research Report 7: 3-11.

NELSON DL & COX MM. 2011. Princípios de Bioquímica de Lehninger. 5a ed.: Editora Artmed, RS: Porto Alegre, 1274 p.

NIAN F, GUO YM, RU YJ, LI FD & PÉRON A. 2011. Effect of exogenous xylanase supplementation on the performance, net energy and gut microflora of broiler chickens fed wheat-based diets. A Austr J Anim Scie 24: 400-406. Doi: https://doi.org/10.5713/ajas.2011.10273.

PAES MCD. 2006. Aspectos físicos, químicos e tecnológicos do grão de milho. Embrapa Milho e Sorgo, Sete Lagoas. (Circular técnica, 75). Available at: https://www.infoteca.cnptia.embrapa.br/bitstream/doc/489376/1/Circ75.pdf.

RAVINDRAN V & ABDOLLAHI RM. 2021. Nutrition and Digestive Physiology of the Broiler Chick: State of the Art and Outlook. Animals 11(10): 2795. Doi: https://doi.org/10.3390/ani11102795.

REECE WO. 2006. Dukes Fisiologia dos animais domésticos. 12 ed., Ed. Guanabara Koogan, RJ: Rio de Janeiro, 926 p.

ROCHELL SJ, KERR BJ & DOZIER WA. 2011. Energy determination of corn co-products fed to broiler chicks from 15 to 24 days of age, and use of composition analysis to predict nitrogen-corrected apparent metabolizable energy. Poult Sci 90: 1999-2007. Doi: https://doi.org/10.3382/ps.2011-01468.

ROSTAGNO HS ET AL. 2017. Tabelas brasileiras para aves e suínos. Composição de alimentos e exigências nutricionais. 4ª edição, p. 488, UFV, MG, Viçosa.

ROSTAGNO HS, ALBINO LFT, DONZELE JL, GOMES PS, OLIVEIRA RF, LOPES DC, FERREIRA AS, BARRETO SLT & EUCLIDES RF. 2011. Tabelas brasileiras para aves e suínos. Composição de alimentos e exigências nutricionais. 3ª edição, Ed. UFV, MG: Viçosa, 252 p.

SACRANIE A, ADIYA X, MYDLAND LT & SVIHUS B. 2017. Effect of intermittent feeding and oat hulls to improve phytase efficacy and digestive function in broiler chickens. Brit

Poult Sci 58: 442-451. Doi: https://doi.org/10.1080/00071668.2017.1328550.

SACRANIE A, SVIHUS B, DENSTADLI V, MOEN B, IGI PA & CHOCT M. 2012. The effect of insoluble fiber and intermittent feeding on gizzard development, gut motility, and performance of broiler chickens. Poultr Sci 91: 693-700. Doi: https://doi.org/10.3382/ps.2011-01790.

SAFAA HM, JIMÉNEZ-MORENO E, FRIKHA M & MATEOS GG. 2014. Plasma lipid metabolites and liver lipid components in broilers at 21 days of age in response to dietary different fiber sources. Egyptian J Anim Prod 51: 115-127. Doi: https://doi.org/10.21608/ejap.2014.93658.

SAKOMURA NK & ROSTAGNO HS. 2016. Métodos de pesquisa em nutrição de monogástricos. 2ª Ed., Ed. Funep. SP: Jaboticabal, 262 p.

SAS - STATISTICAL ANALYSIS SYSTEM. 2008. Version 9.0. North Carolina, USA. Institute Cary: The SAS Institute.

SCHNEIDERS JL, NUNES RV, SCHONE RA, FRANK R, SAVOLDI TL, TSUTSUMI CY, SCHERER C & CASTILHA LD. 2015. Energy coefficients of plant foods for broiler chickens at different ages. Semina: Ciênc Agr 38: 2119-2128. Doi: https://doi.org/10.5433/1679-0359.2017V38N4P2119.

SCOTT TA & BOLDAJI F. 1997. Comparison of inert markers [chormic oxide or insoluble ash (CaliteTM)] for determining apparent metabolizable energy of wheat or barley based broiler diets with or without enzymes. Poultry Science 76: 594-598. Doi: https://doi.org/10.1093/ps/76.4.594.

SIBBALD IR & PRINCE K. 1975. Variation in the metabolizable energy values of diets and dietary components feed to adult roosters. Poultry Science 54: 448-456. Doi: https://doi.org/10.3382/ps.0540448.

SILVA EP, RABELO CBV, LIMA MB, LOUREIRO RRS, GUIMARÃES AAS & DUTRA JÚNIOR WM. 2009. Valores energéticos de ingredientes convencionais para aves de postura comercial. Ciênc Anim Bras 10: 91-100.

SKLAN D. 2001. Development of the digestive tract of poultry. W Poult Sci J 57: 415-428. Doi: https://doi.org/10.1079/WPS20010030.

STRINGHINI JH, SANTOS DA, BRITO AB, NUNES RC, RUFINO LM & SANTOS BM. 2009. Desempenho de pintos de corte alimentados com rações contendo milho pré-gelatinizado. Rev Bras Zootec 38(9): 1738-1744. Doi: https://doi.org/10.1590/s1516-35982009000900014.

VAN KEULEN J & YOUNG BA. 1977. Evaluation of acid-insoluble ash as a natural marker in ruminant digestibility studies. J Anim Sci 44: 282:287. Doi: https://doi.org/10.2527/jas1977.442282x.

ZAEFARIAN F, ABDOLLAHI MR, COWIESON A & RAVINDRAN V. 2019. Avian Liver: The Forgotten Organ. Animals 9(2): 63. Doi: https://doi.org/10.3390/ani9020063.

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