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Proximate composition and sensory evaluation of breast meat from slow-growing broilers fed diets containing guarana by-products

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Abstract

The objective of this study was to evaluate the effect of including guarana by-products in the diets of slow-growing broilers on the proximate composition and sensory attributes of breast meat. Two trials were conducted using guarana peel meal and guarana pulp meal. In each trial, 240 broilers were allocated to diets containing 0, 2.5, 5, 7.5, or 10% inclusion levels. At 56 days of age, the birds were slaughtered, and breast samples were analyzed for proximate composition and sensory characteristics. For guarana peel meal, a linear increase in moisture and lipid content was observed, along with a linear decrease in the mineral and protein content. The sensory analysis showed improved flavor and appearance at 10% inclusion and optimal texture at 5%. For guarana pulp meal, no significant changes were detected in the proximate composition. However, there was a linear improvement in flavor, texture, and appearance, with optimal color observed at 2.5% inclusion. Aroma was not affected in either trial. Guarana pulp meal preserved the nutritional profile while enhancing sensory qualities at all inclusion levels. Although guarana peel meal altered the proximate composition, it improved flavor and appearance at higher inclusion levels (10%). It is concluded that both by-products show potential as sustainable ingredients in poultry nutrition.

Keywords: broiler; meat quality; organoleptic properties; *Paullinia cupana*.

Practical Application: The inclusion of guarana by-products in diets for slow-growing broilers represents an innovative and sustainable strategy to enhance meat sensory quality without compromising its nutritional profile. Guarana pulp meal, in particular, preserved the proximate composition and improved flavor, texture, and appearance at all tested levels. These findings highlight the potential of Amazonian agro-industrial residues to reduce feed costs, promote circular economy practices, and add value to regional products in poultry farming systems.

1 INTRODUCTION

The poultry production chain continues to expand, consolidating its prominent position in both production volume and per capita consumption rates (Piccolo et al., 2024), reaching records above 45 kg/inhabitant/year. Brazil is the second-largest producer and the leading exporter of poultry meat (Associação Brasileira de Proteína Animal [ABPA], 2024). However, feed remains the primary economic challenge in poultry farming, accounting for approximately 60–70% of total production costs (Pérez-Palencia & Bolívar-Sierra, 2023). In response to this challenge, the use of alternative feedstuffs emerges as a viable solution (Cruz et al., 2016; Valentim et al., 2021), with guarana (*Paullinia cupana*) residues, by-products of a fruit native to the Amazon, standing out as promising options (Schimpl et al., 2013). Nonetheless, further research is required to assess their effects on animal growth, carcass quality, and the organoleptic characteristics of the meat (Pinotti et al., 2023).

Although alternative feeds may offer nutritional and economic advantages, it is essential to ensure that they do not negatively affect product quality (Brandão et al., 2023; Sanches et al., 2023). In this context, the sensory analysis plays a critical role in quality control (Oliveira et al., 2022), helping to assess consumer acceptance and to standardize industrial processes (Arias-Giraldo & López-Mejía, 2022). Chicken meat is widely recognized for its balanced nutritional profile (Bowles et al., 2019), primarily due to its low lipid content, high protein concentration, and the presence of essential micronutrients (Vannier et al., 2022).

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Consumers associate organoleptic attributes such as color, odor, flavor, and palatability with overall product quality, key determinants of perceived value, and acceptance (Vannier et al., 2022), and these are the main attributes evaluated (Sánchez Barrera & Albarracín Hernández, 2010). Various sensory methods, ranging from traditional to modern approaches, are applied to evaluate the quality and market potential of meat products (Oliveira et al., 2022). The selection of a sensory evaluation method depends on the specific characteristics of the product (Sánchez Barrera & Albarracín Hernández, 2010), and such analyses are essential for product development, market competitiveness, and meeting consumer expectations.

Moreover, evaluating the chemical composition of meat from animals fed with alternative ingredients is fundamental to developing cost-effective diets that utilize regional feed resources (Brandão et al., 2023). Therefore, it was hypothesized that the inclusion of guarana by-products in the diets of slow-growing broilers would not negatively affect the proximate composition of breast meat. Furthermore, it was expected that these by-products could enhance the sensory attributes of the meat, especially flavor, texture, and appearance, depending on the inclusion level. Thus, the objective of this study was to assess the effects of including guarana by-products (guarana peel meal [GPEM] and guarana pulp meal [GPUM]) in the diets of slow-growing broilers on the proximate composition and sensory attributes of breast meat.

1.1 Relevance of the work

This study contributes to the valorization of Amazonian by-products by evaluating the inclusion of guarana residues in the diet of slow-growing broiler chickens. The results show that these by-products can improve the sensory attributes of meat without compromising its nutritional composition, especially when using pulp meal. The research promotes sustainable alternatives for poultry farming, with the potential to reduce costs and environmental impacts, while adding value to regional agro-industrial residues, aligning with the principles of bioeconomy and circular economy in animal production.

2 MATERIAL AND METHODS

This study was conducted at the facilities of the Poultry Sector of the Faculty of Agricultural Sciences, Federal University of Amazonas (UFAM), located in the southern sector of the university campus in Manaus, AM, Brazil. The experimental protocol was submitted to the Ethics Committee on the Use of Animals of the aforementioned university (Protocol No. 010/2022).

The guarana by-products were acquired in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. After separating the fruit fractions, the peels were dried in an oven (45 °C for 24 hours). The seeds were roasted, crushed, and subjected to extract removal, generating the guarana cake, which was also dried in an oven (45 °C for 24 hours). All materials were transported by river to Manaus and ground using a 4-mm sieve crusher, resulting in GPEM and GPUM. The by-products were bagged and stored in a dry environment until use in the experimental diets.

Before the trials, the proximate composition of the guarana by-products (Table 1) was determined at the Fish Technology Laboratory of the Faculty of Agricultural Sciences, UFAM. Moisture content was determined using an oven at 105 °C, according to the Association of Official Agricultural Chemists (AOAC) method 925.10 (AOAC, 2019); ash content by calcination in a muffle furnace at 550 °C, following the AOAC method 923.03 (AOAC, 2019); lipid analysis followed the AOCS Ba 3-38 methodology; total protein was determined using the Kjeldahl method, as per the AOAC method 920.87 (AOAC, 2019); and fiber content was determined according to Van Soest et al. (1991).

To evaluate the influence of guarana by-products on meat sensory characteristics, two performance trials were conducted. The first trial assessed the effects of GPEM inclusion, and the second examined the effects of GPUM. In both trials, 240 slow-growing male broilers of the Label Rouge strain were used. Initially, one-day-old chicks were housed in a protective circle with wood shavings as bedding, along with feeders and drinkers, until seven days of age. They were then allocated to their respective treatments in pens equipped with tubular feeders, pendulum drinkers, and wood shavings. The experimental period was divided into two phases: initial (8–28 days) and final (29–56 days), with *ad libitum* access to feed and water. A suitable lighting program for slow-growing broilers was adopted (Wu et al., 2022).

Experiments 1 (GPEM) and 2 (GPUM) followed a completely randomized design. Treatments consisted of a control diet (0% inclusion) and four inclusion levels of the tested product (2.5, 5.0, 7.5, and 10%), each with four replicates of 12 birds. The experimental diets (Tables 2 and 3) were formulated based on the reference values of Rostagno and Albino (2024), except for GPEM and GPUM, which used values obtained from the prior chemical analysis. Metabolizable energy values of the guarana by-products were estimated using the methodologies described by Sakomura and Rostagno (2016) and Rostagno and Albino (2024). The guarana by-products were treated as fixed components in diet formulation, and other ingredients were adjusted accordingly. Diets were formulated using SuperCrac software (TD Software©, Viçosa, Brazil).

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).

At 56 days of age, after a 12-hour fasting period, 12 birds per treatment were randomly selected for weighing, stunning by electric shock (40 V; 50 Hz), and slaughter via jugular vein incision. Carcasses were scalded in hot water (60 °C for 62 seconds), plucked, and eviscerated according to Mendes and Patricio (2004). Breast meat samples were collected and immediately transported to the laboratory for proximate composition analysis, which included moisture, mineral, fat, and protein contents. The mineral content was determined by muffle furnace calcination at 550 °C following the AOAC Method 923.03 (AOAC, 2019). The lipid content was determined using the AOCS Ba 3-38 method, and total protein using the Kjeldahl method, following the AOAC Method 920.87 (AOAC, 2019). For sensory evaluation, breast cuts were collected, labeled by treatment, and frozen. On the day of analysis, samples were thawed, wrapped in aluminum foil, and cooked in an oven until reaching an internal temperature of 87 °C (Dutcosky, 1996).

Fifty untrained evaluators of both sexes were randomly selected. A 9-point hedonic scale was used to assess the following attributes: color, flavor, aroma, texture, and appearance, ranging from “disliked extremely” (1) to “liked extremely” (9), according to Dutcosky (1996). Sensory evaluations were conducted in individual booths under white lighting at the Sensory Analysis Laboratory of UFAM. Broiler breast meat was cut into uniform 1-cm cubes and served hot (approximately 40 °C) in 50-ml disposable cups, each marked with a randomized three-digit code corresponding to one of the treatments. Each evaluator received one sample from each treatment and a glass of mineral water to cleanse the palate between samples.

The collected data were analyzed by analysis of variance (ANOVA) using the R software (version 4.1.3). Means were compared by Tukey’s test at a 5% significance level. In addition, linear regression analyses were performed to evaluate the effects of inclusion levels on the response variables.

3 RESULTS

In the proximate composition of the breast meat (Table 4), a linear increase ($p < .05$) in moisture and lipid content was observed as the levels of GPEM increased in the diets of slow-growing broilers. Conversely, a linear decrease ($p < .05$) in mineral and protein contents was noted. However, no significant

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

Feedstuffs	**Pre-initial (1–7 days)**	**Initial (8–28 days)**					**Final (29–56 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

ADF: acid detergent fibre; NDF: neutral detergent fibre.

[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.

differences were found in the proximate composition of breast meat from broilers fed increasing levels of GPUM (Table 5), indicating that GPUM inclusion preserved the basic nutritional profile of poultry meat.

Regarding the sensory characteristics of breast meat from slow-growing broilers, the inclusion of GPEM produced significant results (Table 6). The scores ranged from 4.96 to 6.18 on the 9-point hedonic scale, where 1 indicates “disliked extremely” and 9 “liked extremely.” The most frequent ratings by panelists were 5 (indifferent) and 6 (slightly liked). Flavor and appearance exhibited a linear increase from the control (0%) to the highest inclusion level (10%), indicating greater acceptability at this level. This trend was supported by positive

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

Feedstuffs	Pre-initial (1–7 days)	Initial (8–28 days)					Final (29–56 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	55.4	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

ADF: acid detergent fibre; NDF: neutral detergent fibre.

[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.

Table 4. Proximate composition of breast fillets from slow-growing broilers fed diets containing Guarana peel meal[1].

Variables[2]	Guarana peel meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
MO	70.48 ± 0.69^{c}	71.20 ± 0.23^{b}	71.15 ± 0.35^{b}	73.04 ± 0.76^{a}	73.65 ± 0.47^{a}	< .01	1.83	0.63	$Y = 70.268 + 0.3272x$	0.90
MI	1.21 ± 0.02^{a}	1.14 ± 0.06^{b}	1.12 ± 0.17^{b}	1.04 ± 0.23^{c}	1.02 ± 0.15^{c}	< .01	6.63	−0.79	$Y = 1.202 - 0.0192x$	0.96
FA	1.69 ± 0.11^{b}	1.39 ± 0.15^{c}	1.53 ± 0.18^{b}	1.58 ± 0.13^{b}	1.81 ± 0.23^{a}	< .01	10.12	0.38	$Y = 1.6526 - 0.0937x + 0.0111x^2$	0.84
PR	26.62 ± 0.59^{a}	26.27 ± 0.15^{a}	26.20 ± 0.18^{a}	24.34 ± 0.28^{b}	23.52 ± 0.36^{c}	< .01	5.05	−0.65	$Y = 27.016 - 0.3252x$	0.87

[1]All data represent the average of 12 replicates (broilers) per treatment.

[2]MO: Moisture (%); MI: Minerals (%); FA: Fats (%); PT: Proteins (%).

[3]The means followed by lowercase letters in the lines differ using the Tukey test ($p < .05$). Not significant = $p > .05$.

[4]CV: Coefficient of variation.

[5]COR: Correlation coefficient between the independent variable (PCPM levels) and the dependent variable analyzed.

[6]MM: Mathematical model adjusted according to the influence of the independent variable (PCPM levels) on the dependent variable.

correlations for both variables. For texture and color, a quadratic relationship was observed: texture peaked at 5% inclusion, while color peaked at 7.5% GPEM inclusion. In contrast, aroma did not differ significantly across GPEM inclusion levels, indicating that GPEM had no perceptible effect on the aroma of broiler breast meat.

The inclusion of GPUM in the diets of slow-growing broilers demonstrated distinct and significant effects on the sensory attributes of breast meat (Table 7). Flavor was the most responsive parameter, showing a linear increase from the control diet (0%) to the highest inclusion level (10%). Texture also improved consistently and significantly with increasing GPUM inclusion, while appearance followed a similar linear trend. The robustness of the regression models and the significant correlation reinforce the potential of guarana pulp as a sensory-enhancing ingredient. A quadratic response was observed for color, with the highest score at 2.5% inclusion. In contrast, aroma showed no significant differences among treatments.

4 DISCUSSION

The inclusion of GPEM in broiler diets resulted in a linear increase in moisture and lipid contents, as well as a linear reduction in the mineral and protein contents of breast meat. GPEM contains a considerable amount of fiber in its composition (Santos et al., 2024), which can influence the metabolism of other nutrients (Cho et al., 2024; Rufino et al., 2021) and promote

Table 5. Proximate composition of breasts samples of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Variables[2]	Guarana pulp meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
MOS	73.07 ± 1.12	73.32 ± 2.37	73.11 ± 0.58	73.58 ± 0.94	73.49 ± 0.96	.24	1.30	-	-	-
PRO	1.09 ± 0.20	0.98 ± 0.33	1.01 ± 0.23	0.78 ± 0.20	0.97 ± 0.17	.39	1.96	-	-	-
FAT	1.75 ± 0.34	1.57 ± 0.13	1.48 ± 0.24	1.51 ± 0.35	1.24 ± 0.22	.31	1.41	-	-	-
MIN	24.09 ± 2.87	24.13 ± 4.45	24.40 ± 3.56	24.13 ± 2.96	24.30 ± 3.13	.22	1.79	-	-	-

[1]All data represent the average of 48 replicates (broilers) per treatment.
[2]MOS: Moisture (%); PRO: Proteins (%); FAT: Fats (%); MIN: Minerals (%).
[3]The means followed by lowercase letters in the lines differ using the Tukey test ($p < .05$). Not significant = $p > .05$.
[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.

Table 6. Sensory analysis of breasts samples of slow-growing broilers fed diets containing increase 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	2.50	5.00	7.50	10.00					
APE	5.12 ± 2.00[c]	5.62 ± 2.33[b]	5.84 ± 2.19[b]	5.92 ± 2.20[ab]	6.10 ± 2.22[a]	.03	18.54	0.63	$Y = 5.268 + 0.0904x$	0.89
TEX	5.52 ± 1.88[c]	6.38 ± 2.23[a]	6.42 ± 2.03[a]	6.12 ± 2.30[b]	5.92 ± 2.43[b]	.05	16.13	0.33	$Y = 5.6126 + 0.3027x - 0.0281x^2$	0.85
ARO	5.76 ± 2.15	6.24 ± 1.83	5.78 ± 2.06	6.18 ± 2.08	5.86 ± 2.00	.87	13.94	-	-	-
COL	5.42 ± 2.03[b]	5.50 ± 2.27[b]	5.66 ± 1.97[b]	5.98 ± 1.95[a]	5.28 ± 1.80[c]	.05	16.15	0.34	$Y = 5.328 + 0.168x - 0.016x^2$	0.80
FLA	4.96 ± 2.18[c]	5.70 ± 2.37[b]	5.94 ± 2.29[b]	6.12 ± 2.19[a]	6.04 ± 2.49[a]	.02	10.55	0.64	$Y = 5.236 + 0.1032x$	0.85

[1]All data represent the average of 50 replicates per treatment.
[2]APE: Appearance; TEX: Texture; ARO: Aroma; COL: Color; FLA = Flavor.
[3]The means followed by lowercase letters in the lines differ using the Tukey test ($p < .05$). Not significant = $p > .05$.
[4]CV: Coefficient of variation.
[5]COR: Correlation coefficient between the independent variable (Guarana peel meal 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.

Table 7. Sensory analysis of breasts samples of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Variables[2]	Guarana pulp meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
APE	6.22 ± 1.57[b]	6.11 ± 1.63[b]	6.27 ± 1.55[b]	6.59 ± 1.59[ab]	6.77 ± 1.55[a]	.05	14.86	0.52	$Y = 6.076 + 0.0632x$	0.81
TEX	6.25 ± 1.55[b]	5.96 ± 1.99[c]	6.25 ± 2.00[b]	6.81 ± 1.82[a]	6.81 ± 1.79[a]	.04	18.81	0.42	$Y = 6.022 + 0.0788x$	0.87
ARO	6.35 ± 1.76	6.61 ± 1.65	6.07 ± 1.72	6.11 ± 1.83	6.42 ± 1.81	.64	17.85	-	-	-
COL	6.24 ± 1.69[b]	6.74 ± 1.51[a]	6.20 ± 1.55[b]	6.27 ± 1.65[b]	6.25 ± 1.29[b]	.05	14.25	0.45	$Y = 6.3686 + 0.0311x - 0.0049x^2$	0.76
FLA	5.42 ± 2.49[c]	6.20 ± 2.27[b]	6.20 ± 2.41[b]	6.33 ± 2.27[a]	6.37 ± 1.90[a]	.05	17.53	0.57	$Y = 0.0812x + 5.698$	0.87

[1]All data represent the average of 50 replicates per treatment.
[2]APE: Appearance; TEX: Texture; ARO: Aroma; COL: Color; FLA: Flavor.
[3]The means followed by lowercase letters in the lines differ using the Tukey test ($p < .05$). Not significant = $p > .05$.
[4]CV: Coefficient of variation.
[5]COR: Correlation coefficient between the independent variable (Guarana pulp meal levels) and the dependent variable analyzed.

water retention in muscle tissues. According to Carvalho and Brochier (2008), dietary components can also influence meat composition; in their study, increasing brewery waste levels in lamb diets led to higher muscle moisture.

The high concentration of soluble fiber in GPEM, corresponding to 61.34% of neutral detergent fiber (NDF) (Santos et al., 2024), can increase intestinal viscosity and potentially impair nutrient absorption (Hung et al., 2022), which may explain the observed reductions in mineral and protein contents in chicken breast meat. In contrast, no significant differences were found in the proximate composition of breast meat from broilers fed GPUM, supporting the findings of Costa et al. (2020), who also reported no alterations in the proximate composition of broiler meat. Other studies have shown that the inclusion of unconventional ingredients such as rice bran, cassava leaves, leucaena hay, and tucumã bran at levels up to 10–15% in poultry diets does not significantly affect meat quality parameters or chemical composition (Chaves et al., 2024; Faria et al., 2012). Chemical and physical analyses are crucial to assess parameters such as protein, lipid content, pH, and water retention capacity (Moura et al., 2015).

The samples with the highest flavor acceptability came from broilers fed with the 10% inclusion level of both GPEM and GPUM. Flavor perception is a complex multisensory experience involving taste, smell, and oral-somatosensory stimuli (Spence, 2015). Although aroma scores did not differ significantly among treatments, olfactory perception plays a critical role in the overall flavor experience (Durán & Costell, 1999).

Texture acceptability peaked at 5% GPEM inclusion, whereas for GPUM, the highest inclusion levels yielded better sensory results. Although texture influences flavor perception (Durán & Costell, 1999), this relationship was not evident in the present study. As Denardin et al. (2023) noted, the meat's internal moisture content directly affects its juiciness and tenderness. The highest acceptability for color was observed at 7.5% GPEM inclusion and 2.5% GPUM inclusion. Appearance responded positively to the increasing inclusion levels of both by-products, with the highest scores recorded at 10%.

The poultry industry continues to face challenges in meeting consumer demands for high meat quality. Sensory traits such as color, aroma, juiciness, tenderness, and texture are increasingly prioritized (Osório et al., 2009). Research on chicken meat consumption in Brazil shows that consumers associate intrinsic characteristics, such as aroma, flavor, and juiciness, with overall product quality (Vannier et al., 2022). Regional studies further emphasize the importance of food preservation, facility hygiene, and product appearance in purchasing decisions (Lima et al., 2020; Oliveira et al., 2015).

Another critical factor affecting meat quality, including color, flavor, and shelf life, is lipid oxidation. Chicken and lamb meats are especially vulnerable due to their high levels of unsaturated fatty acids (Lima Júnior et al., 2013; Mariutti & Bragagnolo, 2009). Oxidation is influenced by multiple factors, including processing, storage conditions, and slaughter methods (Lima Júnior et al., 2013). Natural antioxidants such as sage, garlic, and guarana seed extracts have shown promising effects in preserving meat quality (Mariutti & Bragagnolo, 2009; Pateiro et al., 2018). Notably, guarana seed extracts, which are rich in phenolic compounds, are effective in inhibiting lipid and protein oxidation, surpassing synthetic antioxidants like BHT (Pateiro et al., 2018). This may help explain the positive sensory attributes observed in breast meat from broilers fed increasing levels of GPEM and GPUM.

Farias et al. (2020), while producing craft beer with guarana bark, found that higher inclusion levels increased both bitterness and color intensity. This highlights the importance of sensory evaluation in food product development, encompassing discriminative, descriptive, and affective tests to assess sensory attributes and consumer acceptance (Teixeira, 2009). Similarly, Rodrigues et al. (2024) reported high acceptability for rabbit meat kibbeh based on chemical and sensory analyses, while cookies enriched with 5% sesame residue flour achieved higher sensory scores than those with higher inclusion levels (Silva et al., 2023).

These studies reinforce that agricultural by-products can be effectively incorporated into various food products, whether for animal or human consumption, enhancing nutritional value and reducing environmental impact. However, the optimal inclusion level depends on the specific by-product and its intended application (Silva Júnior et al., 2020).

5 CONCLUSIONS

This study evaluated the effects of including GPEM and GPUM on the proximate composition and sensory attributes of breast meat from slow-growing broilers. GPUM proved to be more versatile, as it preserved the nutritional quality of the meat and enhanced sensory acceptance at all tested inclusion levels (2.5–10%). Although GPEM altered the proximate composition, it improved key sensory attributes, such as flavor and appearance, at higher inclusion levels (10%). The incorporation of guarana by-products into poultry diets aligns with circular economy principles, contributing to waste reduction and lowering reliance on conventional feed inputs. In summary, both by-products show potential as sustainable ingredients in poultry farming, offering a pathway to increased innovation, cost reduction, and valorization of Amazonian agro-industrial resources.

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