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Performance and carcass characteristics of broilers fed whole corn germ

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ABSTRACT - The objective of this study was to evaluate the effect of including whole corn germ (WCG) on the performance; diet metabolizability; yields of carcass, cuts, and offal; and quality of meat of broilers. A total of 648 chicks were assigned to six treatments in a completely randomized design with six replicates, with 18 birds in each. Treatments consisted of a corn- and soybean meal-based control diet (0 g kg^{-1} WCG) and five test diets including WCG at the levels of 40, 80, 120, 160, and 200 g kg^{-1}. Birds and diets were weighed at each seven days to determine feed intake (FI), body weight gain (BWG), and feed conversion ratio (FCR). The partial collection methodology was employed to determine the apparent metabolizable energy (AME), nitrogen-corrected AME (AME$_n$), and the apparent metabolizability coefficients of gross energy (AMC$_{GE}$), dry matter (AMC$_{DM}$), crude protein (AMC$_{CP}$), and ether extract (AMC$_{EE}$) of the diets. In the evaluation of meat quality, we analyzed the pH, cooking losses, shear force, water-holding capacity, color, and peroxide index of the meat. There was a difference for BWG and FCR in the total rearing period (1 to 42 days), for which optimum BWG was estimated as 2921 g/bird, with 118 g kg^{-1} inclusion of WCG. There was no difference for the AME, AME$_n$, and AMC$_{CP}$ of the diets, although AMC$_{GE}$, AMC$_{DM}$, and AMC$_{EE}$ declined as WCG was included. The increasing levels of WCG did not influence the yields of carcass and cuts or the meat quality. There was an increase in the yield of gizzard and proventriculus. Whole corn germ can be used at low levels in the diet of broilers without compromising their productive rates.

Keywords: carcass yield, corn byproduct, lipid source, meat quality, metabolizable energy

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Introduction

In poultry farming, corn and soybean are the main sources of energy and protein used in the formulation of diets. Therefore, any variation in the price or supply of those ingredients influences the costs of the activity.

During the wet-milling step, the corn grain used in the food industry generates several products for human consumption and byproducts (Paes, 2006) such as whole corn germ (WCG), which can be used in animal feeding. Whole corn germ is the byproduct obtained from the wet degermination of corn grain without the oil-extraction process (Corn Refiners Association, 2006).

World corn production was 1,099,900 t, of these 6,995,000 t of corn grain were industrially processed (USDA, 2018). The germ represents 11% of this grain; part of the extracted germ is used for oil extraction, which generates the defatted germ, and the other part is used in animal feeding.

Among the compounds present in WCG, ether extract (EE) is present at concentrations ranging from 470.7 to 598.2 g kg^{-1} (Ciurescu, 2008; Lima, 2008; Lima et al., 2012; Albuquerque et al., 2014; Lima et al., 2016), which characterizes WCG as a high-energy feedstuff. It also contains high levels of gross energy (GE), which may vary from 7,039 (Albuquerque et al., 2014) to 7,243 kcal/kg (Lima et al., 2012) and apparent metabolizable energy content for broilers of 4,157 kcal/kg (Lima, 2008). Therefore, this ingredient may partially replace corn and soybean meal in the diet of those animals (Ciurescu et al., 2014). This byproduct also stands out for its crude protein content of 104 to 114.8 g kg^{-1} (Lima et al., 2012; Albuquerque et al., 2014; Ciurescu et al., 2014) and essential amino acids methionine (1.90 g kg^{-1}), lysine (4.80 g kg^{-1}), and threonine (4.00 g kg^{-1}) (Albuquerque et al., 2014) for poultry.

Observing these premises, the present study proposes to examine performance; diet metabolizability; yields of carcass, cuts, and offal; and quality of meat of broilers fed diets with increasing levels of WCG from 1 to 42 days of age.

Material and Methods

The study was conducted in Recife – PE, Brazil (8°02'10" S and 34°95'39" W, 18 m asl), approved by the local Ethics Committee on Animal Use (case no. 083/2015).

A total of 648 one-day-old chicks of the Cobb 500 strain were evaluated in a completely randomized design, with six treatments and six replicates with 18 birds each. The treatments consisted of a corn- and soybean meal-based control diet (0 g kg^{-1} WCG) and five test diets including WCG at the levels of 40, 80, 120, 160, and 200 g kg^{-1}, respectively (Tables 1 and 2). The diets with 200 g kg^{-1} WCG did not include soybean oil due to their high lipid content. The nutritional levels were according to recommendations of Rostagno et al. (2011) for high-performance male broilers, and the same was applied for the composition of feedstuffs, except WCG, whose composition was determined based on the results obtained in a previous metabolism trial (Table 3). The WCG used in the trial contained 7,183 kcal/kg GE and nitrogen-corrected apparent metabolizable energy (AME_n) values of 4,307, 4,566, and 4,900 kcal/kg for the pre-starter, starter, and grower phases, respectively, determined in previous experiments (Lopes, 2018) and established by the inflection point of broken-line statistical model.

Birds were housed in a masonry shed divided into cages measuring 2×1 m that were lined with wood shavings poultry litter and equipped with a trough feeder and a nipple drinker. Feed and water were available *ad libitum*. Temperature and air relative humidity were recorded daily throughout the experimental period using a data logger (HOBOware® U12-012), and the following means were obtained: 31.43 °C and 69.80% in the pre-starter phase; 28.53 °C and 74.75% in the starter phase; 29.06 °C and 70.44% in the grower phase; and 29.15 °C and 68.81% in the finisher phase.

The methodology adopted to determine the metabolizability of the diets was marker-aided partial excreta collection. In this way, 10 g kg^{-1} of the acid-insoluble ash were added to the diets (Scott and Boldaji, 1997).

During the performance trial, excreta were collected twice daily, in the morning and in the afternoon, by lining the floor with paper. Two days were used as a period of acclimation to the diet containing the marker, followed by two days of excreta collection in the pre-starter (days 5 and 6), starter (days 18 and 19), and grower (days 32 and 33) phases.

Excreta and diets were analyzed for the dry matter (DM), nitrogen, and EE contents according to the methods described by AOAC (1990); GE, by using a bomb calorimeter (Model IKA C-200) standardized with benzoic acid; and acid-insoluble ash by following the methodology described by Van Keulen and Young (1977). Amino acids analyses of WCG were made by High performance liquid chromatography (HPLC) by a commercial laboratory according to the method of Hagen et al. (1989).

Table 1 - Chemical composition and nutritional values of the diets used in the pre-starter (1 to 7 days) and starter (8 to 21 days) phases

Item	Level of whole corn germ (g kg^{-1})											
	1 to 7 days						8 to 21 days					
	0	40	80	120	160	200	0	40	80	120	160	200
Ingredient (g kg^{-1})												
Ground corn 78.6 g kg^{-1}	543.3	514.6	486.0	457.3	428.7	400.0	567.7	541.2	514.7	488.2	461.6	435.0
Soybean meal 450 g kg^{-1}	388.0	381.4	374.8	368.2	361.6	355.0	359.5	352.6	345.6	338.7	331.8	325.0
Whole corn germ	00.0	40.0	80.0	120.0	160.0	200.0	00.0	40.0	80.0	120.0	160.0	200.0
Soybean oil	24.49	19.60	14.69	9.79	4.89	0.00	33.29	26.63	19.97	13.32	6.66	0.00
Dicalcium phosphate	19.03	18.88	18.74	18.59	18.45	18.30	15.56	15.40	15.25	15.09	14.94	14.78
Limestone	8.82	8.94	9.06	9.18	9.30	9.42	9.16	9.28	9.41	9.53	9.66	9.78
Common salt	3.71	3.69	3.67	3.65	3.63	3.61	3.46	3.44	3.42	3.40	3.38	3.36
DL-methionine 990 g kg^{-1}	3.64	3.71	3.78	3.86	3.93	4.00	3.12	3.15	3.18	3.20	3.23	3.26
L-lysine HCl 788 g kg^{-1}	2.90	2.97	3.04	3.12	3.19	3.26	2.40	2.48	2.56	2.64	2.72	2.80
L-threonine 985 g kg^{-1}	1.16	1.21	1.26	1.31	1.36	1.41	0.81	0.86	0.91	0.96	1.01	1.06
Zinc bacitracin	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Salinomycin sodium	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium bicarbonate	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Vitamin-mineral supplement[1]	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Calculated nutritional composition (g kg^{-1})												
AMEn (kcal/kg)	2960	2960	2960	2960	2960	2960	3050	3050	3050	3050	3050	3050
Crude protein	224.0	224.0	224.0	224.0	224.0	224.0	212.0	212.0	212.0	212.0	212.0	212.0
Fat	50.63	62.35	74.08	85.81	97.53	109.3	59.75	69.81	79.86	89.92	99.97	110.0
Gross energy (kcal/kg)[2]	3621	3628	3736	3797	4053	4060	3625	3633	3753	3801	3870	4063
Crude fiber	29.96	39.59	49.23	58.86	68.49	78.13	28.87	38.53	48.18	57.84	67.49	77.15
Neutral detergent fiber	118.31	136.28	154.25	172.22	190.18	208.15	117.30	135.48	153.66	171.84	190.01	208.19
Calcium	9.20	9.20	9.20	9.20	9.20	9.20	8.41	8.41	8.41	8.41	8.41	8.41
Available phosphorus	4.70	4.70	4.70	4.70	4.70	4.70	4.01	4.01	4.01	4.01	4.01	4.01
Sodium	2.20	2.20	2.20	2.20	2.20	2.20	2.10	2.10	2.10	2.10	2.10	2.10
Chlorine	2.73	2.73	2.72	2.71	2.70	2.69	2.58	2.57	2.56	2.56	2.55	2.54
Potassium	8.68	8.50	8.32	8.14	7.96	7.78	8.22	8.04	7.86	7.68	7.51	7.33
Digestible amino acids (g kg^{-1})												
Methionine + cysteine	9.53	9.53	9.53	9.53	9.53	9.53	8.76	8.76	8.76	8.76	8.76	8.76
Methionine	6.52	6.52	6.52	6.52	6.52	6.52	5.88	5.90	5.92	5.93	5.95	5.97
Lysine	13.24	13.24	13.24	13.24	13.24	13.24	12.17	12.17	12.17	12.17	12.17	12.17
Threonine	8.61	8.61	8.61	8.61	8.61	8.61	7.91	7.91	7.91	7.91	7.91	7.91
Tryptophan	2.52	2.52	2.51	2.51	2.50	2.50	2.37	2.36	2.36	2.35	2.35	2.34
Leucine	17.27	17.12	16.97	16.83	16.68	16.54	16.57	16.43	16.30	16.16	16.03	15.89
Arginine	14.15	14.11	14.08	14.05	14.01	13.98	13.32	13.29	13.25	13.22	13.18	13.15
Phenylalanine	10.31	10.23	10.16	10.08	10.01	9.93	9.76	9.69	9.61	9.54	9.46	9.39
Phenylalanine + tyrosine	17.62	17.21	16.80	16.38	15.97	15.56	16.70	16.29	15.88	15.46	15.05	14.64
Valine	9.44	9.42	9.41	9.40	9.38	9.37	8.96	8.94	8.93	8.92	8.90	8.89

AME_n - AMEn - nitrogen-corrected metabolizable energy.
[1] Vitamin-mineral supplement (provides per kilogram of product): vitamin A, 7,500,000 IU; vitamin D3, 2,500,000 IU; vitamin E, 18,000 IU; vitamin K3, 1200 mg; thiamine, 1500 mg; riboflavin, 5500 mg; pyridoxine, 2000 mg; vitamin B12, 12,500 mcg; niacin, 35 g; calcium pantothenate, 10 g; biotin, 67 mg; iron, 60 g; copper, 13 g; manganese, 120 g; zinc, 100 g; iodine, 2500 mg; selenium, 500 mg.
[2] Determined values.

Table 2 - Chemical composition and nutritional values of the diets used in the grower (22 to 35 days) and finisher (36 to 42 days) phases

Item	Level of whole corn germ (g kg^{-1})											
	22 to 35 days						36 to 42 days					
	0	40	80	120	160	200	0	40	80	120	160	200
Ingredient (g kg^{-1})												
Ground corn 78.6 g kg^{-1}	597.8	573.6	549.2	524.8	500.5	476.2	642.6	618.2	593.8	569.2	544.9	520.4
Soybean meal 450 g kg^{-1}	323.6	316.2	309.0	301.7	294.4	287.2	284.5	277.0	269.6	262.2	254.6	247.2
Whole corn germ	0.00	40.0	80.0	120.0	160.0	200.0	0.00	40.0	80.0	120.0	160.0	200.0
Soybean oil	42.37	33.90	25.42	16.95	8.47	0.00	40.92	32.73	24.55	16.36	8.18	0.00
Dicalcium phosphate	13.35	13.19	13.02	12.86	12.70	12.54	11.23	11.07	10.90	10.73	10.57	10.40
Limestone	8.63	8.75	8.88	9.01	9.13	9.26	7.73	7.85	7.96	8.08	8.20	8.32
Common salt	3.21	3.19	3.17	3.14	3.12	3.10	3.08	3.06	3.03	3.01	2.99	2.96
DL-methionine 990 g kg^{-1}	2.93	2.96	2.99	3.02	3.05	3.08	2.72	2.74	2.76	2.79	2.82	2.84
L-lysine HCl 788 g kg^{-1}	2.40	2.49	2.57	2.66	2.75	2.84	2.67	2.76	2.84	2.93	3.01	3.10
L-threonine 985 g kg^{-1}	0.72	0.77	0.82	0.88	0.92	0.98	0.76	0.81	0.85	0.90	0.95	1.00
Zinc bacitracin	0.50	0.50	0.50	0.50	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Salinomycin sodium	0.50	0.50	0.50	0.50	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Sodium bicarbonate	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Vitamin-mineral supplement[1]	2.00	2.00	2.00	2.00	2.00	2.00	1.80	1.80	1.80	1.80	1.80	1.80
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Calculated nutritional composition (g kg^{-1})												
AMEn (kcal/kg)	3150	3150	3150	3150	3150	3150	3200	3200	3200	3200	3200	3200
Crude protein	198.0	198.0	198.0	198.0	198.0	198.0	184.0	184.0	184.0	184.0	184.0	184.0
Fat	69.24	77.57	85.91	94.24	102.6	110.9	68.77	77.45	86.13	94.81	103.5	112.2
Gross energy (kcal/kg)[2]	3685	3717	3764	3918	4030	4124	3699	3737	3780	3941	4050	4146
Crude fiber	27.49	37.17	46.85	56.52	66.19	75.87	26.20	35.89	45.59	55.29	64.99	74.69
Neutral detergent fiber	115.96	134.36	152.75	171.14	189.53	207.92	115.89	134.29	152.69	171.09	189.49	207.88
Calcium	7.58	7.58	7.58	7.58	7.58	7.58	6.63	6.63	6.63	6.63	6.63	6.63
Available phosphorus	3.54	3.54	3.54	3.54	3.54	3.54	3.09	3.09	3.09	3.09	3.09	3.09
Sodium	2.00	2.00	2.00	2.00	2.00	2.00	1.95	1.95	1.95	1.95	1.95	1.95
Chlorine	2.43	2.42	2.41	2.41	2.40	2.39	2.37	2.36	2.35	2.34	2.34	2.33
Potassium	7.66	7.48	7.30	7.12	6.94	6.76	7.07	6.89	6.71	6.53	6.35	6.17
Digestible amino acids (g kg^{-1})												
Methionine + cysteine	8.26	8.26	8.26	8.26	8.26	8.26	7.74	7.74	7.74	7.74	7.74	7.74
Methionine	5.54	5.56	5.58	5.60	5.62	5.64	5.19	5.21	5.23	5.25	5.27	5.29
Lysine	11.31	11.31	11.31	11.31	11.31	11.31	10.6	10.6	10.6	10.6	10.6	10.6
Threonine	7.35	7.35	7.35	7.35	7.35	7.35	6.89	6.89	6.89	6.89	6.89	6.89
Tryptophan	2.17	2.16	2.16	2.15	2.15	2.14	1.97	1.97	1.96	1.95	1.95	1.94
Leucine	15.70	15.57	15.44	15.32	15.19	15.06	14.86	14.73	14.60	14.47	14.34	14.21
Arginine	12.29	12.25	12.21	12.17	12.13	12.09	11.20	11.16	11.12	11.08	11.05	11.01
Phenylalanine	9.09	9.01	8.94	8.86	8.79	8.72	8.39	8.31	8.24	8.16	8.09	8.01
Phenylalanine + tyrosine	15.54	15.13	14.71	14.30	13.89	13.47	14.34	13.93	13.51	13.10	12.68	12.27
Valine	8.34	8.33	8.32	8.30	8.29	8.28	7.73	7.71	7.70	7.69	7.67	7.66

AME_n - nitrogen-corrected metabolizable energy.
[1] Vitamin-mineral supplement (provides per kilogram of product): vitamin A, 7,500,000 IU; vitamin D3, 2,500,000 IU; vitamin E, 18,000 IU; vitamin K3, 1200 mg; thiamine, 1500 mg; riboflavin, 5500 mg; pyridoxine, 2000 mg; vitamin B12, 12,500 mcg; niacin, 35 g; calcium pantothenate, 10 g; biotin, 67 mg; iron, 60 g; copper, 13 g; manganese, 120 g; zinc, 100 g; iodine, 2500 mg; selenium, 500 mg.
[2] Determined values.

Subsequently, equations described by Matterson et al. (1965) were used to determine the apparent metabolizable energy (AME), AME_n, and the apparent metabolizability coefficients of GE (AMC_{GE}), dry matter (AMC_{DM}), crude protein (AMC_{CP}), and ether extract (AMC_{EE}) using equations described by Sakomura and Rostagno (2016).

For the performance trial, the broilers and diets were weighed weekly and the feed intake (FI, g/bird), body weight gain (BWG, g/bird), and feed conversion ratio (FCR, g/g) were measured.

At 42 days of age, two broilers (close to the average body weight) from each replicate were selected. Then, they were stunted, bled, and eviscerated and then the cuts were obtained and weighed. The yields of carcass (without feet, head, or offal), parts (breast, drumsticks, thighs, back, and wings), edible offal (heart, gizzard, proventriculus, and liver), and abdominal fat (abdominal fat plus the fat around the gizzard) were measured. Gizzard and proventriculus were weighed empty.

Breast analyses were performed on the *pectoralis major* muscle. The pH was determined using a portable meat pH meter with a fine-tip probe (HACCP-HI 99163) that was inserted directly into the breast samples. To determine cooking losses (CL), a sample of the *pectoralis major* muscle was weighed, wrapped in aluminum foil, and cooked on a griddle until reaching an internal temperature

Table 3 - Chemical and energy composition of whole corn germ (WCG) used to formulate the experimental diet, expressed on an as-is basis

Item	$g\ kg^{-1}$
Nutrient	
Dry matter	953.5
Crude protein	127.2
Ether extract	443.3
Crude fiber	262.0
Neutral detergent fiber	557.4
Gross energy (kcal/kg)	6419
Mineral matter	10.30
Metabolizable energy – 1 to 7 days (kcal/kg)[1,2]	3848
Metabolizable energy – 8 to 21 days (kcal/kg)[1,3]	4080
Metabolizable energy – 22 to 42 days (kcal/kg)[1,4]	4378
Mineral	
Calcium	0.40
Available phosphorus	1.50
Sodium	0.38
Chlorine	0.60
Potassium	0.60
Digestible amino acids in birds	
Methionine	1.70
Lysine	4.14
Methionine + cystine	3.15
Threonine	3.39
Tryptophan	1.20
Arginine	6.84
Leucine	8.08
Isoleucine	3.25
Valine	5.28
Phenylalanine	4.18
Histidine	3.19

AME_n - nitrogen-corrected apparent metabolizable energy.
[1] Metabolizable energy was calculated based on the metabolizability coefficient of gross energy of the WCG used in the digestibility trial, whose maximum point was estimated by the broken-line model ($AMC_{GE} = AME_{nfeedstuff}/GE_{feedstuff}$).
[2] AMC_{GE} = 4307/7183 × 100 = 59.96%, AME_n = 6419 × 59.96/100 = 3848 kcal/kg.
[3] AMC_{GE} = 4566/7183 × 100 = 63.57%, AME_n = 6419 × 63.57/100 = 4080 kcal/kg.
[4] AMC_{GE} = 4900/7183 × 100 = 68.22%, AME_n = 6419 × 68.22/100 = 4378 kcal/kg.

of approximately 80 °C, which was monitored using a special thermometer for meat cooking; next, the samples were placed on absorbent paper until reaching room temperature (20-25 °C). Cooking loss was calculated as the difference in weight of the samples before and after cooking and expressed in percentage terms (Honikel, 1998). After the CL were determined, the same samples were used to determine shear force. For this step, four rectangle-shaped (2×2×1 cm) sub-samples were extracted per experimental unit. Samples were placed with the fibers in a direction perpendicular to the blades of a Warner-Bratzler Shear Force machine (Model 3000, G-R Manufacturing Co.) with a load cell of 25 kgf and crosshead speed of 20 cm/min. Water-holding capacity (WHC) was measured by using the methodology described by Hamm (1960). Meat samples weighing 0.5 g were placed between two circular filter-paper sheets and then a 3-kg weight was placed on the top sheet and left for 5 min. The breast-meat sample was then weighed, and the amount of water lost was calculated by difference. The result was expressed as a percentage of exuded water relative to the initial weight of the sample. Breast and drumstick meat color was determined with a colorimeter (Konica Minolta, CR-400) under the CIELAB system (L*, a*, b*), in accordance with the methodology described by Honikel (1998). The peroxide index was determined according to AOAC (2003). The meat of breast, drumsticks, and thighs was ground and homogenized. In the laboratory, the Goldfisch method was applied for the extraction of fat, which was followed by addition of potassium iodate and starch as a marker. Titration was carried out using a sodium thiosulfate solution, in which the amount of thiosulfate consumed was proportional to the amount of peroxides present in the analyzed sample.

Data were analyzed for the principles of error normality and homogeneity of variances. The statistical model used for analyzes was the completely randomized design, as described below:

$$Y_{ij} = \mu + T_i + \varepsilon_{ij},$$

in which Y_{ij} is the response variable, μ is the overall mean, T_i is the treatment effect, and ε_{ij} is the random error.

The broken-line model was fitted to the data using SAS software (Statistical Analysis System, version 9.2), applying the PROC NLIN procedure for the performance variables, yields of carcass and offal, and energy utilization of the diets, as described below:

$$y = \alpha + \beta\,(\gamma - x),$$

in which y is the independent variable, α is the maximum response of the model, β is the slope up to the model breaking point, γ is the optimum level, and x is WCG intake.

MANOVA and multivariate analysis of factors was applied to the meat-quality data.

Results

The data analyzed in this study followed the principles of error normality and homogeneity of variances. There was no difference in FCR in the phase of 1 to 7 days of age, or in FI from 1 to 35 and from 1 to 42 days of age (Table 4). During the pre-starter phase (1 to 7 days), an average FI of 149.6 g/bird and an average BWG of 136.2 g/bird were estimated at an optimum WCG inclusion level of approximately 98 g kg^{-1}. From 1 to 21 days of age, the analyzed variables differed, with optimum performance obtained when 118.6, 101.0, and 60 g kg^{-1} WCG were added to the diets (FI, BWG, and FCR, respectively). However, in the period of 1 to 35 days of age, only BWG and FCR differed. This response was also seen in the entire period (1 to 42 days), for which the optimum BWG was estimated at 2384.8 and 2921 g/bird at the respective WCG inclusion levels of 104 and 118 g kg^{-1}.

There was no difference for AME, AME_n, or AMC_{CP} in the diets supplied in the three studied phases (Table 5). However, AMC_{GE}, AMC_{DM} and AMC_{EE} declined as the dietary WCG inclusion level was elevated. The nitrogen balance was influenced only in the starter phase.

According to the regression equations, the increasing inclusion levels of WCG in broiler diets led to a significant reduction in the metabolizability of GE, whose coefficients of 74.15, 76.05, and 78.99%

were obtained with the inclusion of 40.0, 155.4, and 132.0 g kg^{-1} WCG in the phases of 1 to 7, 8 to 21, and 22 to 35 days of age, respectively.

The best inclusion levels of WCG for the metabolizability of DM were 80.0, 80.0, and 104.3 g kg^{-1} in pre-starter, starter, and grower diets, respectively. The highest metabolizability coefficients of EE were 67.77, 85.25, and 80.06%, obtained at the WCG inclusion levels of 165.5, 59.2, and 137.1 g kg^{-1} in the respective phases.

The increasing WCG inclusion levels did not influence the yields of carcass, breast, drumsticks, thighs, wings, back, and neck (Table 6). However, they affected the yield of gizzard and proventriculus. The equation estimated an average gizzard yield of 1.32% at 167 g kg^{-1} inclusion of WCG and an average

Table 4 - Mean values for feed intake (FI), body weight gain (BWG), and feed conversion ratio (FCR) of broilers fed diets with increasing levels of whole corn germ, in all rearing phases

Inclusion level (g kg^{-1})	Evaluated period (days)			
	1 to 7	1 to 21	1 to 35	1 to 42
	Feed intake (g/bird)			
0	152.2	1327.8	3566.4	4776.8
40	151.1	1339.4	3614.8	4861.6
80	145.4	1308.5	3608.8	4842.9
120	147.4	1324.9	3606.6	4855.0
160	144.5	1282.8	3596.4	4884.0
200	140.2	1247.4	3464.2	4787.1
Mean	146.8	1305.1	3576.2	4834.6
CV (%)	3.87	2.50	3.60	4.36
P	0.0049*	<0.0001*	0.0665	0.8813
SEM	0.170	0.169	0.169	0.170
	Body weight gain (g/bird)			
0	138.5	1013.9	2376.2	2898.5
40	137.7	1033.4	2411.4	2951.5
80	132.5	1003.9	2366.8	2913.0
120	134.3	1001.5	2357.5	2921.0
160	131.7	965.8	2306.7	2832.5
200	127.9	933.6	2236.1	2761.5
Mean	133.8	992.0	2342.4	2879.7
CV (%)	3.14	2.38	2.70	4.11
P	0.0011*	<0.0001*	<0.0001*	0.0101*
SEM	0.170	0.169	0.169	0.169
	Feed conversion ratio (g/g)			
0	1.099	1.309	1.501	1.648
40	1.097	1.296	1.499	1.648
80	1.097	1.304	1.524	1.662
120	1.097	1.323	1.529	1.663
160	1.096	1.328	1.559	1.724
200	1.096	1.336	1.550	1.736
Mean	1.097	1.316	1.527	1.680
CV (%)	2.89	2.07	1.76	2.73
P	0.9884	0.0182*	<0.0001*	0.0003*
SEM	0.170	0.170	0.169	0.171

CV - coefficient of variation; P - probability, significant when P<0.05; R^2 - coefficient of determination; SEM - standard error of the mean.
* Differed significantly.
Equations 1 to 7 days: FI = 149.6 + 0.892(97.95 − X), R^2 = 0.84; BWG = 136.2 + 0.794(98.34 − X), R^2 = 0.88; Equations 1 to 21 days: FI = 1325.2 + 9.691(118.55 − X), R^2 = 0.94; BWG = 1017.1 + 8.494(100.98 − X), R^2 = 0.97; FCR = 1.303 − 0.003(59.92 − X), R^2 = 0.78; Equations 1 to 35 days: BWG = 2384.8 + 15.167(104.15 − X), R^2 = 0.93; FCR = 1.549 − 0.004(166.72 − X); R^2 = 0.93; Equations 1 to 42 days: BWG = 2921 + 19.948(118.56 − X), R^2 = 0.81; FCR = 1.648 − 0.007(71.05 − X), R^2 = 0.90.

proventriculus yield of 0.28% at 40 g kg^{-1} inclusion. There was no difference for the analyzed meat quality variables (Table 7).

Discussion

The reduction observed in FI and BWG may be attributed to the high amount of fat present in the diets containing higher levels of WCG, besides the difference in the GE levels of the diets. In the pre-starter phase, the diet with 200 g kg^{-1} inclusion of WCG contained 109.3 g kg^{-1} fat, whereas control diet had

Table 5 - Mean values for apparent metabolizable energy (AME) and nitrogen-corrected AME (AME_n), apparent metabolizability coefficients, and nitrogen balance (NB) of broilers fed diets with increasing levels of whole corn germ (as-is basis)

Inclusion level (g kg^{-1})	Variable						
	AME (kcal/kg)	AME_n (kcal/kg)	AMC_{GE} (%)	AMC_{CP} (%)	AMC_{DM} (%)	AMC_{EE} (%)	NB (kcal/kg)
Pre-starter diet (1 to 7 days)							
0	3351	3107	74.08	70.66	67.99	87.68	244.4
40	3388	3152	74.48	70.60	66.72	85.46	235.9
80	3391	3159	72.85	69.36	65.74	78.36	237.3
120	3386	3152	71.19	68.17	64.72	74.33	235.7
160	3393	3146	70.86	70.74	64.96	68.78	240.6
200	3395	3157	69.29	70.04	62.13	68.45	238.0
Mean	3384	3145	72.13	69.93	65.38	77.18	238.7
CV (%)	2.58	2.60	2.50	2.87	3.85	4.89	2.74
P	0.5774	0.9289	<0.0001	0.9983	<0.0001	<0.0001	0.7428
SEM	0.1685	0.1680	0.1681	0.1784	0.1714	0.1683	0.1715
Starter diet (8 to 21 days)							
0	3609	3368	79.18	72.97	73.69	85.42	240.6
40	3618	3374	78.08	71.06	72.20	85.08	244.4
80	3634	3406	78.49	71.57	73.66	84.30	227.6
120	3634	3402	76.39	70.77	72.34	82.04	231.6
160	3636	3415	76.19	70.76	70.72	78.54	220.8
200	3646	3407	75.87	70.69	70.91	77.99	237.9
Mean	3629	3396	77.37	71.30	72.25	82.23	233.8
CV (%)	2.31	2.31	1.83	3.55	2.73	3.25	3.57
P	0.6852	0.4191	<0.0001	0.2506	0.0159	<0.0001	0.0146
SEM	0.1689	0.1704	0.1695	0.1682	0.1705	0.1701	0.1678
Grower diet (22 to 35 days)							
0	3739	3522	82.23	72.69	78.85	85.58	216.6
40	3742	3514	81.24	73.32	78.41	84.71	227.5
80	3753	3533	80.50	71.94	76.93	82.43	221.4
120	3727	3515	79.16	70.51	77.00	80.66	217.3
160	3737	3516	79.33	72.63	76.35	81.31	221.8
200	3724	3503	78.65	72.96	76.20	78.81	221.2
Mean	3737	3517	80.19	72.34	77.29	82.25	220.9
CV (%)	1.97	1.88	1.96	3.85	2.28	2.83	3.07
P	0.8522	0.8215	0.0001	0.7225	0.0083	<0.0001	0.9964
SEM	0.1704	0.1697	0.1694	0.1694	0.1692	0.1686	0.1697

AMC_{GE} - apparent metabolizability coefficient of gross energy; AMC_{CP} - apparent metabolizability coefficient of crude protein; AMC_{DM} - apparent metabolizability coefficient of dry matter; AMC_{EE} - apparent metabolizability coefficient of ether extract; CV - coefficient of variation; P - probability, significant when $P<0.05$; SEM - standard error of the mean.

Equations pre-starter diet: $AMC_{GE} = 74.153 + 0.305(40.00 - X)$, $R^2 = 0.95$; $AMC_{DM} = 67.777 + 0.435(80.00 - X)$, $R^2 = 0.95$; $AMC_{EE} = 68.454 + 1.223(165.58 - X)$, $R^2 = 0.99$; Equations starter diet: $AMC_{GE} = 76.056 + 0.205(155.47 - X)$, $R^2 = 0.92$; $AMC_{DM} = 73.112 + 0.216(80.00 - X)$, $R^2 = 0.79$; $AMC_{EE} = 85.250 + 0.561(59.22 - X)$, $R^2 = 0.96$; $NB = 230.100 + 1.614(86.03 - X)$, $R^2 = 0.79$; Equations grower diet: $AMC_{GE} = 78.991 + 0.249(132.02 - X)$, $R^2 = 0.92$; $AMC_{DM} = 76.516 + 0.241(104.27 - X)$, $R^2 = 0.82$; $AMC_{EE} = 80.060 + 0.426(137.13 - X)$, $R^2 = 0.94$.

50.63 g kg^{-1} fat and the finisher diet had fat contents ranging from 112.2 to 68 g kg^{-1}. Similarly, Lima (2008) found a linear decrease in the FI of broilers fed diets with 0 to 160 g kg^{-1} WCG. It is known that oils and fats are added at 30 to 80 g kg^{-1} in poultry diets (Sakomura et al., 2014), and the addition of higher levels thereof is directly related to increases in the density of these diets. The crude fiber (CF) content also rose in the diets with higher levels of WCG, ranging from 29.9 to 78.1 in control diets in the pre-starter phase and from 26.2 to 74.6 g kg^{-1} in the finisher phase.

Table 6 - Yields of carcass, offal, and total fat of broilers fed diets with increasing levels of whole corn germ

Variable	Whole corn germ inclusion level (g kg^{-1})						CV (%)	P	SEM
	0	40	80	120	160	200			
	Calculated yield (%)								
Carcass	78.45	78.87	77.92	78.05	77.91	77.77	1.11	0.130	0.169
Breast	36.07	35.92	36.46	36.73	36.57	36.15	2.49	0.408	0.168
Drumsticks	12.71	12.61	12.78	12.74	12.67	12.98	3.91	0.192	0.169
Thighs	15.83	16.08	15.69	16.07	16.00	15.72	3.99	0.102	0.169
Wings	9.38	9.53	9.51	9.28	9.31	9.47	3.80	0.074	0.172
Back	18.38	18.65	17.98	18.07	17.91	18.62	5.56	0.281	0.175
Neck	6.34	6.03	6.34	6.11	6.48	5.96	9.98	0.674	0.171
Liver	1.47	1.35	1.41	1.42	1.44	1.33	7.75	0.097	0.169
Gizzard	1.15	1.13	1.17	1.30	1.32	1.33	10.68	0.003	0.168
Proventriculus	0.29	0.29	0.28	0.32	0.35	0.35	13.05	0.007	0.169
Heart	0.403	0.382	0.37	0.42	0.44	0.40	12.12	0.162	0.170
Abdominal fat	1.56	1.39	1.50	1.39	1.43	1.27	15.26	0.194	0.171

CV - coefficient of variation; SEM - standard error of the mean; P - probability, significant when P<0.05. R^2 - coefficient of determination.
Equations of calculated yield: Gizzard = 1.3281 − 0.0130(16.7705 − X), R^2 = 0.85 and Proventriculus = 0.2858 − 0.0045(4.1238 − X), R^2 = 0.83.

Table 7 - Means and analysis of variance of meat quality parameters of broilers at 42 days of age fed diets with whole corn germ

Variable	Whole corn germ inclusion level (g kg^{-1})						P	SEM
	0	40	80	120	160	200		
pH	5.8	5.9	5.9	5.8	5.9	5.8	0.2213	0.0166
WHC (%)	36.17	36.23	37.47	39.01	39.79	39.86	0.9140	0.2817
SF (kgf/cm^2)	1.04	1.01	1.02	1.01	1.00	0.98	0.9827	0.0033
CL (g)	30.00	27.47	24.11	28.87	27.17	27.18	0.8592	0.3317
$THIGH_{PI}$ (mEq/kg)	14.78	15.70	15.18	12.56	15.66	15.87	0.3757	0.2067
DRU_{PI} (mEq/kg)	12.88	14.88	16.52	16.02	14.77	15.74	0.3613	0.2150
BRE_{PI} (mEq/kg)	16.90	16.05	17.50	16.07	18.73	16.30	0.2622	0.1750
$BREA_{L*}$	58.75	58.48	59.39	61.62	58.25	57.57	0.0938	0.2900
$BREA_{a*}$	0.86	0.62	1.41	0.80	1.69	0.43	0.7122	0.0817
$BREA_{b*}$	6.49	4.46	4.72	3.88	4.28	3.14	0.0896	0.1867
DRU_{L*}	57.98	58.18	55.56	60.04	59.38	44.99	0.6781	0.9367
DRU_{a*}	1.96	2.46	2.66	2.32	1.81	1.98	0.5259	0.0550
DRU_{b*}	4.32	3.30	8.11	2.89	2.13	2.16	0.3692	0.3750

MANOVA

Test	F	Effect	Error	p
Wilks	0.049	0.750	64	0.852

P - probability, significant when P<0.05; SEM - standard error of the mean; WHC - water-holding capacity; SF - shear force; CL - cooking loss; $THIGH_{PI}$ - peroxide index of thighs; DRU_{PI} - peroxide index of drumsticks; $BREA_{PI}$ - peroxide index of breast; $BREA_{L*}$ - lightness intensity of breast; $BREA_{a*}$ - red color intensity of breast; $BREA_{b*}$ - yellow intensity of breast; DRU_{L*} - lightness intensity of drumsticks; DRU_{a*} - red color intensity of drumsticks; DRU_{b*} - yellow intensity of drumstick.

The amount of fat was negatively related to FI. Consequently, it affected the overall intake of all nutrients, resulting in lesser growth of the chicks fed high levels of the test ingredient. Furthermore, the worsening of FCR reinforces the occurrence of decreased utilization of WCG at the highest inclusion levels, which was not only due to the fat but also to the increasing amount of fiber in the diets. A synergistic effect could be observed between the high levels of fat and fiber in the diet, leading to decreased utilization of the dietary nutrients by broilers.

Traditionally, in most research studies on poultry feeding, the dietary fiber has been considered a diluent in the diet, influencing voluntary FI and nutrient digestibility (Rougière and Carrè, 2010). Consequently, the formulation of diets, mainly those of young chickens, must include less than 30 g kg^{-1} of an insoluble fiber source (Mateos et al., 2012). However, it has been shown that the inclusion of moderate quantities of fiber from different sources improves the development of digestive organs (Hetland and Svihus, 2007; Svihus, 2011) and increases the secretion of hydrochloric acid, biliary acids, and enzymes (Svihus, 2011; Mateos et al., 2012). These alterations may result in improved nutrient digestibility (Amerah et al., 2009), growth (González-Alvarado et al., 2010), and health of the gastrointestinal tract (Perez et al., 2011).

Nevertheless, in an experiment testing WCG with a high fat content (471 g kg^{-1} EE), Ciurescu et al. (2014) observed that WCG inclusion at levels of up to 210 g kg^{-1} in the diet of broilers from 11 to 42 days did not influence FI, BWG, or FCR. Jiang et al. (2014) evaluated another byproduct of corn, dried distillers grains with solubles (DDGS), included at 150 g kg^{-1} in broiler diets and did not observe differences in performance.

The fat levels in WCG did not influence their AME and AME_n contents but interfered with the metabolizability coefficients of GE, DM, and EE. This finding agrees with the hypothesis that the amount of fat can lead to different responses regarding the ability of birds to utilize it, i.e., depending on the source and level of fat used in the diet, the response in terms of its energy contribution may be linear, curvilinear, and, in some cases, exceed its GE content (Sibbald and Kramer, 1978). Fiber also has effects on birds according to the inclusion level, physicochemical characteristics, physical form, and animal species (Mateos et al., 2012).

The decreasing metabolizability of the DM from the experimental diets might have been due to the larger presence of CF and higher DM value in them, which led to increased excretion of DM. The increasing DM content of the diets was a result of the elevated level of EE in WCG. By contrast, the reduction observed in the metabolizability coefficients of GE and EE are due to the greater excretion of GE and fat by the birds. A higher quantity of lipids is known to improve the energy efficiency of diets; however, the utilization of this energy will depend on the age of the birds, as a function of the production of digestive enzymes (Sakomura et al., 2004).

The current results agree with those mentioned by Lima (2008), who did not observe an effect of experimental diets containing levels of WCG (0 to 160 g kg^{-1}) on the yields of carcass and primal cuts of broilers. The lack of treatment effects on the weight and yield of the parts indicates that, despite the lipid increase in the diets, there was satisfactory balance in the intake of amino acids and protein. This reflected mainly in the deposition of meat in the breast, which represents half of the edible protein in chickens (Amarante Júnior et al., 2005; Garcia et al., 2006). Likewise, Ciurescu et al. (2014) observed that the yields of carcass, breast, and legs, abdominal fat deposition, and liver weight did not differ significantly between the groups consuming WCG (11 and 210 g kg^{-1}). However, the yields of breast and legs were higher in both groups with WCG compared with control.

Jiang et al. (2014) showed that the inclusion of 150 g kg^{-1} DDGS did not influence the yields of carcass, breast and drumsticks, or abdominal fat in broilers. Similarly, Kim et al. (2013) evaluated the replacement of up to 100% of soybean oil by the oil extracted from DDGS in chicken diets and did not find significant differences for the weights of carcass, total fat, or breast.

The higher yields of gizzard and proventriculus can be explained by the high concentrations of CF and neutral detergent fiber in WCG. In this regard, Hetland et al. (2003) reported that high-fiber diets cause an increase in the gizzard because fiber is more difficultly ground than other nutrients, and, as such, accumulates in the gizzard, increasing its mechanical work. Martínez et al. (2010) also reported a heavier weight of digestive and accessory organs when insoluble fiber sources were added to broiler diets. Fibers affect the development and function of digestive organs, especially the gizzard (Svihus, 2011).

In terms of peroxidation, the oil from corn germ is oxidatively stable when stored at room temperature because of its tocopherol content (Moreau et al., 2011; Winkler-Moser and Breyer, 2011). Ciurescu et al. (2014) showed that the peroxide value in WCG did not increase significantly until six weeks of storage.

The meat pH values observed in this study agree with literature results (Takahashi et al., 2012; Oliveira et al., 2015). The pH and its variations can influence shear force and CL, which are extremely important for the acceptance of meat by the consumer (Oliveira et al., 2015). Shear force is directly related to CL, since meats with higher CL require greater force for the muscle fibers to be torn (Brossi et al., 2009).

In all treatments, the L*, a*, and b* values found in the breast characterized normal chicken breast meat (L*<55) at 24 h postmortem (Battula et al., 2008; Corzo et al., 2009; Schilling et al., 2010). On the other hand, the present values were higher than those reported by Corzo et al. (2009), who worked with a byproduct of corn (DDGS). Van Laack et al. (2000) described that normal-appearing breasts had an L* value of 55 and pale-appearing breasts had an L* of 60. The authors also stated that high L* values and low final pH (<5.7) are indicative of pale chicken meat with low water-holding capacity.

Conclusions

Even with a reduction in performance, increase in gizzard and proventriculus yield, and reduction of digestibility of diet fats with the highest levels of whole corn germ, this byproduct can be used at low levels in the diet of broilers without compromising their productive rates.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: W.M. Dutra Júnior. Data curation: E.C. Lopes, M.J.B. Santos and W.M. Dutra Júnior. Formal analysis: E.C. Lopes and M.J.B. Santos. Investigation: E.C. Lopes and C.C. Lopes. Methodology: E.C. Lopes, M.J.B. Santos, C.C. Lopes, C.R.C. Oliveira, D.A. Silva and D.P. Oliveira. Project administration: C.B.V. Rabello. Resources: C.B.V. Rabello. Software: E.C. Lopes and M.J.B. Santos. Supervision: C.B.V. Rabello. Validation: E.C. Lopes. Visualization: C.B.V. Rabello, C.C. Lopes, C.R.C. Oliveira and W.M. Dutra Júnior. Writing-original draft: E.C. Lopes. Writing-review & editing: E.C. Lopes, C.B.V. Rabello and M.J.B. Santos.

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