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EDITED BY
Loh Teck Chwen,
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Wittawat Molee,
Suranaree University of Technology, Thailand

*CORRESPONDENCE
Fernando Barbosa Tavares
fernando.tavares@ufra.edu.br

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Dehydrated guava by-product in feed for slow-growing broilers

Silvia Silva Vieira[1], Fernando Barbosa Tavares[2]*, Ernilde Dos Santos Vieira[1], Eslane da Silva Moura[1], Wanderson dos Santos Lopes[1], Andressa Martins Marinho[1], Cassio Pinho dos Reis[3], Luckas Thiago Oliveira Galvão[1] and Ernestina Ribeiro dos Santos Neta[1]

[1]Federal Rural University of the Amazon, Parauapebas, Brazil, [2]Institute of Animal Health and Production, Federal Rural University of the Amazon, Belém, Brazil, [3]Institute of Mathematic, Federal University of Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil

This study evaluated the use of dehydrated guava by-products (DGBP) in the feed of slow-growing broilers as a substitute for corn. A total of 324 one-day-old broiler Naked Neck from a slow-growing lineage were used. At 30 days of age, the broilers were distributed in an entirely randomized experimental design consisting of four treatments with nine replicates and nine birds in each replicate. The treatments were differentiated by varying concentrations of DGBP (0, 5, 10, and 15%) in the feed. Performance data [feed intake, weight gain, and feed conversion ratio (FCR)] were evaluated from 30 to 60 days and 61 to 84 days of age. At 84 days of age, the broilers were slaughtered; subsequently, the analyses of carcass and organ yield in terms of chemical composition of the breast, thigh and drumstick, and meat quality parameters (coloration, pH, weight loss by cooking and dripping, shear force, and sensory evaluation) were performed. There was no effect of DGBP on the average weight, weight gain, feed consumption, and FCR of the broilers ($P > 0.05$). However, there was an increasing linear effect ($P < 0.05$) on the gizzard yield and a quadratic effect on the liver and abdominal fat yield, where treatments with 5 and 10% DGBP obtained the highest yield percentages. There was no effect ($P > 0.05$) of DGBP addition on chemical composition, pH, shear force, and weight loss by cooking and dripping. A linear increasing effect on coloration ($P < 0.05$) was found due to dietary DGBP in all the cuts of meat. In addition, a significant difference ($p < 0.05$) was found in the texture of the breast meat, where the greater the amount of DGBP added, the greater the scores attributed by the tasters. In conclusion, DGBP can be included up to 15% in the diet of slow-growing broilers without altering the production performances, carcass and cut yield, and meat quality parameters. Furthermore, it promoted a reddish coloration of the breast skin and thigh skin of the birds.

KEYWORDS

consumption, bioproducts, performance, meat quality, weight gain

1 Introduction

The creation of slow-growing broilers has aroused greater interest for small, medium and large producers, due to the end consumer demand for meat from chickens raised in systems closer to their natural habitat. This market segment takes into account the quality characteristics of the meat, considering it more tasty and visually attractive (Amorim et al., 2019). Therefore, the growth rate of these broilers, though consistent, is challenging to measure. Moreover, given the low supply of the product in relation to demand, it has been observed that large companies, cooperatives, and integrators are offering these free-range products in the market at greater price points compared to industrial broiler.

Feed production is one factor that increases the cost of rearing slow-growing broilers and represents about 70% of the costs. Therefore, increasing the production of slow-growing broilers requires the use of by-products to replace traditional ingredients (corn and/or soybean meal) and reduce costs (Broch et al., 2017). Such by-products must be easily accessible on the property, have low acquisition costs, and have a high utilization rate by the broilers.

Using by-products can affect the sensory attributes of the meat. In general, slow-growing poultry has peculiar attributes due to the organoleptic characteristics of the meat that draws the consumer's attention, and these are influenced by feeding. Therefore, including alternative foods into the diet of slow-growing broilers must maintain the desired characteristics (Amorim et al., 2020), i.e., meat with a marked flavor, more pigmentation, and firm textures (Amorim, 2013).

Guava (*Psidium guajava* L.) is among the major products produced in Brazil. In 2019, 584,226 tons of guava were produced, making the country the largest producer of red guava globally (IBGE, 2020). In guava processed to obtain pulp, there is a production of 40% of by-products (Oliveira, 2016; Souza et al., 2016), it becomes necessary to add value to these by-products to reduce economic and environmental impacts.

Utilizing guava by-products in poultry feed can be an interesting alternative since its bromatological composition includes 10.09% crude protein (CP), 11.71% ether extract (EE), 55.62% crude fiber (CF), 4,290 kcal/kg gross energy (GE), 0.15% calcium (Ca), 0.36% phosphorus (P) (Lousada Junior et al., 2006; Santos et al., 2009; Silva et al., 2009), 112.71 mg/100 g ascorbic acid (Gutiérrez et al., 2008), 5.31 g/100g of total sugars (Uchoa et al., 2008), and 644.9 μg/100 g carotenoids (Sousa et al., 2011), which renders a red coloration to the peel (Menezes et al., 2016; Mesquita, 2018).

Despite the high production of guava and the large volume of by-products generated, using guava by-products in animal feed has not been well studied. Thus, the present study aimed to evaluate the use of dehydrated guava by-products (DGBP) as a substitute for corn in the feed of slow-growing broilers by determining its production performances, organoleptic characteristics, and meat quality.

2 Material and methods

The experiment was conducted in the poultry sector of the Federal Rural University of the Amazon, Belém, Pará, Brazil. The research was previously approved by the Ethics Committee on the Use of Animals of the Federal Rural University of the Amazon, protocol number 018b/2018 (CEUA-UFRA).

A total of 324 day-old mixed-sex chicks of the Naked Neck slow-growing lineage were used. At 30 days of age, the animals were divided into 36 boxes at a density of 4.5 birds/m^2, containing a tubular feeder, a pressurized drinking fountain, and access to a paddock with an area of 3 m^2/bird. The broilers were weighed individually and distributed in the plots for maximum uniformity, considering a standard deviation of ± 10% of the mean weight, and distributed in an entirely randomized experimental design, comprised of four treatments and nine replicates, with nine birds per replicate.

The diets were formulated to meet the nutritional requirements according to Rostagno et al. (2017) (Table 1) and adjusted for the growth phase (30 to 60 days of age) and the finishing phase (61 to 84 days). The treatments consisted of varying concentrations of DGBP in the feed: 0, 5, 10, and 15% in the diet. The fresh guava by-product was dried in the sun for four days, ground in a mill, and subsequently added to the experimental feed rations (Table 2).

To determine the production performance in the experimental period from growth phase (30 to 60 days of age) and the finishing phase (61 to 84 days). Body weight (BW, g) was recorded, and based on the differences, the average body weight gain (BWG, g). Based on these recordings, the average daily feed intake was calculated (FI, g feed/broiler). The feed conversion ratio (FCR, kg feed/kg weight) was calculated, were evaluated and corrected for bird mortality during the experiment, as proposed by Sakomura and Rostagno (2016). During the experimental period, the data on ambient temperature, black globe temperature, and relative humidity were collected through a black globe thermometer and thermo hygrometer located in the center of the barn. Daily readings were taken at 07:00, 10:00, 13:00, and 16:00 hours. The average temperature was 28.4 °C, the Wet Bulb Globe Temperature (WBGT) was 32.7 °C, and the relative humidity was 76%.

At 84 days of age, the birds were weighed and fasted for 10 hours. Three males from each plot (totaling 108) were sampled, with their body weight close to the plot average (± 5%). The 72 carcasses were divided in half (a total of 144 carcass halves), 36 wereused to evaluate the chemical composition, 36 to evaluatethe drip loss, 36 to evaluate the cooking loss and 36 for the shear force. After fasting, the broilers were weighed individually, identified, slaughtered by cervical dislocation, plucked, and eviscerated. Weights of the hot carcass and viscera (proventriculus, gizzard, liver, pancreas, intestine, and abdominal fat) were measured and then cooled for about 24 hours in a cold chamber with a temperature range of -3 to -5 °C.

After cooling, the whole carcass and the individual cuts (breast, back, wings, drumsticks, and thighs) were weighed on digital scales, and their yields were calculated in relation to the weight of the eviscerated carcass to evaluate the absolute weight (g) and yield (%) of the carcasses (excluding the feet, head, and neck).

To evaluate the chemical composition of the meat, the drumstick, thigh, and breast cuts were separated and deboned, and the skin, fat, and ligaments were removed to perform the laboratory analyses. The cuts were ground separately in a cutter,

TABLE 1 Percentage and nutritional composition of diets.

Ingredients (%)	Growth phase (30 – 60 days old)				Finishing phase (61 – 84 days old)			
	0%DGBP	5%DGBP	10%DGBP	15%DGBP	0%DGBP	5%DGBP	10%DGBP	15%DGBP
Corn	62.9	59.0	55.3	48.4	69.0	62.0	55.2	48.2
Soybean meal	31.0	30.4	30.0	30.2	26.8	26.9	27.0	27.3
DGBP	–	5.0	10.0	15.0	–	5.0	10.0	15.0
Dicalcium phosphate	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Limestone	1.6	1.6	1.6	1.6	0.9	0.9	0.9	0.9
Soybean oil	–	0.8	1.4	3.1	1.5	3.3	5.1	6.8
Sodium bicarbonate	0.25	0.25	0.25	0.25	0.3	0.3	0.3	0.3
Premix*	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Salt	0.25	0.25	0.25	0.25	0.3	0.3	0.3	0.3
Inert**	28.0	15.0	–	–	–	–	–	–
Calculated nutritional composition (% of natural matter)								
CP[1]	19.5	19.4	19.4	19.4	18.0	18.0	18.0	18.0
NDF[2]	11.5	14.2	16.7	19.4	11.6	14.1	16.5	18.9
ADF[3]	4.5	7.2	9.9	12.6	4.4	7.0	9.7	12.3
ME[4] (Mcal)	2.86	2.86	2.85	2.85	3.10	3.10	3.10	3.10
EE[5]	2.5	3.8	4.8	6.9	4.2	6.3	8.4	10.5
Digestible lysine	0.90	0.89	0.87	0.86	0.82	0.81	0.80	0.79
Met+Cis[6] Digestible	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Potassium	0.76	0.74	0.72	0.70	0.70	0.68	0.66	0.65
Calcium	0.96	0.95	0.95	0.95	0.68	0.70	0.68	0.70
Available phosphorus	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Sodium	0.21	0.21	0.20	0.21	0.23	0.23	0.21	0.21
Chlorine	0.18	0.19	0.18	0.18	0.20	0.20	0.20	0.20

* Premix: Provided the following quantities of vitamins and micro-minerals per kilogram of complete diet[12]: folic acid 118.5mg kg^{-1}, pantothenic acid 525mg kg^{-1}, BHT 20.5g kg^{-1}, biotin 0.625mg kg^{-1}, hill 13.75g kg^{-1}, iron 6.250mg kg^{-1}, phytase 52.5 FTU kg^{-1}, iodine 105.25mg kg^{-1}, lysine 263.75g kg^{-1}, methionine 247.5g kg^{-1}, selenium 37.5mg kg^{-1}, vitamin A 350.000UI kg^{-1}, vitamin B1 2.5mg kg^{-1}, vitamin B12 525mg kg^{-1}, vitamin B2 250mg kg^{-1}, vitamin B6 12.5mg kg^{-1}, vitamin D3 100,000 UI kg^{-1}, vitamin E 3,000UI kg^{-1}, vitamin K3 100mg kg^{-1}, zinc 7500mg kg^{-1}; DGBP – dehydrated guava by-products [1]Crude Protein; [2] Neutral detergent fiber; [3] Acid detergent fiber; [4]Metabolizable energy; [5]Ether extract; [6]Digestible methiome + cystine.
** Inert: washed sand.

pre-dried in an oven at 55°C, and pre-degreased in a Soxhlet machine to remove excess water and fat. Then, the samples were ground in a ball mill and analyzed to determine the chemical composition (dry matter: DM, crude protein: CP, ether extract: EE, and ash). The water and fat contents removed during the pre-drying and pre-fattening steps were taken into account in the value correction of the subsequent analyses. All wet samples were analyzed following the Association of Official Analytical Chemists (AOAC) protocols for dry matter (DM, method 930.15), crude protein (CP, method 990.03), and ether extract (EE, method 920.39) (AOAC, 2007).

TABLE 2 Chemical composition of the dehydrated guava by-products (DGBP) used in experimental feeds as DM basis.

Variables (%)	%
Dry Matter	93.16
Ash	2.21
Crude Protein	11.15
Ether Extract	8.10

Coloration analysis was performed on the carcass 15 minutes after slaughter and 24 hours after refrigeration. Coloration data was obtained from the skin, breast fillets, drumsticks, and thighs. Furthermore, data were collected from four points using a CR-400 colorimeter for evaluation in the Cielab system for the following parameters: L (brightness – level from dark to light), a* (red/green intensity), and b* (yellow/blue intensity) (Honikel, 1998). The pH data of the cold carcasses of these same cuts were also recorded with a portable penetration pH meter, model HI99163 (Olivo et al., 2001).

The drip weight loss (DWL) and cooking weight loss (CWL) analyses were performed using 36 carcasses (drumstick, thigh, and breast), following the methodology proposed by Honikel (1998). The cuts were thawed, deboned, and divided into halves, using one half for DWL and the other half for CWL. To perform the DWL analyses, the samples were cut and immediately weighed in a 0.1g precision semi-analytical balance, placed in a net bag, identified, and suspended in the refrigerator grid. After 24 hours of cooling (1-5 °C), the samples were again weighed. For the CWL analysis, the broilers breast samples were weighed on semi-analytical scales with a precision of 0.1 g, packed in polyethylene plastic bags, and cooked in an MA-184 thermostatic bath at a temperature of 85 °C for 10 minutes. After cooking, they were cooled down to room temperature for subsequent weighing. Both the DWL and the CWL were determined by the equation: ((initial weight - final weight)/initial weight) *100), and expressed in percentage.

For shear force (SF) analysis, breast fillet samples were baked in an electric oven for ±10 minutes or until they reached a temperature of 85°C. Then, the collected samples were cut into a cylindrical shape (1.27 cm in diameter) and were placed with the fibers oriented perpendicular to the blades of a Warner-Bratzler apparatus (Ramos and de Gomide, 2017).

Sensory evaluation was performed using fillets of the thigh, drumstick, and breast through the acceptance test with a 9-point hedonic scale from 9 (like extremely) to 1 (dislike extremely) (Dutcosky, 2013). The samples were thawed, deboned, and subjected to a 10% brine solution for approximately five minutes, cooked on a metal plate for 10 minutes until they reached a temperature of 85 °C, and immediately diced, coded, and served in 15-gram portions. Each untrained taster evaluated four samples and filled out an individual form after each sample to evaluate the sensory characteristics (appearance, aroma, texture, flavor, and overall acceptance) according to the aforementioned hedonic scale (1-9). Water and sea salt biscuits were served between tastings to prevent the previous sample from affecting the evaluation of the next sample. Each taster evaluated one cut of one experimental unit for the four treatments, totaling 1080 questionnaires. Each replicate of each cut was evaluated by 10 persons, and each cut in each treatment received 90 evaluations.

The data from the analyzes were examined using regression analysis using polynomial models. The significance level of up to 5% of the F-test and the determination coefficient (R^2) were considered to adjust the models. The statistical analyses were performed using the GLM program of SAS 9.0 (2002). The data from the sensory analysis were submitted to the non-parametric test to evaluate Spearman's correlation coefficient, using the R Core Team (2019). The significance of Spearman's correlation coefficient was calculated via t-test.

3 Results

There was no effect of DGBP on weight gain, average weight, FI, and FCR of the broilers ($P > 0.05$) in the evaluated production phases (30 to 60 and 61 to 84 days) (Table 3). These results indicate that the utilization of nutrients was similar to that in the control group, favoring the use of nutrients for weight gain.

The yield of the carcass, cuts (breast, drumstick, and thigh), and proventriculus were not affected by the addition of DGBP ($P > 0.05$) in the diet. An increasing linear effect ($P < 0.05$) was observed on gizzard yield, as well as a quadratic effect on the liver and abdominal fat yield, wherein treatments with 5.0 and 10.0% of dietary DGBP resulted in the highest yield percentages (Table 4).

There was no effect ($P > 0.05$) of DGBP addition on the composition of DM and CP for any of the evaluated cuts (breast, drumstick, and thigh) (Table 5). An decreasing linear effect ($P < 0.05$) was observed on the composition of EE, where the treatment with 15.0% of dietary DGBP resulted in the lowest percentage.

. In addition, no differences ($P > 0.05$) were observed for pH, SF, CWL, and DWL of the breast, drumstick, and thigh cuts (Table 6).

Luminosity (L*) was not affected by the addition of DGBP in the diets ($P > 0.05$). However, there was an increasing linear effect on the color a* ($P < 0.05$) of the skin for all cuts. There was a quadratic effect was detected for the color b* ($P < 0.05$) in the thigh meat,

TABLE 3 Performance of slow-growing broilers fed increasing levels of dehydrated guava by-product (DGBP) in the diet.

Inclusion of DGBP (%)	0	5	10	15	Linear	Quadratic	SEM*
Growth phase (30 - 60 days old)							
FI (g)	2574.44	2380.00	2626.67	2711.11	0.2017	0.2248	0.2194
BW (g)	2237.89	2285.22	2305.67	2317.11	0.1016	0.6038	0.3868
BWG (g)	1523.33	1578.89	1591.11	1598.89	0.1231	0.4839	0.3944
FCR	1.67	1.52	1.65	1.69	0.6248	0.1232	0.2146
Finishing phase (61 - 84 days old)							
FI (g)	3385.56	3167.78	3575.56	3878.89	0.4199	0.3273	0.0741
BW (g)	3547.78	3524.79	3539.22	3617.11	0.5975	0.5913	0.8996
BWG (g)	1310.00	1240.00	1232.22	1301.11	0.9220	0.3801	0.8481
FCR	2.67	2.58	2.98	2.44	0.7070	0.2211	0.2123

*SEM, standard error of mean; body weight gain (BWG), feed intake (FI), body weight (BW), and feed conversion ratio (FCR).

TABLE 4 Carcass, cuts and organ yields of slow-growing broilers males fed with different levels of dehydrated guava by-product in the diet.

Inclusion of DGBP (%)	0	5	10	15	Linear	Quadratic	SEM
Carcass weight*** (g)	2881.88	2768.24	2873.69	2956.92	0.1884	0.1484	0.2739
Carcass (%)	70.80	69.79	69.84	69.28	0.2752	0.1423	0.2739
Breast (%)	30.68	31.49	31.62	30.45	0.8068	0.5752	0.2481
Thigh (%)	15.32	15.01	15.24	15.85	0.2691	0.2154	0.4306
Drumsticks (%)	18.91	19.08	18.90	18.41	0.3715	0.4393	0.7056
Proventriculus (%)	0.24	0.22	0.22	0.23	0.2703	0.0740	0.2260
Gizzard (%)	1.35	1.38	1.58	1.69	<0.001	0.4616	<0.001
Liver (%)	1.37	1.46	1.42	1.21	0.0691	0.0219	0.0346
Pancreas (%)	0.15	0.13	0.14	0.13	0.2415	0.7446	0.1883
Abdominal fat (%)	3.28	4.17	4.07	3.59	0.5760	0.0428	0.2039

DGBP, dehydrated guava by-products; SEM, standard error of mean; n = 108 broilers.
*** hot carcass.

where the addition of 5.0 and 10.0% of dietary DGBP showed the highest values of yellow coloration (Table 7).

No effect of DGBP addition was found on the sensory characteristics of appearance, aroma, flavor, and overall acceptance. Considering the texture evaluation, there was no observable effect on the drumstick and thigh cuts. However, there was a difference ($P < 0.05$) in the texture of the breast meat, wherein the greater the DGBP content, the greater the scores attributed by the tasters and the treatments. Moreover, treatments with 10.0 and 15.0% of dietary DGBP were statistically different from the treatment without DGBP (Table 8).

4 Discussion

In the present study, the levels of neutral detergent fibers (NDF) in the diets increased from 11.5 and 11.6 in the control group to 19.4 and 18.9 in the group treated with the highest DGBP content (Table 1) in the phases of growth and finishing, respectively. This could be caused by a greater rate of passage of the digested food and less utilization of the nutrients of the diet (Andriguetto et al., 2002), but this was not verified. According to Rufino et al. (2017) and Hetland et al. (2004), moderate levels of fiber in poultry diets can improve digestibility because the food is retained longer in the gizzard, providing better particle grinding, and thus making smaller and better-absorbed particles in the intestine, which justifies the absence of effect on the performance parameters.

The digestion and absorption of nutrients may suffer interference from various factors such as age, breed, sex, and the chemical composition of the diets, which may cause an increase or decrease in FI, and consequently, in the performance of the birds. However, it should be taken into consideration that these foods can improve the intestinal health of the animals and optimize the use of

TABLE 5 Chemical composition of meat from slow-growing broilers males fed different levels of dehydrated guava by-product in the diet.

Inclusion of DGBP (%)	0	5	10	15	Linear	Quadratic	SEM
Breast							
DM	26.01	24.59	26.81	25.17	0.9250	0.6803	0.8885
CP	25.13	23.83	26.24	24.79	0.2405	0.7056	0.9256
EE	0.59	0.48	0.63	0.34	0.5567	0.2150	0.4127
Thigh							
DM	24.20	24.41	25.48	25.07	0.2756	0.6803	0.3627
CP	21.62	22.06	23.14	22.79	0.0803	0.4878	0.2890
EE	1.88	1.48	0.96	0.72	0.0049	0.7891	0.1611
Drumsticks							
DM	30.81	29.14	30.56	28.65	0.3131	0.9103	0.5508
CP	27.26	25.77	27.24	25.59	0.3409	0.9201	0.4141
EE	2.80	1.83	2.36	1.94	0.2146	0.4582	0.1860

DGBP, dehydrated guava by-products; DM, dry matter; CP, crude protein; EE, Ether extract; SEM, standard error of mean; n=36 samples.

TABLE 6 Meat quality characteristics of slow growing broiler males meats fed with different levels of dehydrated guava by-product in the diet.

Inclusion of DGBP (%)	0	5	10	15	Linear	Quadratic	SEM
Breast							
pH	5.60	5.55	5.61	5.56	0.9442	0.9825	0.9753
SF (Kgf)	1.24	1.19	1.67	1.40	0.2587	0.5595	0.2546
CWL (%)	18.07	16.53	18.13	16.53	0.2831	0.9650	0.1008
DWL (%)	6.67	6.19	8.19	7.01	0.4277	0.6838	0.3801
Thigh							
pH	5.60	5.61	5.56	5.50	0.4786	0.7101	0.8837
CWL (%)	16.87	19.97	18.01	17.98	0.2738	0.4035	0.5702
DWL (%)	5.46	5.80	5.38	5.70	0.8991	0.9845	0.9263
Drumsticks							
pH	5.51	5.70	5.37	5.58	0.5647	0.7094	0.5284
CWL (%)	19.14	21.39	19.67	19.98	0.8963	0.4807	0.6946
DWL (%)	5.75	6.08	5.42	6.08	0.9023	0.7744	0.8252

DGBP, dehydrated guava by-products; SEM, standard error of mean; SF, Shear Force (kilogram-force per square meter); CWL, Cooking Weight Loss; DWL, Drip Weight Loss; n=36 samples.

nutrients present in the diets. According to Jha et al. (2019), the microbial fermentation of dietary fiber produces metabolites that promote the growth of beneficial intestinal bacteria capable of fermenting complex carbohydrates into short-chain fatty acids. This may not have influenced productive performance, even with higher levels of fiber in the diet.

In addition, guava and its by-products have phenolics, antioxidants, and bioactive derivatives, which can enhance metabolism (Barakat and El-Garhy, 2019) by preventing the oxidation of several food ingredients, protecting the healthy cells of the body, acting as antimicrobial agents, and enhancing the digestion and absorption of nutrients.

The addition of DGBP in the diets up to 15% did not interfere with the availability of nutrients for the broilers. Age and the different ingredients present in the diet can influence the development of the digestive system (Sousa et al., 2015). Therefore, it can be inferred that the slow-growing broilers, which are older when slaughtered, may present a greater development of the digestive system and take better advantage of the nutrients present in the by-products. This is particularly because of the great amount of dietary fiber present in these foods that favor fermentation in the cecum and better digestion.

Furthermore, the combination of proteins and carbohydrates in diets containing DGBP and their availability to birds may have favored fiber digestibility and the utilization of nutrients present in the diet (Camelo et al., 2015), resulting in nutritional similarity for all the broilers. This corroborates the absence of effects on carcass characteristics (Table 4), considering that the energy/protein ratio and the amount of protein in the diet are among the main factors that reduce carcass yield (Sakomura et al., 2014). Since the diets were formulated to be equally nutritious, the results found in this study are justified.

In addition to the type of diet, the time the food remains in some organs can determine their size. Gastric secretions in the proventriculus are responsible for the beginning of digestion, but DGBP did not negatively affect it since the food spends a short time in this organ.

In contrast, the larger the food particles, the longer the food remains in the organ. Although the DGBP went through a drying and grinding process, larger seed particles remain in the gizzard for a long time and are subjected to greater enzyme action and muscle contraction activity (Rutz et al., 2015). This may have contributed to the greater functioning of the gizzard and, consequently, increased size and performance. In addition, the action of the insoluble fiber fraction present in the food may have caused it to have a longer retention time in this portion of the gastrointestinal tract, favoring the thickening of the gizzard muscle wall (Okrathok and Khempaka, 2020). Consumers of slow-growth chickens prefer meat and skin with higher pigmentation, which is why there is a positive effect of guava in the birds' diet.

The liver is responsible for the metabolism of several nutrients and is the main metabolic organ of the body; thus, food and nutrition can interfere with this organ's function. Increased metabolic activity will result in increased size of the liver. In the same way, restricted diets that decrease metabolic activity can reduce the liver size (Marcato et al., 2010). Therefore, DGBP provided more fiber (5 and 10% of DGBP) and may have increased the fat content and nutritional complexity, thereby contributing to the increase in metabolic activity, consequently favoring increased liver performance.

To maintain the isoenergetic diets, we needed to gradually increase the amount of oil in the diets containing DGBP. This addition might have resulted in an increase in abdominal fat deposition. However, at the same time, the increase in dietary

TABLE 7 Meat coloration of slow growing broiler males fed with different levels of dehydrated guava by-product in the diet.

Inclusion of DGBP (%)	0	5	10	15	Linear	Quadratic	SEM
Breast Skin							
L*	65.56	66.27	65.44	65.60	0.7569	0.6027	0.6628
a*	6.31	6.65	6.77	7.48	0.0111	0.5550	0.0668
b*	20.03	21.06	19.84	19.15	0.2343	0.2385	0.3064
Breast Meat							
L*	62.30	65.29	65.28	62.18	0.8742	0.6197	0.9644
a*	9.23	9.66	9.84	10.61	0.0890	0.7637	0.3728
b*	12.39	13.09	12.50	11.87	0.2312	0.0964	0.1904
Thigh Skin							
L*	64.70	64.90	64.64	64.69	0.9234	0.9052	0.9918
a*	5.38	5.18	5.64	6.13	0.0260	0.2071	0.0759
b*	16.16	16.98	16.50	15.72	0.5560	0.2429	0.6020
Thigh Meat							
L*	59.82	59.95	59.63	59.22	0.3725	0.6146	0.7787
a*	10.95	10.90	11.17	11.23	0.5498	0.9114	0.9328
b*	7.98	10.04	9.18	8.30	0.9681	0.0106	0.0471
Drumsticks Skin							
L*	69.11	69.41	69.52	68.82	0.7496	0.3523	0.7932
a*	4.83	4.79	5.37	5.65	0.0034	0.4790	0.0185
b*	17.90	19.34	18.31	18.13	0.8905	0.1602	0.2907
Drumsticks Meat							
L*	58.98	58.40	58.58	57.86	0.1583	0.8883	0.4632
a*	11.60	12.05	12.71	11.97	0.3114	0.1259	0.2478
b*	6.49	6.96	7.04	6.29	0.7413	0.0920	0.3870

DGBP, dehydrated guava by-products; L*, luminosity; a*, redness; b*, yellowing; SEM, standard error of mean; n = 108 broilers.

fiber levels might have favored the quadratic effect on abdominal fat deposition and thus reduced its deposition.

Okrathok and Khempaka (2020) evaluated the effect of modified dietary fiber from cassava pulp and found a reduction of abdominal fat in broilers. They suggested that the addition of fiber in diets reduced lipid emulsion and inhibited bile acid reabsorption, which contributed to decreased lipid digestibility and reduced abdominal fat deposition.

The by-products fruits used in animal feed usually have low amounts of protein, which makes it necessary to increase the amount of soybean meal to maintain the optimal protein content in diets. Since the levels of soybean meal in the diets were similar for all the study groups, there was no imbalance of amino acids sufficient to increase protein deposition in the cuts. According to de Oliveira et al. (2018), state that guava had phenolic compounds such as flavonoids, Norazmir and Ayub (2010) attributed these compounds to pink guava, which may have an anti-obesity effect. In this study, a linear reduction in the content of ether extract in chicken thigh meat was observed, as the inclusion of guava increased, more studies are needed to explain the interruption of this reduction and also the effects that this reduction would have on the health of the consumers who consume this meat.

Corn has 0.12% methionine and 0.23% lysine (She et al., 2018), whereas the guava by-product has 0.17% methionine and 0.16% lysine (Silva et al., 2009). These amino acids are essential in muscle deposition; because their contents are suboptimal in the guava by-products, it may have contributed to the absence of effects on the yield of various cuts and protein deposition.

These results were similar to those found by Barakat and El-Garhy (2019), who evaluated the increasing addition (0, 10, and 20%) of guava seed powder to commercial feed for ducks. The authors found that the treatments did not interfere with the chemical composition of the carcass. El-Sayed et al. (2013) found an increase in DM and reduction of EE in breast and drumstick cuts of broilers that were fed diets supplemented with ground guava leaves and canola oil.

The absence of effects of diets with DGBP on CWL and DWL (Table 6) probably occurred due to the non-variation of pH (Oliveira, 2015). The pH was maintained in the ideal range (5.5

TABLE 8 Sensory evaluation of meat of slow growing broiler males fed with different levels of dehydrated guava by-product in the diet.

Inclusion of DGBP (%)	0	5	10	15
Breast				
Appearance	7.58	7.38	7.61	7.51
Aroma	7.36	7.35	7.65	7.44
Texture	7.29[a]	7.61[ab]	7.71[b]	7.78[b]
Flavor	7.31	7.44	7.40	7.56
Global Acceptance	7.34	7.46	7.63	7.51
Thigh				
Appearance	6.71	6.99	7.20	6.58
Aroma	7.14	7.03	7.41	6.90
Texture	7.13	7.53	7.50	7.13
Flavor	7.18	7.34	7.46	7.19
Global Acceptance	7.14	7.46	7.50	7.00
Drumsticks				
Appearance	7.25	7.10	7.20	6.98
Aroma	7.64	7.23	7.19	7.29
Texture	7.49	7.58	7.51	7.50
Flavor	7.44	7.36	7.16	7.38
Global Acceptance	7.45	7.40	7.29	7.24

Hedonic scale from 9 (like extremely) to 1 (dislikeextremely); Different superscript letters within groupd indicate significant pairwise differences between medians; n=320 samples.

to 6.3) so that PSE or DFD (pale, soft, exudative or dark, firm, dry) effects in the meat would not occur. These findings are also supported by the similarity in effects of the treatments on SF (1.37 kgf) (Table 6), which characterized these meats as extremely tender (below 3.62 kgf) (Ramos and de Gomide, 2017). The sensory analysis also proved that there was no effect of the treatments on the meat texture (Table 8). All these, along with meat color, are important characteristics in evaluating meat quality, affecting consumer preference and positively validating the use of DGBP (Ozturk et al., 2012).

The coloration of broilers meat is defined by the myoglobin and hemoglobin present in the blood and by the muscle fibers of the meat (Oliveira, 2015). In addition, pigmentation is also influenced by carotenoids present in the diet, and this is the main reason for the increased use of pigments in poultry feed to produce vividly pigmented meat or eggs. Carotenoids of plant origin are the main food source of provitamin A, and β-carotene is the best-known carotenoid (Botelho et al., 2017; Marounek and Pebriansyah, 2018). Guava has high levels of β-carotene and is deposited in the peel as vitamin A when there is an excess (Mesquita, 2018) which may have provided the change in coloration (Table 7).

Guava has high lycopene (25.95 µg/g) and β-carotene (22.67 µg/g) content present in its composition (Menezes et al., 2016). Lycopene is an acyclic isomer of β-carotene, with provitamin A activity present in many fruits and vegetables. Carotenoids in the feed containing DGBP are converted into vitamin A in the intestinal mucosa, and the unconverted part is deposited in the broilers skin or egg yolk (Mesquita, 2018).

In the meat texture evaluation, the lowest score was attributed to the appearance of the drumstick cut, with a score of 6.58 for the animals fed with 15% DGBP in the diet. In contrast, the highest score was 7.78, attributed to the breast cut for the animals fed with 15% DGBP. All samples received scores above 5, which is the minimum value required for the meat to be acceptable within the 9-point hedonic scale (Igbabul et al., 2013).

5 Conclusion

The DGBP can be included up to 15% in the diet as a replacement for corn meal in the diets of slow-growing broilers without altering the production performances, yield of carcass and cuts, and meat quality parameters. It promoted a reddish coloration of the breast skin and thigh skin of the birds.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was reviewed and approved by Committee on Animal Research and Ethics of the Federal Rural University of the Amazon.

Author contributions

I declare that all authors were involved in all phases of the research, from the development of the research project to its implementation, including the execution of the experimental trial, collection of data, statistical and laboratory analyses of the collected data, the writing of the article, as well as the review and approval of the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Amorim, A. (2013). Estudo Comparativo das Características Físico-GuÍmicas e Sensoriais de Carne de Capão, Galo," Frango Comercial" e" Frango do Campo". Thesis (Doutorado em qualidade e segurança alimentar). Instituto Politecnico de Braganca (Portugal). Available at: http://hdl.handle.net/10198/9212.

Amorim, A. F., Rodrigues, K. F., Campos, C. F. A., Soares, J. A. R., and Araujo, C. C. O. (2020). Rendimento de carcaça e qualidade da carne do peito de frangos caipira alimentados com torta de algodão. *Agri-environ. Sci.* 6, 11–21. doi: 10.36725/agries.v6i0.2440

Amorim, A. F., Rodrigues, K. F., Vaz, R. G. M. V., Vieira, D. V. G., Silva, G. F., Sousa, L. F., et al. (2019). Diet metabolisability and performance of slow-growing chickens fed with cottonseed cake. *Sem.: Cienc. Agrar.* 40, 379–388. doi: 10.5433/1679-0359.2019v40n1p379

Andriguetto, J. M., Perly, L., Minardi, J. S., Souza, G. A., and Bona Filho, A. (2002). *Nutrição animal: as bases e os fundamentos da nutrição animal: os alimentos. 4nd* (São Paulo, SP: Nobel), 395.

AOAC (2007) *Association of official analytical chemists. official methods of analysis, 18nd* (Arlington, VA, USA: AOAC) (Accessed February 8, 2022).

Barakat, H., and El-Garhy, O. H. (2019). Incorporation of guava seeds powder into a commercial diet improves the growth performance, nutritional and quality characteristics of Muscovy duck's meat. *J. @ Food Chem. Nanotec.* 5, 20–29. doi: 10.17756/jfcn.2019-067

Botelho, L. F. R., Maciel, M. P., Silva, M. L. F., Reis, S. T., Alves, E. E., Aiura, F. S., et al. (2017). Levels of saffron (Curcuma longa) in diets rations for broiler chickens containing sorghum replacing corn. *Arch. Zootec.* 66, 35–43. doi: 10.21071/az.v66i253.2123

Broch, J., Nunes, R. V., Oliveira, V., Silva, I. M., Souza, C., and Wachholz, L. (2017). Dry residue of cassava as a supplementation in broiler feed with or without addition of carbohydrases. *Sem. Ciên. Agr.* 38, 2641–2658. doi: 10.5433/1679-0359.2017v38n4Supl1p2641

Camelo, L. C. L., Lana, G. R. Q., Santos, M. J. B., Camelo, Y. A. R. P., Marinho, A. L., and Rabello, C.B.-v. (2015). Inclusão de farelo de goiaba na dieta de codornas européias. *Cienc. An. Bras.* 6, 343–349. doi: 10.1590/1089-6891v16i324342

Dutcosky, S. D. (2013). *Análise sensorial de alimentos* (Curitiba: Champagnat), 531.

Gutiérrez, R. M. P., Mitchell, S., and Solis, R. V. (2008). Psidium guajava: e review of its traditional uses, phytochemistry and pharmacology. *J. @ Ethnop.* 117, 1–27. doi: 10.1016/j.jep.2008.01.025

Hetland, H., Choct, M., and Svihus, B. (2004). Role of insoluble non-starch polysaccharides in poultry nutrition. *Wor. Poul. Sci. J.* 60, 415–422. doi: 10.1079/WPS200325

Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *J. Meat. Sci.* 49, 447–457. doi: 10.1016/S0309-1740(98)00034-5

IBGE (2020). *Instituto brasileiro de geografia e estatística. levantamento sistemático da produção agrícola: pesquisa mensal de previsão e acompanhamento das safras agrícolas no ano civil* Vol. 26 (Rio de Janeiro, RJ: IBGE), 1–83.

Igbabul, N., Adole, D., and Sule, S. (2013). Proximate composition, functional and sensory properties of bambara nut (Voandzeia subterranean), cassava (Manihot esculentus) and soybean (Glycine max) flour blends for "Akpekpa" production. *Cur. Res. Nutt. Food Sci.* 1, 147–155. doi: 10.12944/CRNFSJ.1.2.06

Jha, R., Fouhse, J. M., Tiwari, U. P., Li, L., and Willing, B. P. (2019). Dietary fiber and intestinal health of monogastric animals. *Diet. Fib. Gast. Health* 1. doi: 10.3389/fvets.2019.00048

Lousada Junior, J. E., Costa, J. M. C., Neiva, J. N. M., and Rodriguez, N. M. (2006). Physical-chemical characterization of tropical fruit by-products for use in animal feed. *Agronomic Science Magazine.* 37 (1), 70–76. Available at: https://www.proquest.com/scholarly-journals/physical-chemical-characterization-tropical-fruit/docview/1468940560/se-2

El-sayed, M. R., Doaa, I., and El-sayed, B. M. (2013). Effect of supplementation of broiler diets with guava leaves and/or olive oil on growth, meat composition, blood metabolites and immune response. *Benha Veterinary Medical Journal.* 25 (2), 23–32. Available at: https://bvmj.bu.edu.eg/issues/25-2/3.pdf

Marcato, S. M., Sakomura, N. K., Fernandes, J. B. K., Siqueira, J. C., Dourado, L. R. B., and Freitas, E. R. (2010). Crescimento e deposição de nutrientes nos órgãos de frangos de corte de duas linhagens comerciais. *Rev. Bras. Zootec.* 39, 1082–1091. doi: 10.1590/S1516-35982010000500019

Marounek, M., and Pebriansyah, A. (2018). Use of carotenoids in feed mixtures for poultry: a review. *Agr. Trop. Sub.* 51, 107–111. doi: 10.2478/ats–2018–0011

Menezes, P. E., Dornelles, L. L., Fogaça, A. O., Boligon, A. A., Athayde, M. L., and Bertagnolli, S. M. M. (2016). Composição centesimal, compostos bioativos, atividade antioxidante e caracterização fenólica da polpa de goiaba. *Disc. Sci.* 17, 205–217. doi: 10.1590/1983-084X/13_066

Mesquita, A.C.N.de. (2018) *Composição nutricional de resíduos de frutas com uso potencial na alimentação de aves.* Available at: https://repositorio.ufersa.edu.br/handle/prefix/1982.

Norazmir, M. N., and Ayub, M. Y. (2010). Beneficial lipid-lowering effects of pink guava puree in high fat diet induced-obese rats. *Malaysian. J. Nutr.* 16 (1), 171–185. Available at: https://pubmed.ncbi.nlm.nih.gov/22691864/

Okrathok, S., and Khempaka, S. (2020). Modified-dietary fiber from cassava pulp reduces abdominal fat and meat cholesterol contents without affecting growth performance of broiler chickens. *J. @ App. Poul. Res.* 29, 229–239. doi: 10.1016/j.japr.2019.10.009

Oliveira, M. D. (2015) *Efeito antioxidante do subproduto da goiaba na dieta de frangos sobre o desempenho e qualidade de carne.* Available at: http://repositorio.bc.ufg.br/tede/handle/tede/5405.

Oliveira, H. F. (2016) *Extrato do resíduo do processamento da goiaba na alimentação de codornas japonesas.* Available at: http://repositorio.bc.ufg.br/tede/handle/tede/5799.

de Oliveira, M.D., de Mello, H.H.C., Stringhini, J. H., Mascarenhas, A. G., Arnhold, E., Conceição, E.C.da, et al. (2018). Antioxidant effect of the guava byproduct in the diet of broilers in the starter phase. *Rev. Bras. Zootecnia.* 47, e20160290. doi: 10.1590/rbz4720160290

Olivo, R., Soares, A. L., Ida, E. I., and Shimokomaki, M. (2001). Dietary vitamin e inhibits poultry PSE and improves meat functional properties. *J. @ Food Bioch.* 25, 271–283. doi: 10.1111/j.1745-4514.2001.tb00740.x

Ozturk, E., Ocak, N., Turan, A., Erener, G., Altop, A., and Cankaya, S. (2012). Performance, carcass, gastrointestinal tract and meat quality traits, and selected blood parameters of broilers fed diets supplemented with humic substances. *J. Sci. Food Agr.* 92, 59–65. doi: 10.1002/jsfa.4541

Ramos, E. M., and de Gomide, L.A.M. (2017). *Avaliação da qualidade de carnes: fundamentos e metodologias. 2nd* (Viçosa, MG: UFV), 472.

Rostagno, H. S., Albino, L. F. T., Hannas, M. I., Donzele, J. L., Sakomura, N. K., Perazzo, F. G., et al. (2017). *Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais. 4nd* (Viçosa, MG: UFV), 488.

Rufino, J. P. F., Cruz, F. G. G. C., De Oliveira Filho, P.A., Melo, R. D., Da Feijó, J.C., and Melo, L. D. (2017). Fibra alimentar em dietas para aves – uma revisão. *Rev. Cient. Avic. e Suin.* 3, 33–42. Available at: https://periodicos.ufam.edu.br/index.php/RECAS/article/view/4669

Rutz, F., Roll, V. F. B., Xavier, E. G., Anciuti, M. A., and Lopes, D. C. N. (2015). *Fisiologia da digestão e da absorção em aves. anais do XVI simpósio brasil sul de avicultura e VII brasil sul poultry fair, Chapecó, Santa Catarina, Brazil.* 58–71.

Sakomura, N. K., and Rostagno, H. S. (2016). *Métodos de pesquisa em nutrição de monogástricos. 2nd* (Jaboticabal, SP: FUNEP).

Sakomura, N. K., Vilar-silva, J. H., Perazzo-costa, F. G., Fernandes, J. B. K., and Hauschild, L. (2014). *Nutrição de não-ruminantes* (Jaboticabal, SP: FUNEP), 678.

Santos, E. L., Ludke, M. C. M., Barbosa, J. M., Rabello, C. B.-V., and Ludke, J. V. (2009). Digestibilidade aparente do farelo de coco e resíduo de goiaba pela tilápia do nilo (*Oreochromis niloticus*). *Rev. Caat.* 22, 175–180. Available at: https://www.redalyc.org/pdf/2371/237117600029.pdf

She, Y., Sparks, Jc., and Stein, H. H. (2018). Effects of increasing concentrations of an *Escherichia coli* phytase on the aparent ileal digestibility of amino acids and the apparent total tract digestibility of energy and nutrients in corn-soybean meal diets fed to growing pigs. *J. @ Anim. Sci.* 96, 2804–2816. doi: 10.1093/jas/sky152

Silva, E. P., Silva, D. A. T., Rabello, C. B.-V., Lima, R. B., Lima, M. B., and Ludke, J. V. (2009). Composição fisico-química e valores energéticos dos resíduos de goiaba e tomate para frangos de corte de crescimento lento. *Rev. Bras. Zootec.* 38, 1051–1058. doi: 10.1590/S1516-35982009000600012

Sousa, D. C., Oliveira, N. L. A., Santos, E. T., Guzzi, A., Dourado, L. R. B., and Ferreira, G. J. B. C. (2015). Caracterização morfológica do trato gastrointestinal de frangos de corte da linhagem Cobb 500®. *Pesq. Vet. Bras.* 35, 61–68. doi: 10.1590/S0100-736X2015001300011

Sousa, M. S. B., Vieira, L. M., Silva, M. J. M., and Lima, A. (2011). Caracterização nutricional e compostos antioxidantes em resíduos de polpas de frutas tropicais ciênc. *Agrotec* 35, 554–559. doi: 10.1590/S1413-70542011000300017

Souza, H. A., Parent, S-é., Rozane, D. E., Amorim, D. A., Modesto, V. C., Natale, W., et al. (2016). Guava waste to sustain guava (Psidium guajava) agroecosystem: nutrient "Balance" concepts. *Front. Plant Sci.* 7. doi: 10.3389/fpls.2016.01252

Uchoa, A. M. A., da Costa, J.M.C., MAIA, G. A., Silva, E. M. C., de Carvalho, A.F.F. U., and Meira, T. R. (2008). Parâmetros físico-químicos, teor de fibra bruta e alimentar de pós alimentícios obtidos de resíduos de frutas tropicais. *Seg. Alim. e Nut.* 15, 58–65. doi: 10.20396/san.v15i2.1817