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Original Article

Performance and Carcass of Broiler Quails Fed Distillers' Dried Grains with Solubles (DDGS)

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ABSTRACT

This study determined the metabolizable energy of DDGS for broiler quails (Experiment I) and evaluated the effect of different dietary levels of DDGS on performance, carcass, organ weight, meat quality, and economic viability (Experiment II). In Experiment I, 72 broiler quails were randomly distributed into two treatments (reference or test diets). The experimental period consisted of 5 days of adaptation, followed by 5 days of total excreta collection. Experimental diets consisted of a reference or a test diet containing 800 g/kg reference diet and 200 g/kg DDGS. In experiment II, 432 unsexed broiler quails were randomly distributed into groups fed six levels of DDGS (0, 50, 100, 150, 200, or 250 g/kg). At 43 days of age, birds were slaughtered and evaluated for carcass yield, organ weight, and meat quality. Apparent metabolizable energy values corrected for nitrogen retention of DDGS were 2,488 and 2,466 kcal/kg for males and females, respectively. In the growth phase and the overall period, feed intake increased linearly (p=0.015 and 0.040) and feed conversion ratio worsened (p=0.038 and 0.001) with the inclusion of DDGS in the diet, respectively. A linear increasing (p=0.001) of gizzard weight was observed with increasing dietary DDGS levels, while the economic variables were affect depending on seasonal feedstocks prices. It is concluded that dietary levels up to 250 g/kg DDGS do not affect growth, carcass characteristics, and meat quality of broiler quails. However, the prices of ingredients in the harvest and off-season period should be considered to determine the level of inclusion of DDGS.

INTRODUCTION

The production of ethanol, especially from feedstock such as corn and sorghum, is considerably increasing worldwide, reducing dependence on oil to meet the demand for biofuels and thus generating a positive environmental impact. During the ethanol production process, different distillery co-products are generated, which are ingredients of high nutritional value in animal feed (Silva *et al.*, 2016).

Distillers dried grains with solubles (DDGS) are residues of the cereal fermentation process for ethanol production, a protein co-product with expressive amounts of energy, vitamins and minerals that can replace traditional ingredients and reduce the cost of feed. However, due to its higher fiber concentration in comparison to corn and soybean meal, the inclusion of DDGS may limit the performance of non-ruminant animals that do not have an expressive capacity to digest dietary fiber (Cremonez *et al.*, 2015).

The greater is the amount of fiber present in the food, the harder is the utilization of nutrients in the diet, since fiber in higher concentration increases the passage rate of food and decreases the metabolizable energy of the diet, the digestibility, and the utilization of nutrients (Schöne *et al.*, 2017).

In this regard, Karadagoglu *et al.* (2015) recommended the inclusion of up to 15% DDGS in diets for 35-day-old Japanese quails without negative effects on performance, while Bittencourt *et al.* (2019) suggested that the inclusion of up to 20% DDGS in the diet of 23- to 31-week-old Japanese quails is feasible, because it is a low-cost ingredient and has no negative effects on bird performance.

Thus, it is necessary to determine the effects of the inclusion of DDGS in diets for broiler quails and its most appropriate level, since the nutritional composition of co-products can widely vary according to several factors such as the batch of corn used, drying process, the production method within the same ethanol industry, or even between different industries (Cremonez *et al.*, 2015).

The purpose of this study was to determine the nutritional value of DDGS for broiler quails (Experiment I) and its dietary effects on productive performance, carcass characteristics, meat quality, organ weights, and economic viability (Experiment II).

MATERIAL AND METHODS

Both experiments were approved by the Ethics Committee for Animal Use of the Federal University of Mato Grosso (Sinop-MT, Brazil), under Protocol No. 23108.046809/2019-01.

Physicochemical composition of DDGS

The co-product used had 307.1 g/kg of crude protein (CP), 61.9 g/kg of ether extract (EE), 16.2 g/kg of mineral matter (MM), 659.5 g/kg of neutral detergent fiber (NDF), and 4,469 kcal/kg of gross energy (GE on dry-matter basis). The geometric mean diameter of DDGS was 399 µm and the geometric standard deviation was 1.71 µm. The bromatological analyses were performed in the Monogastric Nutrition Laboratory at Federal University of Mato Grosso (UFMT) - Sinop Campus.

Experiment I - Metabolism test

Animals, experimental design, and diets

A total of 72 28-days-old female and male quails (*Coturnix coturnix coturnix*) with an average live weight of 100 ± 20 g were distributed in an entirely randomized design experiment with two treatments, six repetitions, and three birds per experimental unit. The birds were housed in metabolism cages made of galvanized wire (dimensions 18 cm high × 34 cm wide × 34 cm long), equipped with a trough feeder, nipple drinker with cup and tray for excreta collection.

The experimental diets comprised a reference diet of corn and soybean meal, formulated to meet the nutritional requirements of broiler quails recommended by Silva *et al.* (2012), and a test diet, obtained by replacing 200 g/kg of the reference diet with corn DDGS (Table 1).

Table 1 – Composition and calculated values of the reference diet (RD).

Ingredients, g/kg	RD
Corn	568.9
Soybean meal, 460 g/kg	391.1
Soybean oil	9.6
Limestone	10.2
Dicalcium phosphate	9.6
Salt	3.7
DL-methionine, 985 g/kg	2.8
L-lysine HCl, 998 g/kg	0.2
Mineral and vitamin premix[1]	4.0
Calculated nutritional composition, g/kg	
AMEn, kcal/kg	2,954.5
Crude protein	225.0
Ether extract	9.97
Neutral detergent fiber	209.4
Calcium	7.5
Available phosphorus	2.9
Sodium	1.6
Digestible lysine	11.4
Digestible methionine + cystine	8.9
Digestible threonine	7.8
Digestible tryptophan	2.7
Analyzed nutritional composition, g/kg	
Dry matter	889.9
Mineral matter	59.1
Crude protein	200.8
Ether extract	9.97
Neutral detergent fiber	242.4
Total phosphorus	7.9
Gross energy, kcal/kg	3,413.1
AMEn, kcal/kg	2,600.5

[1]Mineral and vitamin premix provided per kg of diet: Manganese 5.8 g; zinc 5 g; iron 5 g; copper 1.2 g; iodine 100 mg; selenium 32 mg; retinyl acetate (vitamin A) 300 mg; cholecalciferol (vitamin D_3) 5 mg; α-tocopherol acetate (vitamin E) 2.500 mg; menadione 200 mg; thiamine 150 mg; riboflavin 600 mg; pyridoxine 240 mg; vitamin B_{12} 1.200 µg; folic acid 70 mg; pantothenic acid 1.2 g; biotin 7 mg; niacin 3.5 g; choline 35 g.

AMEn = Apparent metabolizable energy corrected for nitrogen balance.

Environmental conditions

The feeding period consisted of five days of adaptation to the experimental diets and the metabolic cages, followed by five days of total excreta collection. Throughout the experimental period, the birds received water and feed *ad libitum* and a lighting program of 23h light and 1h dark, with 40W incandescent lamps. The mean values for maximum and minimum ambient temperature (°C) and relative humidity (%) during the experimental period were respectively 34.4 and 27.3 °C, and 79.4 and 60.4%.

Sample Collection and Analyses

The total excreta collection method was used, with 2 g/kg of ferric oxide utilized as a marker for the beginning and end of the collection period. The excreta were collected daily at 8h and 16h after removal of possible contaminants such as feed or skin and feather shedding. The leftover feed was weighed and the feed intake of each experimental unit was determined. The excreta were stored in identified plastic bags at -18 °C, according to the methodology adapted from Sibbald & Slinger (1963).

The excreta were thawed, homogenized, weighed, and dried in a forced-air drying oven at 55 °C for 72h. Feed and excreta samples were then ground in a ball mill and further analyzed according to the methods described by AOAC (2005) to determine dry matter (DM - method 930.15), mineral matter (MM - method 923.03), crude protein (CP - method 954.01), ether extract (EE - method 991.36), neutral detergent fiber (NDF - method 2002.04), total phosphorus (P - method 945.38) and gross energy (GE).

Based on the results of the bromatological analyses and of feed intake and total excreta production, the metabolizability coefficients of DM, CP, EE, NDF, the retention coefficients of MM and P, and the apparent metabolizable energy (AME) corrected by nitrogen retention (AMEn) of DDGS were determined by using the value of 8.22 as the nitrogen balance correction factor and the equations proposed by Matterson *et al.* (1965).

Experiment II - Performance test

Animals, experimental design, and diets

A total of 432 unsexed, 1-day-old animals, with average initial weight of 9.5 ± 0.25 g were used in a completely randomized design experiment with six levels of DDGS inclusion in their diet (0, 50, 100, 150, 200, or 250 g/kg), six repetitions, and 12 birds per experimental unit during the period ranging from 1 to 42 days of age.

The birds were weighed and evenly distributed in brooders equipped with plate type feeders, nursery pressure cup drinkers, excreta collecting trays, and a heating source provided by incandescent lamps, for the period between 1 and 21 days of age. In order to provide more space, the birds were later transferred at 21 days of age to galvanized wire battery type cages (dimensions of 18 cm high × 34 cm wide × 34 cm long), which were properly identified and equipped with a gutter type of feeder, nipple type drinker with cup, and excreta collecting trays. The average values of ambient temperature and relative air humidity during the experimental period were 33.2 and 25.8 °C and 72.4 and 58.4%, respectively, for maximum and minimum.

In order to meet the nutritional requirements of birds, experimental diets were prepared based on the nutritional recommendation for broiler quails from Silva *et al.* (2012), with the exception of the AMEn value of DDGS. The AMEn of corn DDGS determined in experiment I was used for feed formulation. Moreover, the digestible amino acid contents of DDGS were based on the crude protein content of the co-product and the digestibility coefficient of distillers dried grains with solubles proposed by Zhu *et al.* (2018). The nutritional program consisted of two feeding phases to meet the nutritional requirements of broiler quails: early phase (1-21 days; Table 2) and late phase (22-42 days; Table 3). Feed and water were provided *ad libitum* throughout the feeding period.

Rearing management

On a weekly basis, the birds, the feed provided, and its leftovers from each experimental unit were weighed for evaluation of feed intake, weight gain and feed conversion ratio in each rearing phase. Performance variables were corrected for the mortality recorded daily considering the weight of the dead bird and the leftover feed of the experimental unit, as proposed by Sakomura & Rostagno (2016).

At the end of the performance period, one male and one female were selected per experimental unit according to the average weight (±5%) of the experimental unit. They were submitted to an eight-hour solid fasting and then slaughtered (stunning, cervical dislocation, bleeding, dry plucking) and eviscerated by abdominal cutting with scissors.

Hot and cold carcass (without viscera, feet, head and abdominal fat) yield, and breast and leg yield were determined. The weight of the edible viscera (heart, liver, gizzard) and intestine were determined using semi-analytical scales to calculate the relative weight of the organ in relation to body weight. The length of the intestine was measured using a tape measure.

Meat quality

The pH, water holding capacity, absorption capacity and meat cooking shrinkage were determined for samples of quails' whole breasts. pH readings were

Table 2 – Composition and calculated values of diets with different levels of DDGS fed to broiler quails in the early phase (1-21 days of age).

Ingredients, g/kg	DDGS inclusion levels, g/kg						Price (US$/kg)	
	0	50	100	150	200	250	Crop	Off-season
Corn	403.5	384.5	365.2	344.7	325.1	305.4	0.14	0.19
Soybean meal, 460 g/kg	516.1	484.1	452.1	421.0	389.0	357.2	0.36	0.50
DDGS	0.0	50.0	100.0	150.0	200.0	250.0	0.19	0.19
Soybean oil	53.0	53.5	54.0	54.8	55.6	56.20	0.72	0.72
Limestone	5.5	5.7	5.9	5.9	6.0	6.1	0.04	0.04
Dicalcium phosphate	9.8	9.8	9.9	10.1	10.3	10.5	0.55	0.55
Salt	3.2	3.2	3.2	3.2	3.3	3.3	0.07	0.07
DL-Methionine, 985 g/kg	3.4	3.4	3.3	3.2	3.1	3.0	3.00	3.00
L-Lysine HCl, 998 g/kg	0.05	0.6	1.1	1.7	2.2	2.8	2.48	2.48
L-Threonine, 990 g/kg	1.3	1.3	1.4	1.4	1.5	1.5	1.33	1.33
Premix[1]	4.0	4.0	4.0	4.0	4.0	4.0	3.11	3.11
Feed Cost US$/kg	0.40	0.39	0.39	0.38	0.37	0.36		
Calculated nutritional composition, g/kg								
AMEn[2], kcal/kg	2,902.0	2,902.0	2,902.0	2,902.0	2,902.0	2,902.0		
Crude protein	240.0	240.0	240.0	240.0	240.0	240.0		
Ether extract	73.6	75.7	77.80	80.2	82.7	84.9		
NDF[3]	119.3	141.9	164.6	187.2	209.8	232.5		
Calcium	6.0	6.0	6.0	6.0	6.0	6.0		
Available phosphorus	3.1	3.0	3.0	3.0	3.0	3.0		
Sodium	1.4	1.4	1.4	1.4	1.4	1.4		
Digestible lysine	13.7	13.7	13.7	13.7	13.7	13.7		
Digestible met.+cyst.	10.4	10.4	10.4	10.4	10.4	10.4		
Digestible methionine	6.7	6.7	6.7	6.6	6.6	6.6		
Digestible threonine	10.5	10.4	10.4	10.4	10.4	10.4		
Digestible tryptophan	3.1	3.1	3.0	2.9	2.8	2.7		
Digestible valine	11.5	11.5	11.5	11.4	11.4	11.4		
Granulometry								
GMD ± GSD[4] µm	741±2.12	764±2.08	757±2.01	713±2.01	645±2.00	642±1.98		

[1]Mineral and vitamin premix provided per kg of diet: Manganese 5.8 g; zinc 5 g; iron 5 g; copper 1.2 g; iodine 100 mg; selenium 32 mg; retinyl acetate (vitamin A) 300 mg; cholecalciferol (vitamin D_3) 5 mg; α-tocopherol acetate (vitamin E) 2.500 mg; menadione 200 mg; thiamine 150 mg; riboflavin 600 mg; pyridoxine 240 mg; vitamin B_{12} 1.200 µg; folic acid 70 mg; pantothenic acid 1.2 g; biotin 7 mg; niacin 3.5 g; choline 35 g. [2]Apparent metabolizable energy corrected for nitrogen balance. [3]NDF = neutral detergent fiber. [4]GMD = Geometric Mean Diameter and GSD = Geometric Standard Deviation. The particle size of the diets was evaluated using the Baker and Herman (2002) method for determining and expressing the quality of feed and materials by dry sieving, in order to characterize the particle size of the diets and the co-product

taken directly from the right filet (*Pectoralis major*) of the quails, immediately after slaughter and 24h *post mortem,* using a portable pH meter attached to a probe, which was inserted in the center of the breast muscle at a depth of 0.5 to 1.0 centimeters below the muscle surface.

The water holding capacity (WHC) was determined according to the methodology described by Hamm (1960), which consists in measuring the water released when pressure is applied to muscle tissue. For this purpose, meat samples in duplicate slices of 2 g were placed in the center of two filter papers between two glass plates (15 cm × 15 cm × 8 mm) under 10 kg of pressure for 5 minutes. Subsequently, the meat samples were weighed, the amount of water that was lost was calculated as the weight difference, and the result was expressed as the percentage of exuded water in relation to the initial weight.

The water binding capacity (WBC) was determined by adapting the methodology described by Roça (1986). For the analysis of quail meat, exactly 15 g of meat were weighed, 45 mL of distilled water were added, and then the mixture was ground for 90 seconds in a blender. After grinding the meat sample, 12 g of the pulp obtained in duplicates were weighed and centrifuged at 21-25 °C for 15min at 1000 rpm. The supernatant was collected and weighed, and its absorption capacity was determined as follows:

$$WBC (\%) = \{[(PW-MW) - WS] / MW\} \times 100 \quad (1)$$

Where:

PW = Pulp weight (35g)

MW = Meat weight in the pulp

WS = Weight of supernatant.

The determination of the meat cooking shrinkage (MCS) was performed by adapting the methodology

Table 3 – Percent composition and calculated values of diets with different levels of DDGS fed to final stage (22-42 days of age) broilers.

Ingredients, g/kg	DDGS inclusion levels, g/kg						Price (US$/kg)	
	0	50	100	150	200	250	Crop	Off-season
Corn	448.1	428.5	408.0	388.1	368.3	348.4	0.14	0.19
Soybean meal, 460 g/kg	461.7	430.5	399.4	367.8	336.1	304.5	0.36	0.50
DDGS	0.0	50.0	100.0	150.0	200.0	250.0	0.19	0.19
Soybean oil	68.0	68.2	69.1	69.8	70.5	71.3	0.72	0.72
Limestone	4.8	4.9	5.0	5.1	5.2	5.3	0.04	0.04
Dicalcium phosphate	7.3	7.5	7.7	7.9	8.0	8.2	0.55	0.55
Salt	3.2	3.2	3.2	3.3	3.3	3.3	0.07	0.07
DL-Methionine, 985 g/kg	2.9	2.8	2.7	2.6	2.6	2.4	3.00	3.00
L-Lysine HCl, 998 g/kg	0.0	0.4	0.9	1.5	2.0	2.6	2.48	2.48
Premix[1]	4.0	4.0	4.0	4.0	4.0	4.0	3.11	3.11
Feed Cost US$/kg	0.39	0.38	0.37	0.37	0.36	0.35		
Calculated nutritional composition, g/kg								
AMEn[2], kcal/kg	3,055.0	3,055.0	3,055.0	3,055.0	3,055.0	3,055.0		
Crude protein	220.0	220.0	220.0	220.0	220.0	220.0		
Ether extract	89.2	91.0	93.5	95.9	97.7	100.3		
NDF[3]	116.6	139.4	162.0	184.6	207.3	229.9		
Calcium	5.0	5.0	5.0	5.0	5.0	5.0		
Available phosphorus	2.5	2.5	2.5	2.5	2.5	2.5		
Sodium	1.4	1.4	1.4	1.4	1.4	1.4		
Digestible lysine	12.4	12.3	12.3	12.3	12.3	12.3		
Digestible met.+cys.	9.4	9.4	9.4	9.4	9.5	9.4		
Digestible methionine	6.0	6.0	5.9	5.9	5.9	5.8		
Digestible threonine	8.6	8.5	8.5	8.4	8.4	8.3		
Digestible tryptophan	2.9	2.8	2.7	2.6	2.5	2.4		
Digestible valine	10.6	10.6	10.6	10.5	10.5	10.5		
Granulometry								
GMD ± GSD[4], µm	790±1.92	757±1.91	741±1.93	703±1.93	623±1.97	620±1.92		

[1]Mineral and vitamin premix provided per kg of diet: Manganese 5.8 g; zinc 5 g; iron 5 g; copper 1.2 g; iodine 100 mg; selenium 32 mg; retinyl acetate (vitamin A) 300 mg; cholecalciferol (vitamin D_3) 5 mg; α-tocopherol acetate (vitamin E) 2.500 mg; menadione 200 mg; thiamine 150 mg; riboflavin 600 mg; pyridoxine 240 mg; vitamin B_{12} 1.200 µg; folic acid 70 mg; pantothenic acid 1.2 g; biotin 7 mg; niacin 3.5 g; choline 35 g. [2]Apparent metabolizable energy corrected for nitrogen balance; [3]NDF = neutral detergent fiber; [4]GMD = Geometric Mean Diameter and GSD = Geometric Standard Deviation. The particle size of the diets was evaluated using the Baker and Herman (2002) method for determining and expressing the quality of feed and materials by dry sieving, in order to characterize the particle size of the diets and the co-product.

described by Honikel (1987), in which the whole muscle (*Pectoralis major*) on the right side was weighed, packed with aluminum foil, cooked on a metal plate heated on both sides, keeping each side of the filet for three minutes, totaling six minutes of cooking. After cooking, the filets were removed from the foil and cooled on absorbent paper at room temperature and weighed to determine the weight loss due to cooking. The difference between the initial (*in natura* breast) and final (cooked breast) weight was considered the result of the weight loss due to cooking.

Economic feasibility

Economic feasibility was determined based on variations in the live weight of the animals, feed intake, and costs of the different experimental diets used. Moreover, we considered the exchange rate of US$ 1 = R$ 5.08. Two macroeconomic scenarios of prices for the ingredients used in the diets were analyzed, considering the prices charged in the local market of Sinop-MT-Brazil, in the harvest (October to January) and off-season (June to September) periods of soybean cultivation and diet formulation.

Based on the variations in diet costs (Scenario 1 and 2) and feed intake, the feed cost (FC) was determined as:

$$FC = CFC \times FP \quad (2)$$

Where FC = feed cost (US$), CFI = cumulative feed intake (kg) and FP= feed price (US$/kg), according to the methodology proposed by Mendes & Patrício (2004).

The gross income is the dollar value obtained as a result of the live weight multiplied by the selling price per kilo of the product:

$$GI = Q \times SP \quad (3)$$

Where GI= gross income (US$), Q = live weight and SP= the selling price of a kilogram of quail US$= 2.27.

The gross value added (GVA) represents the difference between gross income and feed costs, and is estimated by the formula:

GVA = GI - FC (4)

Where GI = gross income (US$) and FC = feed cost (US$).

The profitability index (PI) indicates the rate of capital available after the payment of feed costs. Therefore, it is the result of the ratio between gross value added (GVA) and gross income (GI), using the formula:

PI = (GVA × GI) / 100 (5)

Statistical Analysis

For the metabolizability study (Experiment I), the results were submitted to analysis of variance (ANOVA) using the GLM procedure of the SAS® software (SAS Institute Inc., Cary, NC). For the performance test (Experiment II), the evaluated parameters were submitted to analysis of variance using SAS® software (SAS Institute Inc., Cary, NC). Subsequently, the effects of dietary DDGS levels (0, 50, 100, 150, 200, or 250 g/kg) on performance carcass meat quality, organ weights and economic viability were estimated using linear and quadratic regression analyses. The proportion of males and females in each experimental unit was the applied covariate in the statistical model.

RESULTS

Experiment I - Nutritional values of DDGS

No difference was observed between males and females ($p>0.05$) for metabolizability coefficients of DM, CP, EE, and NDF, retention coefficients of MM and P, apparent metabolizable energy (AME) and its correction for nitrogen balance (AMEn) values (Table 4). The average AME value of corn DDGS for broiler quails was 2,617 kcal/kg, and the AMEn was 2,476 kcal/kg.

Table 4 – Metabolizability coefficients, apparent metabolizable energy (AME) and its correction for nitrogen balance (AMEn) of distillers' dried grains with solubles in diets for male and female broiler quails from 28 to 32 days of age.

Metabolizability coefficients, g/kg	Sex		Average	SEM	*p*-value
	Males	Females			
Dry matter	611.1	613.5	612.3	0.189	0.909
Crude protein	366.5	393.1	377.2	0.642	0.482
Ether extract	350.1	347.2	348.7	0.210	0.964
Neutral detergent fiber	450.1	443.1	446.6	0.327	0.833
Mineral matter	237.8	275.0	252.7	0.758	0.397
Total phosphorus	456.8	466.6	460.7	0.389	0.732
Gross energy, kcal/kg	3,593.3	3,595.7	3,595.7	0.243	0.856
AME, kcal/kg	2,622.0	2,610.0	2,617.2	0.455	0.861
AMEn, kcal/kg	2,488.0	2,466.5	2,456.9	0.566	0.759

SEM = standard error of the mean.

Experiment II - Productive performance

There was no effect ($p>0.05$) of dietary DDGS inclusion levels on body weight (BW), average weight gain (WG), feed intake (FI), feed conversion ratio (FCR) and viability at 1 to 21 days of age (Table 5). In the phase from 22 to 42 days and from 1 to 42 days of age, the increase in DDGS inclusion levels in the diet linearly increased FI ($p=0.015$; $\hat{Y}=2.501X+742.052$; $R^2=0.89$; and $p=0.001$; $\hat{Y}=2.361X+857.030$; $R^2=0.88$; Figure 1) and worsened FCR ($p=0.038$; $\hat{Y}=0.0229X+4.832$; $R^2=0.36$; and $p=0.001$; $\hat{Y}=-0.005X+ 3.231$; $R^2=0.88$; Figure 2). However, DDGS levels did not influence ($p>0.05$) BW, WG or the economic viability of production in the period from 1 to 42 days of age.

Carcass characteristics and meat quality

The inclusion levels of DDGS in the diet did not affect ($p>0.05$) the characteristics of the carcass (hot and cold), breast and legs and the values of pH_{0h}, pH_{24h}, cooking loss, water holding capacity, and water absorption (Table 6).

Organ weights

There was a linear increase ($p=0.001$; $\hat{Y}=0.026X+3.698$; $R^2=0.98$) in the relative weight of the gizzard with increasing levels of DDGS in the diet (Figure 3). However, its inclusion in the diet did not influence ($p>0.05$) the relative weight of the liver, heart, intestine, abdominal fat, and intestine length of the quails (Table 7).

Economic feasibility

There was a decreasing linear effect for gross value added ($p=0.032$; $\hat{Y}=-0.012X+2.130$; $R^2 =0.61$) and profitability index ($p=0.001$; $\hat{Y}=-0.1955X+62.594$; $R^2 =0.63$) in the harvest period. However, the economic

Table 5 – Performance of broiler quails fed distillers' dried grains with solubles (DDGS).

Item	Dietary DDGS inclusion levels, g/kg						SEM	*p*-value	
	0	50	100	150	200	250		L	Q
1 to 21 days									
BW 21 days, g	124.1	125.2	123.0	116.1	127.9	116.7	0.142	0.366	0.900
BWG, g/bird	114.9	115.9	113.9	106.9	118.7	107.6	0.141	0.373	0.904
FI, g/bird	250.8	260.5	242.4	252.1	248.8	257.9	0.166	0.897	0.469
FCR	2.2	2.3	2.2	2.4	2.1	2.4	0.022	0.215	0.511
22 to 42 days									
BW 42 days, g	274.5	281.9	278.7	277.1	265.2	270.9	0.159	0.142	0.398
BWG, g/bird	150.4	156.7	155.7	160.9	137.4	154.2	0.187	0.490	0.503
FI[1], g/bird	748.9	760.5	750.4	777.3	788.0	814.6	0.327	0.015	0.402
FCR[2]	5.0	4.9	4.9	4.8	5.8	5.3	0.039	0.038	0.414
1 to 42 days									
BWG, g/bird	265.3	271.8	269.6	267.9	256.1	261.8	0.159	0.145	0.399
FI[3], g/bird	861.3	879.6	860.9	892.9	898.2	926.4	0.325	0.040	0.496
FCR[4]	3.2	3.2	3.2	3.3	3.5	3.5	0.025	0.001	0.287
Viability, %	89.4	85.7	89.0	91.7	86.6	75.9	0.155	0.171	0.176

BW = body weight; BWG = body weight gain; FI = feed intake; FCR = feed conversion ratio; SEM = standard error of the mean; L = linear; Q = quadratic.

[1]$\hat{Y}_{FI\ 22\ to\ 42\ days} = 2.5005x + 742.0520$; $R^2=0.89$.

[2]$\hat{Y}_{FCR\ 22\ to\ 42\ days} = 0.02287x + 4.8321$; $R^2=0.36$.

[3]$\hat{Y}_{FI\ 1\ to\ 42\ days} = 2.3613x + 857.0295$; $R^2=0.88$.

[4]$\hat{Y}_{FCR\ 1\ to\ 42\ days} = - 0.00498x + 3.2305$; $R^2=0.88$.

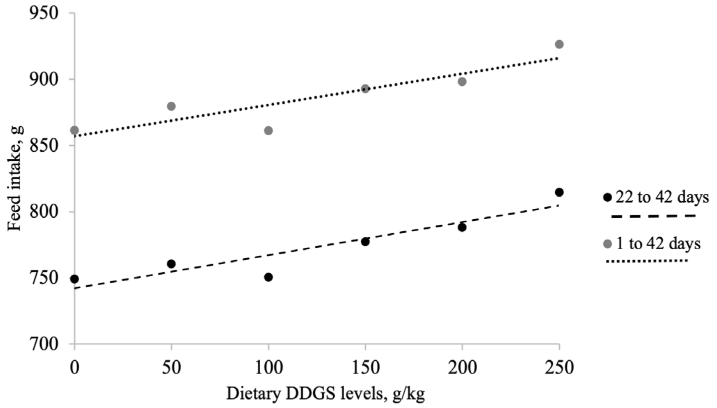

Figure 1 – Feed intake of broiler quails from 22 to 42 days and 1 to 42 days in function of DDGS levels in their diet.v

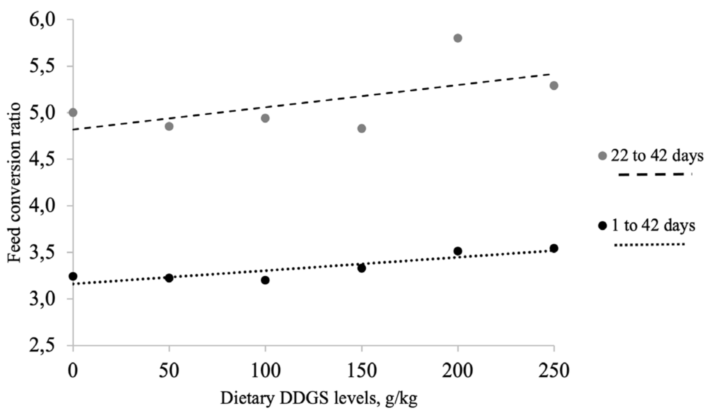

Figure 2 – Feed conversion ratio of broiler quails from 22 to 42 days and 1 to 42 days in function of DDGS levels in their diet.

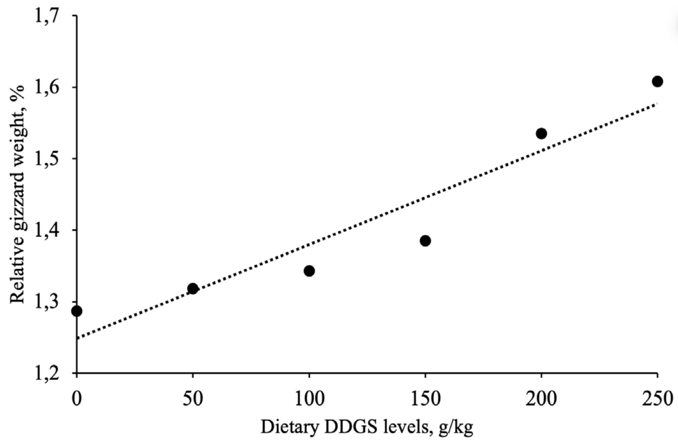

Figure 3 – Relative gizzard weight of broiler quails at 42 days in function of DDGS levels in their diet.

viability in the off-season period was not influenced (*p*>0.05) by the inclusion of DDGS in the diets (Table 8).

DISCUSSION

Experiment I - Nutritional values of DDGS

The metabolizability coefficient for DM (612.3 g/kg) and CP (379.8 g/kg) were lower than those obtained by Oliveira (2020), who studied 21-day-old broilers and obtained 724.1 g/kg of dry matter and 631.6 g/kg for CP.

Due to it being common to use mixed flocks in quail production and there being no difference (*p*>0.05)

Table 6 – Carcass and meat quality of broiler quails fed distillers' dried grains with solubles (DDGS) at 42 days of age.

Item	DDGS inclusion levels, g/kg						SEM	*p*-value	
	0	50	100	150	200	250		L	Q
Absolute weight, g									
Live weight	288.7	295.3	295.0	289.6	272.4	276.0	8.245	0.741	0.896
Hot carcass	191.5	200.9	199.1	194.9	184.6	184.9	5.885	0.089	0.149
Cold carcass	198.8	205.9	205.9	202.8	193.5	192.5	5.789	0.145	0.150
Chest	75.1	78.3	80.4	76.9	74.4	74.7	2.581	0.433	0.174
Legs	42.9	41.7	43.1	42.6	41.6	41.2	1.469	0.441	0.679
Meat quality									
pH_{0h}	6.11	6.08	6.09	6.17	6.08	6.17	0.017	0.468	0.993
pH_{24h}	5.9	5.74	5.8	5.83	5.79	5.77	0.015	0.773	0.862
MCS, %	30.9	30.8	30.7	29.9	32.5	31.1	0.059	0.527	0.588
WHC, %	26.7	26.5	26.7	27.7	29.0	28.4	0.065	0.101	0.796
WBC, %	43.4	45.6	46.0	46.5	40.9	38.6	0.117	0.129	0.101

MCS = Meat Cooking Shrinkage; WHC = Water holding capacity; WBC = Water binding capacity; SEM = standard error of the mean; L = linear; Q = quadratic.

Table 7 – Relative organ weight of broiler quails fed distillers' dried grains with solubles (DDGS) at 42 days.

Item	DDGS inclusion levels, g/kg						SEM	*p*-value	
	0	50	100	150	200	250		L	Q
Relative weight, g/100g BW									
Gizzard[1]	1.287	1.318	1.343	1.385	1.535	1.608	0.052	0.001	0.482
Liver	1.878	1.653	1.720	1.590	1.613	1.522	0.105	0.064	0.932
Heart	0.785	0.810	0.817	0.845	0.860	0.798	0.032	0.674	0.336
Abdominal fat	2.232	2.828	2.038	2.418	1.842	2.053	0.487	0.348	0.762
Intestine									
Weight	2.948	2.697	2.810	2.702	2.678	2.660	0.129	0.056	0.876
Length (cm)	65.71	64.75	66.63	66.79	63.08	66.38	2.008	0.929	0.954

SEM = standard error of the mean; L = linear; Q = quadratic

[1]$\hat{Y}Relative_{gizzard\ weight}=0.02602X+3.6981$; $R^2 = 0.94$.

Table 8 – Economic feasibility of broiler quail production fed with dried distillers' grains with solubles (DDGS) in the harvest and off-season period.

Item	DDGS inclusion levels, g/kg						SEM	*p*-value	
	0	50	100	150	200	250		L	Q
Harvest period									
Gross value added[1], US$	0.356	0.386	0.371	0.360	0.335	0.342	0.008	0.032	0.064
Profitability index[2], %	57.36	60.54	58.81	57.50	55.80	55.86	0.642	0.001	0.193
Off-season period									
Gross value added, US$	0.278	0.318	0.303	0.295	0.274	0.283	0.008	0.152	0.222
Profitability index, %	44.86	49.92	47.99	47.09	45.61	46.33	0.877	0.458	0.130

SEM = standard error of the mean; L = linear; Q = quadratic

[1]$\hat{Y}_{Gross\ value\ added}=-0.0014X+0.3750$; $R^2 = 0.88$.

[2]$\hat{Y}_{Profitability\ index}=-0.1318X+59.2898$; $R^2 = 0.94$.

between males and females, it is seen as plausible to use the average value of 2,476 kcal/kg for the AMEn value of DDGS. When comparing the apparent metabolizable energy value (AME) of corn DDGS (2,617 kcal/kg) with other feeds, it can be seen that the value is higher than the value of soybean meal (2,239 kcal/kg) and lower than the AME value of corn (3,363 kcal/kg) proposed by Rostagno *et al.* (2017). Therefore, the AMEn value of 2,476 kcal/kg, determined in this study was similar to the values determined for chicken broilers by Guney *et al.* (2013) and Santos *et al.* (2019), who evaluated five samples of DDGS in diets for chicken broilers in the 21 to 28 days of age phase and observed an AMEn value of 2,617 ± 318 kcal/kg, based on dry matter.

According to Pedersen *et al.* (2014), there are antinutritional factors that limit the use of DDGS in non-ruminant diets, such as non-starch polysaccharides (NSP) that contain pentosans, arabinoxylans, D-xylans, β-glucans, D-mannans, galactomannans, xyloglucans, and rhamnogalacturonan. These hinder fiber digestion, reduce feed energy and limits digestibility and nutrient utilization (Freitas *et al.*,2014), due to its the ability to bind to large amounts of water, resulting in an increase in the viscosity of the intestinal contents and the passage rate of the digesta. Thus, the expossure time of enzymes (exogenous and endogenous) on the food is decreased and, consequently, the absorption of nutrients (Jaworski *et al.*, 2015).

Besides the presence of NSP, there are other factors that may contribute to the reduced nutrient digestibility of DDGS, such as the ability of fiber to create physical barriers to the action of certain digestive enzymes, reducing the absorption and digestibility of diets (Saki *et al.*, 2011). Moreover, there is the amount of nitrogen adhered to the fibrous fraction of the feed, which should be interpreted as protein that is not available for the maintenance and production processes of the animal, given that more than 12% of nitrogen adhered to fibers indicates a reduced digestibility of crude protein, due to factors such as exposure of the feed to high temperatures (Vasconcelos, 2014).

Adeola & Cowieson (2011), corroborating what was observed, stated that the inclusion of ingredients with the presence of soluble and insoluble NSP in the diet makes food digestion a nutritional challenge for non-ruminant animals, generating increased consumption of concentrates and low nutritional use. In fact, when evaluating the chemical composition of different samples of corn DDGS, Pedersen *et al.* (2014) observed that this co-product of the ethanol industry contains approximately 23.1% of total NSP, 88% of which insoluble and 12% soluble. Therefore, the low utilization of nutrients in the diet may be related to the high fibrous content and its negative effects on nutrient digestibility (Stein *et al.*, 2016).

Additionally, the variations observed in the energy composition of the co-product may be associated both with the variety of corn used in the production of ethanol, and consequently present in the DDGS, and with the ethanol production process, which cause the ether extract contents of the sources to vary. This may be related to the partial extraction of corn oil, a technique adopted by several ethanol producing industries (Meloche *et al.*, 2013).

Experiment II - Productive performance

The results showed that DDGS can be used as an alternative ingredient in the diet of broiler quails up to 250 g/kg in the phase from 1 to 21 days of age, without affecting body weight, weight gain, feed intake, feed conversion ratio and economic viability. Similar results were observed by Konca *et al.* (2015), who concluded that the inclusion of up to 300 g/kg of DDGS can be used in the diet of Japanese quails at 35 days of age without impairing performance and meat quality, as long as the requirements of essential amino acids and metabolizable energy are adapted.

Therefore, in the present study, the formulation of nutritionally balanced diets was considered, both in the initial and final phases of growth. These were formulated using digestible amino acids and industrial amino acids to adjust the SID amino acid: lysine ratio as DDGS levels increased.

In the phase from 22 to 42 days and in the period from 1 to 42 days, the FI and FCR observed in this study were negatively influenced by the increase of DDGS inclusion in the diet. According to Lima *et al.* (2011), the laying quails (*Coturnix coturnix japonica*) and European quails (*Coturnix coturnix coturnix*) are birds that have an early sexual maturity (35 to 40 days of age), which can compromise their productive performance due to processes of sexual maturity requiring greater energy and nutrient expenditure (Rezende *et al.* 2004). All results that can be attributed to the early sexual maturity of quails and its residual effect on the results can be observed in the phase from 22 to 42 days of age.

According to Bolu *et al.* (2012), the inclusion of up to 100 g/kg of corn DDGS in diets for broilers in the period from 22 to 42 days of age is feasible, since the inclusion of the coproduct did not affect weight gain and feed conversion ratio. When evaluating the inclusion of 0 to 160 g/kg of DDGS in the diet of broilers in the final phase (36 to 42 days), Valentim (2018) also observed no differences on feed intake, weight gain, and feed conversion ratio, contrary to the results observed in this research.

Therefore, a possible explanation for these results is that European and Japanese quails both show maximum growth rate at 27 days of age. After this, growth rate decreases and weight gain has a progressively decreasing return, with increased fat deposition in the viscera, nutrient retention in the oviduct-ovary, and increased dietary energy requirements (Silva *et al.*, 2012). This causes nutrient expenditure from the growth process to be directed to the process of sexual maturity and its production and maintenance, due to the nutritional supply of diets being insufficient to ensure the development of these physiological functions in quails (Lima *et al.*, 2011). In fact, according to the work of Reis *et al.* (2007), lower weight birds required higher feed intake to maximize growth rate and reach sexual maturity, resulting in worse feed conversion.

Carcass and meat quality

The results for carcass and meat quality were not affected by increasing the inclusion levels of DDGS in the diets, and it can be reaffirmed that the inclusion of up to 250 g/kg of corn DDGS in the diet did not impair the protein deposition and meat quality of quail broilers. Results of the present study are similar to those observed by Konca *et al.* (2011), who conducted a study in which they evaluated the inclusion of DDGS levels (0 to 300 g/kg) in diets of Japanese quails in the period from 1 to 35 days. They recommended the inclusion of up to 300 g/kg of DDGS without any effect on carcass yield, internal organs, and characteristics of the gastrointestinal system. Shim *et al.* (2018) and Kim *et al.* (2016) confirmed these results as they observed no changes in carcass yield and prime cuts in broilers fed with DDGS levels (60 to 300 g/kg) in the 21- to 42-day-old phase.

These results contradict those observed by Schöne *et al.* (2017), who evaluated the effect of five levels of corn DDGS (0 to 20%) and concluded that the inclusion of 20% in the diet of broilers from 22 to 42 days of age affects carcass yield and promotes greater abdominal fat deposition in females, results that were attributed to an amino acid deficiency (Corzo, 2012).

Regarding meat quality, the increased inclusion of DDGS in the diets did not influence water holding capacity and absorption, meat cooking shrinkage, and both the initial and 24 hours *post-mortem* pH value. The pH values observed in this study (pH_{0h} 6.08 to 6.17 and pH_{24h} 5.7 to 5.9) are within the standards set by Brossi *et al.* (2009), which considers pH values for broilers to be between 6.3 to 6.6 measured 15 minutes after slaughter, being able to reach pH values 24 hours *post-mortem* around 5.8 to 6.2.

These results corroborate those presented by Damasceno (2018), whose inclusion of up to 160 g/kg of DDGS in the diet of broilers did not influence the water holding capacity and absorption, meat cooking shrinkage, and pH values 24 hours after slaughter. Unstable pH values in meat, according to Alves *et al.* (2016), are factors that can interfere with the carcass characteristics and meat quality, such as water holding capacity and absorption, meat cooking shrinkage, tenderness, juiciness, color, texture, and microbial stability.

In summary, pH values 24 hours *post-mortem* higher than 6.2 imply greater water retention, shorter storage time and dark coloration, characteristics of DFD (Dark, Firm and Dry) meat. On the other hand, pH values lower than 5.8 after slaughter imply lower water retention, pale and soft coloration, characteristic of PSE (Pale, Soft and Exudative) meat (Silva, 2017).

Organ weights

The relative weight of the gizzard increased linearly according to the levels of DDGS in the diets. The results of the present study corroborate those reported by Braz *et al.* (2011): as fiber levels in the diet increase, greater development and increase in gizzard weight occurs. Pires Filho (2017) observed that the inclusion of 20 to 120 g/kg of DDGS in broiler diets linearly increased the relative gizzard weight. Thus, the addition of fiber in the diets of non-ruminant animals can cause expansion of the bolus and increased mechanical activity of the gizzard muscles, leading to augmentation its weight (Mourão *et al.*, 2008).

The influence of feed on gizzard characteristics is believed to be associated with the mechanical stimulation of the organ, which depends on the level, type of ingredient, and size and characteristics of the feed's particles. Thus, the more stimulated the mechanical activity is, the greater the size and weight of the gizzard (González-Alvarado *et al.* 2010). In general, the other organ weights variables were not affected by dietary DDGS inclusion levels.

Economic feasibility

An inversely proportional relationship was observed for economic feasibility. As the inclusion of DDGS in the diets increases, there is a reduction in the gross added value and, consequently, in the profitability index. In general, the results obtained in this investigation demonstrate the possibility of using DDGS as an alternative ingredient with a higher profitability index (57.50%) with the inclusion of 150 g/kg of DDGS in the harvest period, and of 43.33% with the inclusion of 250 g/kg of DDGS in the off-season period.

In this context, Valentim (2018) indicated that the inclusion of up to 160 g/kg of DDGS in broilers' diets in the period from 36 to 42 days is feasible, since it is less expensive than inputs such as soybean meal and corn, and also it does not affect performance variables, as reported in this work. Santos and Grangeiro (2012) state that alternative ingredients become a viable possibility of cost reduction for the producer and can also obtain expressive productivity results in economic and zootechnical aspects.

Regarding the results observed in the harvest period, the inclusion of other ingredients such as L-lysine, DL-methionine, L-threonine, and soybean oil, which were used to correct the nutritional deficit of the diets, impaired the economic viability of developing diets with higher inclusion of DDGS.

Summarizing, the average AMEn value of DDGS for broiler quails is 2.476 kcal/kg. The recommended quantity of DDGS to be included in the diet of broiler quails, without affecting the productive performance in the initial phase (1 to 21 days of age), is of up to 250 g/kg. In the phase from 22 to 42 days and in the total period from 1 to 42 days of age, the inclusion of up to 150 g/kg of corn DDGS in the harvest period and up to 250 g/kg in the off-season period might be recommended based on economically feasible and without affecting animal growth, carcass, and meat quality.

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