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Original Article

Growth Performance and Economic Feasibility of Guarana By-products in Diets for Slow-growing Broilers[I]

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ABSTRACT

The study evaluated the inclusion of guarana by-products, guarana peel meal (GPEM), and guarana pulp meal (GPUM) in diets for slow-growing broilers to assess their impact on growth performance and economic feasibility. To evaluate the effects of guarana by-products, two experiments were conducted. In both experiments, 240 slow-growing male broilers of the Label Rouge strain were used. Both experiment 1 (testing GPEM) and experiment 2 (testing GPUM) were conducted using a completely randomized design, with treatments consisting of a control diet (without the inclusion of the tested product) and four levels of inclusion of the tested product (2.5%, 5.0%, 7.5%, and 10%) in the diets, each with four replicates of 12 birds. GPEM, with higher fiber content, improved feed efficiency and weight gain at higher inclusion levels (up to 10%), while GPUM, with higher energy content, showed optimal performance at intermediate levels (7.5%). Both by-products enhanced meat production and economic returns compared to the basal diet. The results suggest that GPEM is suitable for systems prioritizing feed efficiency and cost-effectiveness, while GPUM is better suited for phases requiring higher energy intake and weight gain. Additionally, the use of these agro-industrial residues promotes sustainability by integrating circular economy practices into poultry production. The findings highlight the potential of guarana by-products as alternative feed ingredients to improve productivity and reduce costs, particularly in regions with abundant availability of these residues.

INTRODUCTION

In various regions of Brazil, especially in the Amazon, logistics for inputs significantly increase the cost of feedstuffs used in the formulation and production of balanced diets (Cruz *et al.*, 2016). This scenario encourages research testing alternative feeds, especially those using agro-industrial residues to reduce feed costs, which can account for 60% to 80% of total production costs in activities such as poultry farming (Rufino *et al.*, 2015; Cruz *et al.*, 2016; Costa *et al.*, 2018a,b; Aride *et al.*, 2016, 2018, 2020; Polese *et al.*, 2022). These residues are often processed into meals and incorporated into poultry diets as nutritional supplements, while also providing competitive advantages for producers (Cruz & Rufino, 2017).

The Amazon region presents numerous native species with economic, technological, and nutritional potential, which have sparked scientific interest in various fields such as food, pharmaceuticals, cosmetics, flavorings, and essences, as well as their potential applications in animal feeding (Clement *et al.*, 2005; Oliveira *et al.*, 2010). In this context, one fruit that is produced intensively and generates a large amount of residue during the harvest season, with potential for use in animal feed, is guarana (*Paullinia cupana*) (Ferreira *et al*., 2022). This fruit, native to the Amazon, is cultivated in several parts of Brazil and holds great economic and social importance due to its high demand from the beverage industry for the production of soft drinks and energy drinks (Espinola *et al*., 1997; Marques *et al*., 2016; Ferreira *et al*., 2022).

Among the poultry farming segments that require these alternative feeds, slow-growing broiler production has stood out, particularly for small and medium producers (Machado *et al*., 2018; Sarica *et al*., 2020; Cruz *et al*., 2023). These broilers exhibit greater tolerance to temperature variations and resistance to certain microorganisms (Sarica *et al*., 2020), along with a more gradual and proportional growth rate compared to fast-growing strains (Machado *et al*., 2018; Cruz *et al*., 2023). However, their longer growth period can lead to higher production costs, making these strains less economically attractive for large-scale production, though they remain appealing for alternative production systems (Lusk *et al*., 2019; Sarica *et al*., 2020).

References to the use of guarana or its by-products in poultry diets are very scarce in the literature (Santos *et al*., 2024). However, considering its rich nutritional properties, a high volume of production that generates residues, and its importance to Brazilian agribusiness, guarana by-products may exhibit good biological and productive potential as well as economic viability for inclusion in poultry diets (Cruz & Rufino, 2017; Costa *et al*., 2018a,b; Santos *et al*., 2024). Moreover, they contribute to a circular economy within these production chains (Cruz & Rufino, 2017; Oliveira, 2018; Ali *et al*., 2021). Based on this information, the present study aimed to evaluate the growth performance and economic feasibility of slow-growing broilers fed diets containing increasing levels of guarana by-products.

MATERIALS AND METHODS

The current experiment was conducted at the Faculty of Agrarian Sciences of the Federal University of Amazonas, located in Manaus City, Amazonas State, Brazil. All experimental procedures were conducted in accordance with the guidelines of the Local Experimental Animal Care Committee and were approved by the UFAM ethics committee (protocol number 010/2022).

Acquisition and composition analysis of guarana by-products

The guarana by-products were obtained in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. The following steps were performed to obtain guarana peel meal (GPEM): 1) Ripe guarana fruits underwent a manual harvesting process; 2) The harvested fruits were stored in baskets for approximately three days, undergoing a fermentation process; 3) The fruits were separated into seeds and peels; 4) The peels were isolated as residues; 5) The seeds were processed for guarana extract extraction, used in the production of industrialized carbonated beverages; 6) The guarana peels were dried in a closed-circulation oven at 105°C for 24 hours; 7) The dried guarana peels were ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); and 8) the final product, referred to as GPEM, was bagged and stored in a dry and ventilated location for use in the preparation of experimental diets. To obtain guarana pulp meal (GPUM), the following steps were performed: 1) Ripe guarana fruits underwent a manual harvesting process; 2) The harvested fruits were stored in baskets for approximately three days, undergoing a fermentation process; 3) The fruits were separated into seeds and peels; 4) The seeds were processed for guarana extract extraction, used in the production of industrialized carbonated beverages; 5) The residues remaining from the seed extraction were separated and dried in a closed-circulation oven at 105°C for 24 hours; 6) these dried residues were ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); 7) the final product, referred to as GPUM, was bagged and stored in a dry and ventilated location for use in the preparation of experimental diets.

Before conducting the experiment, the proximate composition of both GPEM and GPUM (Table 1) was determined at the Fish Technology Laboratory of UFAM. The dry matter content was determined in an oven at 105 °C following the AOAC 925.10 (2019) method. Mineral content was assessed by incineration in a muffle furnace at 550 °C, in accordance with the AOAC 923.03 (2019) method. Lipid content analysis followed the AOCS Ba 3-38 method. Total protein was determined using the Kjeldahl method, according to AOAC 920.87 (2019). Fiber content (crude fiber, neutral detergent fiber (NDF), and acid detergent fiber (ADF)) was analyzed as described by Van Soest *et al*. (1991).

Table 1 – Composition of guaraná by-products tested.

Variables	Guarana peel meal	Guarana pulp meal
Dry matter, %	89.11	83.93
Crude protein, %	18.72	12.27
Fats, %	5.36	2.41
Minerals, %	5.33	1.01
Crude Fiber, %	44.04	29.17
Neutral detergent fiber, %	61.66	40.84
Acid detergent fiber, %	39.64	26.25
Soluble carbohydrates, %	26.55	55.14
Gross energy, kcal/kg	6,495.65	5,745.42
Metabolizable energy*, kcal/kg	2,258.64	2,828.56

*Determined using the apparent metabolizable energy calculation method described by Sakomura and Rostagno (2016) and Rostagno *et al*. (2024).

Facilities, animals and experimental design

To evaluate the effects of guarana by-products on growth performance and economic viability, two experiments were conducted, one for the inclusion of GPEM, and the other for the inclusion of GPUM.

In both experiments, a poultry house with a ceiling height of 3.25 m was used, with structural adaptations to improve bird welfare. Temperature and relative humidity were monitored using a small digital weather station, recording averages of 27.6 °C and 62.3%, respectively. Throughout the experimental period, the broilers were monitored for potential signs of heat stress caused by the environment, a condition that was not observed during the entire experimental period in either experiment.

240 slow-growing male broilers of the Label Rouge strain were used in both experiments, sourced from the Hatchery Center of UFAM's Poultry Sector. Initially, 1-day-old chicks were housed in a brooder circle with wood shavings as bedding, tray feeders, and cup drinkers, at a density of 50 birds/m², with a central electric heating source, until they reached 7 days of age. Subsequently, they were allocated to their respective treatments in pens measuring 4 m² each, equipped with tubular feeders, pendulum drinkers, and wood shavings bedding on the floor. The experimental stages were divided into an initial (8–28 days) and a final (29–56 days), during which the birds had *ad libitum* access to feed and water. A lighting program suitable for slow-growing broilers was implemented (Wu *et al*., 2022).

Table 2 – Composition of the experimental diets containing guarana peel meal.

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	54.68	51.06	47.45	43.83	63.34	62.88	59.99	56.37	52.75
Soybean meal 46%	38.32	38.35	38.69	39.06	39.44	39.82	32.53	30.64	30.89	31.27	31.64
Guarana peel meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2.50	5.00	7.50	10.00
Limestone	0.93	0.82	0.82	0.81	0.80	0.79	1.02	1.02	0.76	0.75	0.74
Dicalcium phosphate	1.79	1.79	1.80	1.81	1.82	1.83	1.55	1.58	1.59	1.60	1.61
Common salt	0.30	0.10	0.27	0.27	0.27	0.28	0.53	0.34	0.28	0.28	0.28
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.11	0.12	0.12	0.13	0.03	0.04	0.05	0.55	0.06
Soybean oil	0.00	0.27	0.64	1.37	2.09	2.82	0.50	0.50	0.96	1.19	2.41
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Nutrients	**Guarantee levels[3]**										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.76	87.66	87.56	87.46	87.89	87.66	87.49	87.39	87.29
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.18	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	4.39	5.37	6.35	7.33	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	6.15	7.52	8.89	10.26	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.95	4.83	5.71	6.60	2.84	3.66	4.55	5.44	6.32
Total lysine, %	1.21	1.21	1.21	1.21	1.22	1.22	1.06	1.01	1.01	1.01	1.01
Total methionine, %	0.45	0.45	0.45	0.46	0.46	0.47	0.35	0.35	0.35	0.35	0.36
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0.67	0.66	0.66	0.66
Total threonine, %	0.87	0.87	0.87	0.86	0.86	0.85	0.79	0.75	0.75	0.74	0.74
Total tryptophan, %	0.28	0.28	0.28	0.28	0.28	0.29	0.25	0.24	0.24	0.24	0.24

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [3]Levels analyzed and calculated on a dry matter basis.

Both experiment 1 (testing GPEM) and experiment 2 (testing GPUM) were conducted using a completely randomized design, with treatments consisting of a control diet (without the inclusion of the product being tested) and four levels of inclusion of the tested product (2.5%, 5.0%, 7.5%, and 10%) in the diets, each with four replicates of 12 birds. The experimental diets (Tables 2 and 3) were formulated based on the reference values of Rostagno *et al*. (2024), except for the GPEM and GPUM, which used values from prior compositional analyses of the product. The metabolizable energy values of these guarana by-products were determined using estimation methods described by Sakomura and Rostagno (2016) and Rostagno *et al*. (2024).

The guarana by-products were a fixed component in the diet calculations, with other feedstuffs values being adjusted based on the inclusion levels proposed in the experiments. The diets were formulated using the SuperCrac software (TD Software©, Viçosa, Brazil). The composition of these diets was analyzed to confirm their proximate composition according to the methods described by AOAC (2019), where moisture content was determined following method 925.10, mineral content according to method 923.03, lipid content analyses followed method Ba 3-38, total protein content was determined using method 920.87, and fiber content (crude fiber, NDF, and ADF) was determined according to the methods described by Van Soest *et al*. (1991).

Table 3 – Composition of the experimental diets containing guarana pulp meal.

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	56.27	53.17	50.10	47.00	63.34	61.57	58.49	55.40	52.31
Soybean meal 46%	38.32	38.35	35.77	35.66	35.55	35.43	32.53	30.5	30.39	30.28	30.17
Guarana pulp meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2.50	5.00	7.50	10.00
Limestone	0.93	0.82	0.83	0.82	0.81	0.81	1.02	0.76	0.75	0.75	0.74
Dicalcium phosphate	1.79	1.79	1.82	1.84	1.85	1.87	1.55	1.58	1.60	1.61	1.63
Common salt	0.30	0.10	0.27	0.28	0.28	0.28	0.53	0.28	0.28	0.28	0.29
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.14	0.15	0.16	0.18	0.03	0.05	0.06	0.07	0.08
Soybean oil	0.00	0.27	1.90	2.58	3.25	3.93	0.50	2.26	2.93	3.61	4.28
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Nutrients						**Guarantee levels[3]**					
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.86	87.67	87.58	87.50	87.89	87.76	87.59	87.42	87.35
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.15	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	3.94	4.61	5.27	5.93	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	5.52	6.45	7.38	8.30	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.55	4.15	4.74	5.34	4.70	4.54	4.46	4.36	4.27
Total lysine, %	1.21	1.21	1.14	1.12	1.11	1.10	1.06	1,00	0,99	0,98	0,97
Total methionine, %	0.45	0.45	0.47	0.47	0.48	0.49	0.35	0,35	0,35	0,36	0,37
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0,66	0,66	0,66	0,66
Total threonine, %	0.87	0.87	0.82	0.81	0.80	0.79	0.79	0,75	0,73	0,72	0,71
Total tryptophan, %	0.28	0.28	0.27	0.26	0.26	0.26	0.25	0,24	0,23	0,23	0,23

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [3]Levels analyzed and calculated on a dry matter basis.

Experimental analysis

In both experiments, during 56 days, performance data (feed intake and weight gain) were collected from the birds for use in the economic feasibility analysis following the methodological procedures described by Costa *et al*. (2018a,b) and Rufino *et al*. (2018). At 56 days of age, after a 12-hour fasting period, 12 birds from each treatment group were randomly selected for weighing, stunning by electric shock (40 V; 50 Hz), and slaughter by cutting of the jugular vein. The carcasses were then scalded in hot water (60 °C for 62 seconds), defeathered, and eviscerated following the recommendations of Mendes & Patricio (2004).

To determine feed costs and production expenses, only the per-kilogram prices of the feedstuffs used and their updated prices in the region during the experiment were considered. The prices were as follows: corn, R$ 1.66; soybean meal, R$ 3.65; limestone, R$ 0.73; dicalcium phosphate, R$ 4.50; common salt, R$ 0.83; DL-Methionine 99%, R$ 51.00; and mineral and vitamin supplements (F1 - starter; F2 - grower; and F3 - finisher), R$ 28.35/kg (average price). The cost of GPEM and GPUM was calculated considering only transportation and handling expenses (labor), with estimated prices of R$ 0.30 and R$ 0.35 per kilogram, respectively. Fixed costs included depreciation of facilities and equipment (maintenance, water, electricity, etc.), where interest on capital remained unchanged in the short term and was considered constant across all treatments. Variable costs included only bird feed expenses and labor.

The variables were calculated based on the production of each plot. The Productive Efficiency Index (PEI) was determined using the formula:

$$PEI = \frac{DWG*VIAB*100}{FCR}$$

Where:

DWG = daily weight gain of the plot (kg)

VIAB = viability of the plot (%)

FCR = feed conversion ratio of the plot (kg/kg).

The feed cost (FC, R$), the only production cost used as an analysis variable, was determined through the acquisition of ingredients and feed preparation, estimated by the formula:

$$FC=AFI*AP$$

Where:

AFI = accumulated feed intake of the plot (kg)

AP = average price per kilogram of feed, considering both stages (R$/kg).

For total meat production (kg) and meat production per square meter (kg/m²), the carcass yield of slaughtered, scalded, defeathered, and cleaned animals was considered, as described by Costa *et al*. (2018b) and Rufino *et al*. (2018). To calculate the production cost per kilogram of meat (PCKG, R$/kg), the following formula was used:

$$PCKG = \frac{CA}{PRODKG}$$

Where:

FC = feed cost of the plot (R$)

PRODKG = meat production of the plot (kg).

To determine the production cost per square meter of meat (PCPSM, R$/m²), the following formula was used:

$$PCPSM = \frac{CA}{PRODSM}$$

Where:

FC = feed cost of the plot (R$)

PRODSM = meat production per square meter of the plot (kg/m²).

The gross revenue (REV, R$) was calculated based on the relationship between meat production and the selling price per kilogram of the product, using:

$$REV=Q*SP$$

Where:

Q = quantity of meat produced by the plot (kg)

SP = selling price per kilogram of meat produced (R$/kg).

It is important to note that the selling price per kilogram of chicken, applying a gross margin value-added calculation, was determined based on the market price in the region, fixed at R$ 8.00 per kg. Gross profit (PRO, R$) was calculated as the monetary difference between the total revenue from the estimated sale of the chickens (kilograms of chicken meat) and the discounted production cost, which derived from the feed cost, using the formula:

$$PRO=REV-FC$$

Where:

REV = gross revenue of the plot (R$)

FC = feed cost of the plot (R$).

The profitability index (PI, %), which indicates the capital available after covering costs (in this case, feed costs), was derived from the relationship between gross added value and gross revenue, using the formula:

$$PI= \left(\frac{PRO}{REV}\right)*100$$

Where:

PRO = gross profit of the plot (R$)

REV = gross revenue of the plot (R$).

For the break-even point (BE, kg), the quantity of production required to achieve zero return, covering all costs, was considered. In this case, it represents a partial break-even point, as it reflects the production volume necessary to cover feed costs. The formula used was:

$$BE = \frac{REV}{SP}$$

Where:

REV = gross revenue of the plot (R$)

SP = selling price per kilogram of meat produced (R$/kg).

Statistical analyses

The statistical model adopted was as follows:

$$Y_{ik} = \mu + \alpha_i + \epsilon_{ik}$$

Where:

Y_{ik} = Observed value for the variable under study

μ = Overall experiment mean

α_i = Effect of GPEM or GPUM levels

ϵ_{ik} = Experimental error.

All data were analyzed using one-way ANOVA with R software (2021). Commands were executed following Logan's (2010) guidelines. Tukey's Honest Significant Difference (HSD) test was used to examine significant differences among the GPEM or GPUM levels (independent variable) for each dependent variable evaluated. Results are presented as means, and the significance level for differences was set at 0.05.

Subsequently, results for significant variables ($p<0.05$) were subjected to correlation and polynomial regression analysis to evaluate the influence of the independent variable on the dependent variables (Chatterjee & Hadi, 2006; Logan, 2010). The mathematical model, either linear (Y = a + bx) or quadratic (Y = c + bx + ax^2), was selected based on the influence of the independent variable on the dependent variable analyzed (Dormann *et al*., 2013). R-squared values were also considered as a criterion to determine the best model (Chatterjee & Hadi, 2006; Dormann *et al*., 2013).

RESULTS AN DISCUSSION

Experiment 1

The growth performance analysis of slow-growing broilers in the starter stage indicated a significant effect ($p<0.05$) of GPEM inclusion on feed intake and weight gain (Table 4), with the increasing inclusion of GPEM causing a linear increase in these variables; that is, the 10% inclusion level of GPEM provided higher results. However, in the final stage, feed intake and feed efficiency showed an opposite behavior, with the increasing inclusion of GPEM reducing ($p<0.05$) the broilers' feed intake, and the 10% inclusion level of GPEM providing a better feed efficiency result. In this sense, weight gain in this stage increased ($p<0.05$) linearly as the inclusion of GPEM in the diets increased.

Table 4 – Growth performance of slow-growing broilers fed diets containing increasing levels of guarana peel meal[1].

Stage	Variables[2]	Guarana peel meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.5	5.00	7.5	10.00					
Starter	FI	1.43^b	1.48^b	1.69^a	1.71^a	1.74^a	<0.01	7.52	0.47	Y = 1.44 + 0.034x	0.96
	WG	0.87^b	0.94^b	0.98^{ab}	1.01^a	1.06^a	<0.01	2.33	0.42	Y = 0.882 + 0.018x	0.94
	FE	1.64	1.57	1.72	1.69	1.64	0.10	8.28	-	-	-
Final	FI	2.95^a	3.01^a	2.98a	3.01^a	2.63^b	0.05	12.64	-0.08	Y = 2.9269 + 0.0681x - 0.0094x^2	0.95
	WG	1.03^b	1.04^b	1.01^b	1.03^b	1.16^a	0.05	10.69	0.20	Y = 1.004 + 0.01x	0.92
	FE	2.86^a	2.89^a	2.95^a	2.92^a	2.27^b	0.05	4.59	-0.36	Y = 2.8049 + 0.1197x - 0.0166x^2	0.93
General	FI	4.38	4.49	4.67	4.72	4.37	0.09	5.35	-	-	-
	WG	1.90^b	1.98^b	1.99^b	2.04^{ab}	2.22^a	<0.01	4.69	0.29	Y = 1.886 + 0.028x	0.89
	FE	2.31^a	2.27^a	2.35^a	2.31^a	1.97^b	<0.01	4.58	-0.34	y = 2.262 + 0.058x - 0.0083x^2	0.91

[1] All data represent the average of 48 replicates (broilers) per treatment. [2] FI = Feed intake (kg/bird). WG = Weight gain (kg/bird). FE = Feed efficiency (kg/kg). [3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$. [4] CV = Coefficient of variation. [5] COR = correlation coefficient between the independent variable (GPEM levels) and the dependent variable analyzed. [6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana peel meal levels) on the dependent variable.

When observing the cumulative growth performance, it was found that the inclusion of GPEM did not significantly affect ($p>0.05$) the cumulative feed intake in the entire evaluated period. However, the cumulative results of weight gain and feed efficiency showed that these variables were significantly influenced ($p<0.05$) by the inclusion of GPEM, with weight gain increasing linearly, and feed efficiency improving as the levels of GPEM in the diets increased, that is, the 10% inclusion level of GPEM led to better cumulative weight gain and feed efficiency results.

The inclusion of GPEM positively impacted most growth performance variables, notably producing heavier broilers with improved feed efficiency. This result is particularly significant given that GPEM contains a considerable amount of fiber, which increased the dietary fiber levels from 4% to 7%. Despite this increase in fiber contents, broiler performance was not adversely affected by the progressive inclusion of GPEM. Fiber in poultry diets has traditionally posed challenges for researchers and industry, as the avian gastrointestinal tract exhibits limited enzymatic activity for fiber digestion, particularly in broilers, potentially restricting nutrient utilization (Azizi *et al*., 2021). Nonetheless, studies by González-Alvarado *et al*. (2010), Mateos *et al*. (2012), Rufino *et al*. (2021) and Santos *et al*. (2024) suggest that moderate fiber levels in poultry diets play a crucial role in enhancing physiological responses, nutrient utilization, and overall growth performance. Jiménez-Moreno *et al*. (2009a,b) and Svihus (2011) further emphasized that the beneficial effects of moderate fiber levels are linked to improved digestibility through continuous gizzard stimulation, enhanced small intestine activity, and a positive impact on intestinal microbiota due to the prebiotic effects of fiber.

In this sense, Pushpakumara *et al*. (2017) found that including up to 15% palm kernel meal in broiler diets improved feed efficiency and weight gain. Malhado *et al*. (2022) reported no significant effects ($p>0.05$) on weight gain, final weight, or feed efficiency when using barley residues in slow-growing broilers but noted a linear increase ($p<0.05$) in feed intake with higher barley levels. Similarly, Costa *et al*. (2018a) observed improved weight and production efficiency with tucumã meal inclusion, though levels above 25% negatively affected these indices.

The high fiber content in many alternative feeds derived from food processing residues can challenge nutrient metabolism and growth performance (Rufino *et al*., 2015; Cruz & Rufino, 2017; Liu *et al*., 2018; Rufino *et al*., 2021; Cho *et al*., 2024). However, residues from guarana processing like GPEM may provide additional benefits due to bioactive compounds with antioxidant, antimicrobial, and stimulating properties, potentially enhancing nutrient utilization and physiological responses (Marques *et al*., 2016; Yonekura *et al*., 2016; Cruz & Rufino, 2017).

According to the economic analysis on the performance of slow-growing broilers fed diets containing GPEM (Table 5), no significant difference ($p>0.05$) was observed among the treatments for the breakeven point variable. However, all other variables were significantly affected by the inclusion of GPEM.

Table 5 – Economic analysis of the performance of slow-growing broilers fed diets containing increasing levels of guarana peel meal[1].

Variables[2]	Guarana peel meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.5	5.00	7.5	10.00					
PRE-INI, R$/kg	3.09	3.11	3.14	3.18	3.21	-	-	-	-	-
PRE-FIN, R$/kg	2.97	2.90	2.91	2.94	2.97	-	-	-	-	-
PEI	169.91^{b}	204.82^{a}	204.74^{a}	207.05^{a}	208.47^{a}	<0.01	6.19	0.76	$Y = 173.9 + 10.556x - 0.7382x^2$	0.86
FC, R$	132.95^{b}	135.05^{b}	141.61^{a}	144.86^{a}	135.71^{b}	0.03	5.45	0.48	$Y = 131.28 + 3.5629x - 0.295x^2$	0.71
PRODKG, kg	22.92^{c}	23.76^{b}	23.88^{b}	24.60^{b}	26.76^{a}	<0.01	7.23	0.92	$Y = 22.68 + 0.3408x$	0.85
PCKG, R$/kg	5.80^{a}	5.68^{b}	5.93^{a}	5.89^{a}	5.07^{c}	0.03	8.24	-0.56	$Y = 5.6826 + 0.1431x - 0.0193x^2$	0.73
PRODSM, kg/m²	5.73^{c}	5.94^{b}	5.97^{b}	6.15^{a}	6.69^{a}	<0.01	7.23	0.92	$Y = 5.67 + 0.0852x$	0.85
PCPSM, R$/m²	33.24^{b}	33.76^{b}	35.40^{a}	36.21^{a}	33.93^{b}	0.03	5.45	0.48	$Y = 32.823 + 0.8881x - 0.0735x^2$	0.71
REV, R$	160.44^{c}	166.32^{c}	167.16^{c}	172.20^{b}	187.32^{a}	<0.01	7.23	0.92	$Y = 158.76 + 2.3856x$	0,85
PRO, R$	27.49^{b}	31.27^{b}	25.55^{b}	27.34^{b}	51.61^{a}	0.01	5.25	0.64	$Y = 30.717 - 3.7693x + 0.5542x^2$	0.78
PI,	17.13^{b}	18.80^{b}	15.28^{b}	15.88^{b}	27.55^{a}	0,03	4,86	0.56	$Y = 18.79 - 2.0398x + 0.2757x^2$	0.73
BE, kg	18.99	19.29	20.23	20.69	19.39	0.51	5.45	-	-	-

[1] All data represent the average of 48 replicates (broilers) per treatment. [2] PRE-INI = Price of initial diets. PRE-FIN = Price of final diets. PEI = Productive Efficiency Index; FC = Feed Cost; PRODKG = Total Meat Production (kg); PCKG = Production Cost per kg; PRODMQ = Meat Production per m²; PCPSM = Production Cost per m²; REV = Gross Revenue; PRO = Gross Profit; PI = Profitability Index; BE = Break-even point. [3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$. [4] CV = Coefficient of variation. [5] COR = correlation coefficient between the independent variable (GPEM levels) and the dependent variable analyzed. [6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana peel meal levels) on the dependent variable.

In the variables of productive efficiency, total production of chicken meat in kilograms, and meat production per square meter, all broilers fed diets containing GPEM showed better results, with a gradual improvement in efficiency as the inclusion level of this alternative product increased. These findings align with results obtained by Costa *et al*. (2018a, b), who reported improved broiler productivity when including increasing levels of tucumã residue flour in their diets.

As mentioned above, the use of alternative foods in broiler diets often presents challenges related to the balance between their composition and the effects on bird productivity. Many of these feeds are by-products of the food processing industry, often comprising peels and seeds, which naturally contain high fiber levels (Cruz & Rufino, 2017; Rufino *et al*., 2021). However, depending on the specific feed used, its fiber content may vary and can be outweighed by other nutrients of nutritional interest, such as proteins and soluble carbohydrates, which affect feed efficiency and, consequently, productivity (Rufino *et al*., 2021; Rufino *et al*., 2023).

These results of productive indexes directly influence economic variables, such as feed cost, production cost per kilogram, and production cost per square meter, which were higher in several treatments that included GPEM. According to Rufino *et al*. (2015), higher inclusion levels of alternative foods can result in fluctuations in the production volume required to cover feed costs, affecting production costs either by increasing them, as seen in this study, or lowering them as compensation for using cheaper ingredients.

Feed cost represents a significant component of production expenses, and the use of agricultural residues in diets can impact these costs by replacing or reducing conventional ingredients (Nogueira *et al*., 2014; Cruz & Rufino, 2017). Economic analyses of alternative foods for poultry show that factors such as procurement logistics, production volume, and price fluctuations are crucial in deciding whether to use alternative ingredients (Silva *et al*., 2009; Rufino *et al*., 2015; Melo *et al*., 2017; Costa *et al*., 2018a,b; Batalha *et al*., 2019). These parameters confirm the economic viability of alternative feeds, which is closely tied to performance results (Pelizer *et al*., 2007; Costa *et al*., 2009).

In terms of gross income, gross profit, and profitability index, higher inclusion levels of GPEM yielded better results, demonstrating a positive economic impact. Despite apparent increases in production costs, productivity improvements effectively compensated for these, leading to favorable economic outcomes. According to Furtado *et al*. (2011), Rufino *et al*. (2015), Cruz & Rufino (2017), and Brelaz *et al*. (2021), including alternative foods in poultry diets can offer positive effects by utilizing regional agro-industrial by-products unsuitable for human consumption, reducing production costs without compromising bird performance, or enhancing productivity to offset costs. These impacts are especially significant for small and medium-scale poultry operations.

Conducting an economic and financial feasibility analysis of investments is essential, as it estimates and analyzes financial performance perspectives based on production outcomes (Rufino *et al*., 2018). If alternative feeds fail to achieve comparable productive and economic results to conventional feeds, they must be excluded from feed formulations or reconsidered for use under different conditions (Rufino *et al*., 2015).

According to Cruz & Rufino (2017), an alternative feed must meet four essential criteria to validate its use in animal production diets: (1) Proven biological composition with potential for use without anti-nutritional factors; (2) Accessible logistics, sufficient production volume, and year-round availability; (3) Cost similar to or lower than conventional feeds; and (4) A positive impact on productivity, comparable to or exceeding that of conventional diets. These criteria ensure effective technical decisions regarding the use of alternative feeds in poultry diets (Melo *et al*., 2017; Rufino *et al*., 2021; Rufino *et al*., 2023).

Experiment 2

The growth performance analysis (Table 6) of slow-growing broilers in the starter stage showed that increasing GPUM levels significantly (p<0.05) influenced feed intake and weight gain, with 7.5% GPUM inclusion yielding higher results for these parameters. Regarding feed efficiency, GPUM inclusion had a positive effect, as all slow-growing broilers fed diets containing GPUM demonstrated better feed efficiency than those fed the basal diet, with 5% GPUM inclusion providing the best results for feed efficiency. Similarly, in the final stage, slow-growing broilers fed diets with 7.5% GPUM inclusion exhibited higher (p<0.05) feed intake. However, in this stage, broilers fed diets with 2.5% GPUM inclusion achieved better feed efficiency. Cumulatively, all slow-growing broilers fed diets containing GPUM showed higher (p<0.05) feed intake and weight gain compared to those fed the basal diet, with 7.5% inclusion providing optimal results. Feed efficiency during this period exhibited significant (p<0.05) improvement up to 7.5% inclusion, beyond which no further improvements were observed.

When comparing the results of experiment 2 (GPUM) with those obtained in experiment 1 (GPEM), it stands out that GPUM promoted higher feed intake across all stages, especially at the 7.5% inclusion level, whereas GPEM showed a reduction in consumption during the final stage. This reduction may be associated with the higher fiber content, which, although potentially limiting intake, stimulates gizzard function and enhances nutrient digestibility (Sacranie *et al*., 2012; Jiménez-Moreno *et al*., 2019; Santos *et al*., 2024). In terms of weight gain, both guarana by-products had positive impacts, but the effect of GPEM was linear and more pronounced at higher inclusion levels (10%), while GPUM showed optimal results at 7.5%, suggesting that its nutritional profile effectively supports growth at moderate inclusion levels. Regarding feed efficiency, GPEM showed significant improvements across all stages, with the best cumulative performance at 10% inclusion, whereas GPUM achieved peak efficiency at moderate inclusion levels (5%-7.5%).

These observed differences can be primarily attributed to the fiber profile of each by-product. The higher fiber content in GPEM may have stimulated increased gizzard activity, promoting more efficient digestibility and consequently better feed efficiency, as reported in studies highlighting the benefits of moderate fiber levels in poultry diets (Sacranie *et al*., 2012; Abdollahi *et al*., 2019; Jiménez-Moreno *et al*., 2019; Santos *et al*., 2024). In contrast, GPUM, with its lower fiber content and higher metabolizable energy (2,828.56 kcal/kg for GPUM versus 2,258.64 kcal/kg for GPEM), favored more consistent feed intake and higher weight gains, which aligns with findings from other studies using agricultural by-products with moderate fiber levels (Jiménez-Moreno *et al*., 2009; Costa *et al*., 2018b; Oliveira, 2018; Rufino *et al*., 2024).

Table 6 – Growth performance of slow-growing broilers fed diets containing increasing levels of guarana pulp meal[1].

Stage	Variables[2]	Guarana peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.5	5.00	7.5	10.00					
Starter	FI	1.30[c]	1.51[b]	1.52[b]	1.63[a]	1.50[b]	0.04	10.72	0.47	$Y = 1.3051 + 0.0871x - 0.0066x^2$	0.89
	WG	0.50[c]	0.75[b]	0.78[ab]	0.82[a]	0.74[b]	<0.01	8.31	0.60	$Y = 0.5151 + 0.0963x - 0.0074x^2$	0.95
	FE	2.61[a]	1.99[b]	1.94[b]	2.00[b]	2.02[b]	<0.01	14.93	-0.53	$Y = 2.5446 - 0.2057x + 0.0159x^2$	0.87
Final	FI	2.83[b]	2.95[b]	3.10[a]	3.16[a]	3.04[ab]	<0.01	5.17	0.59	$Y = 2.8086 + 0.0903x - 0.0065x^2$	0.93
	WG	1.13	1.20	1.19	1.19	1.05	0.10	8.34	-	-	-
	FE	2.49[c]	2.45[c]	2.59[b]	2.65[b]	2.90[a]	0.02	8.62	0.65	$Y = 2.412 + 0.0408x$	0.82
General	FI	4.13[c]	4.46[b]	4.63[b]	4.80[a]	4.55[b]	<0.01	6.44	0.57	$Y = 4.1123 + 0.1798x - 0.0133x^2$	0.95
	WG	1.64[c]	1.96[a]	1.98[a]	2.01[a]	1.80[b]	<0.01	9.42	0.30	$Y = 1.654 + 0.1348x - 0.012x^2$	0.95
	FE	2.52[a]	2.27[c]	2.33[b]	2.38[b]	2.53[a]	<0.01	5.67	0.13	$Y = 2.276 + 0.2908x - 0.0488x^2$	0.82

[1] All data represent the average of 48 replicates (broilers) per treatment. [2] FI = Feed intake (kg/bird). WG = Weight gain (kg/bird). FE = Feed efficiency (kg/kg). [3] The means followed by lowercase letters in the lines differ using the Tukey test (p<0.05). not significant = p>0.05. [4] CV = Coefficient of variation. [5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed. [6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

These results reinforce important insights reported in the literature, which suggest that the impact of fiber in poultry diets depends not only on its quantity, but also on its composition and interaction with other nutrients (Sanchez *et al*., 2021; Tejeda & Kim, 2021; Santos *et al*., 2024). Previous studies indicate that insoluble fibers, such as those in GPEM, may be more effective at stimulating gastrointestinal motility and improving digestibility in slow-growing broilers, whereas soluble fibers, present in smaller proportions in GPUM, tend to have a lesser effect on gastrointestinal function (Mateos *et al*., 2012; Sanchez *et al*., 2021; Tejeda & Kim, 2021; Machado *et al*., 2022).

Thus, the cumulative effects observed in both experiments underscore the importance of energy balance and nutrient profile when choosing a guarana by-product for the diet of slow-growing broilers. Overall, while GPEM demonstrated a greater ability to sustain performance throughout the production cycle, GPUM exhibited superior performance during the early and intermediate stages. This difference could have significant practical implications depending on the production system's objectives. In systems prioritizing feed efficiency and cost reduction, GPEM emerges as a more advantageous choice (Willems *et al*., 2013; Zampiga *et al*., 2021). Conversely, GPUM may be better suited for systems aiming to maximize feed intake and weight gain during critical growth periods, particularly in nutritional strategies focused on accelerating initial growth (Willems *et al*., 2013; Prakash *et al*., 2020; Zampiga *et al*., 2021).

In the results of the economic analysis (Table 7), all variables evaluated in experiment 2 were statistically significant (p<0.05). Overall, the economic results from experiment 2 showed interesting differences compared to those observed in experiment 1, reflecting the distinct nutritional characteristics of the guarana by-products evaluated. Increasing levels of GPUM inclusion resulted in a proportional rise in feed cost, reaching the highest value at the 7.5% inclusion level. This was also reflected in the cost per kilogram of meat produced, which significantly increased at higher inclusion levels. These results contrast with those of experiment 1, where GPEM demonstrated greater stability in production costs, even at higher inclusion levels. As mentioned above, this difference can be partly attributed to the positive effects of GPEM's insoluble fibers, which optimized digestibility and offset costs through superior feed efficiency (Sacranie *et al*., 2012; Abdollahi *et al*., 2019; Jiménez-Moreno *et al*., 2019).

In terms of meat production and gross revenue, both by-products showed positive gains compared to the control, but with distinct patterns. GPUM inclusion led to higher meat production and gross revenue at intermediate levels, from 2.5% to 7.5%, reflecting its higher soluble carbohydrate content and metabolizable energy, which favored short-term productive performance (Jiménez-Moreno *et al*., 2009; Costa *et al*., 2018b; Oliveira, 2018; Rufino *et al*., 2024). In contrast, GPEM exhibited consistent increases in meat production and revenue across all inclusion levels.

Gross profit and profitability index indicators also highlighted important economic differences between the two by-products. GPUM showed better economic performance at intermediate levels, but its viability was compromised at extreme levels, particularly at 10% inclusion, where additional costs were not offset by increased production. This contrasts sharply with GPEM results, which maintained consistent economic outcomes across the entire range of inclusion levels, with the best results observed at 10%. This reflects GPEM's ability to sustain stable productive and economic performance throughout the production cycle.

In general, the key point in the contrast observed in the economic results of both experiments lies in the relationship between the nutritional profiles and the economic costs of the products and their productive responses. Although the higher fiber content of GPEM may limit feed intake at certain times, it also promotes more efficient nutrient utilization, offsetting the additional costs associated with diet formulation (Mateos *et al*., 2012; Melo *et al*., 2017; Lusk *et al*., 2019). Conversely, GPUM, with its lower fiber content and higher energy density, is more sensitive to higher inclusion levels, as energy saturation can lead to reduced feed efficiency, directly affecting economic viability (Sacranie *et al*., 2012; Oliveira, 2018; Abdollahi *et al*., 2019).

Table 7 – Economic analysis of the performance of slow-growing broilers fed diets containing guarana pulp meal.[1]

Variables[2]	Guarana peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.5	5.00	7.5	10.00					
PRE-INI, R$/kg	3,16	3,18	3,20	3,24	3,25	-	-	-	-	-
PRE-FIN, R$/kg	3,04	3,06	3,08	3,10	3,12	-	-	-	-	-
PEI	186.55[b]	214.01[a]	187.38[b]	184.17[b]	164.62[c]	0.02	12.12	-0.47	$Y = 192 + 5.1206x - 0.8069x^2$	0.72
FC, R$	153.96[c]	167.25[bc]	174.60[b]	182.84[a]	173.69[b]	<0.01	7.06	0.66	$Y = 153.17 + 7.2294x - 0.5027x^2$	0.95
PRODKG, kg	19.70[c]	23.59[a]	23.85[a]	24.22[a]	21.65[b]	<0.01	9.42	0.30	$Y = 19.866 + 1.6452x - 0.1464x^2$	0.95
PCKG, R$/kg	7.82[ab]	7.08[c]	7.32[bc]	7.56[b]	8.04[a]	<0.01	5.87	0.29	$Y = 7.7286 - 0.2421x + 0.0279x^2$	0.87
PRODSM, kg/m²	4.92[c]	5.89[a]	5.96[a]	6.05[a]	5.41[b]	<0.01	9.42	0.30	$Y = 4.9609 + 0.4113x - 0.0366x^2$	0.95
PCPSM, R$/m²	38.49[c]	41.81[bc]	43.65[b]	45.70[a]	43.42[b]	<0.01	7.06	0.66	$Y = 38.294 + 1.806x - 0.1256x^2$	0.95
REV, R$	162.78[c]	188.76[a]	190.82[a]	193.78[a]	173.20[b]	0.01	9.12	0.22	$Y = 163.52 + 11.574x - 1.0539x^2$	0.96
PRO, R$	8.81[b]	21.50[a]	16.21[ab]	10.94[b]	-0.48[c]	0.03	9.51	-0.39	$Y = 10.338 + 4.343x - 0.5509x^2$	0.91
PI,	4.92[b]	11.38[a]	8.46[a]	5.47[b]	-0.57[c]	0.02	9.75	-0.42	$Y = 5.7286 + 2.1895x - 0.2865x^2$	0.92
BE, kg	19.24[c]	20.90[bc]	21.82[b]	22.85[a]	21.71[b]	<0.01	7.06	0.66	$Y = 19.142 + 0.903x - 0.0627x^2$	0.95

[1] All data represent the average of 48 replicates (broilers) per treatment. [2] PRE-INI = Price of initial diets. PRE-FIN = Price of final diets. PEI = Productive Efficiency Index; FC = Feed Cost; PRODKG = Total Meat Production (kg); PCKG = Production Cost per kg; PRODMQ = Meat Production per m²; PCPSM = Production Cost per m²; REV = Gross Revenue; PRO = Gross Profit; PI = Profitability Index; BE = Break-even point. [3] The means followed by lowercase letters in the lines differ using the Tukey test (p<0.05). not significant = p>0.05. [4] CV = Coefficient of variation. [5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed. [6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

Additionally, the difference in profitability results also reflects the composition of the by-products. GPUM, with a lower protein content (12.27%) and mineral content (1.01%), lacks some structural benefits provided by GPEM, such as greater metabolic stability and support for intestinal microbiota development (Jiménez-Moreno *et al*., 2019; Sanchez *et al*., 2021; Tejeda & Kim, 2021). This may explain why GPUM's profitability is more affected at extreme inclusion levels, while GPEM maintains positive results due to the broader support provided by its nutritional profile. It is also important to highlight that both options contribute to a more sustainable approach to poultry production, promoting the use of agro-industrial residues and potentially reducing indirect costs (Rufino *et al*., 2015; Costa *et al*., 2018b; Batalha *et al*., 2019; Brelaz *et al*., 2019).

CONCLUSION

he inclusion of guarana by-products (GPEM and GPUM) in diets for slow-growing broilers has proven to be a viable alternative to enhance growth performance and economic feasibility, promoting the sustainable use of agro-industrial residues. GPEM, despite its higher fiber content, delivered better results in feed efficiency and weight gain at higher inclusion levels (up to 10%), while GPUM was more efficient at intermediate levels (7.5%). Both by-products contributed to greater meat production and economic returns compared to the basal diet, with positive impacts varying according to inclusion levels. The results highlight the importance of considering the specific goals of the production system when selecting the most suitable by-product. The use of GPEM is recommended for systems prioritizing feed efficiency and cost-effectiveness, while GPUM appears to be more appropriate for phases that require higher energy intake and weight gain.

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AUTHOR CONTRIBUTIONS

The experimental plan and design were conceived, planned, and developed by A.N.A. Santos, J.P.F., Rufino and A.T. Oliveira. The primary research draft was written by A.N.A. Santos, C.C. Guimarães, J.P.F. Rufino and A.T. Oliveira. A.N.A. Santos, M.F.S. Gomes, J.M. Mendes, J.L. Silva Junior, F.A.L. Chaves and M.A.F. Mendonça prepared materials and methods, collected data and performed laboratory analysis. J.P.F. Rufino and A.T. Oliveira performed statistical analysis and result interpretation. The manuscript was reviewed and edited by all the authors. The ultimate manuscript was read and approved by all the authors.

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DATA AVAILABILITY STATEMENT

The data of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare no competing interests.

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