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Guarana (*Paullinia cupana* var. *sorbilis*) as a dietary additive for finishing pigs: impacts on digestibility, growth performance, and carcass traits

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This study evaluated the effects of dietary guarana (*Paullinia cupana* var. *sorbilis*) powder as a feed additive for finishing pigs. A 12-day digestibility trial was conducted with 20 barrows (61.8 ± 1.9 kg) distributed in a randomized block design with four dietary inclusion levels of guarana (0%, 1%, 2%, and 4%). In addition, a 30-day performance trial was conducted, with 96 pigs assigned to diets containing 0%, 1%, 2%, and 3% guarana. The growth performance parameters, including the average daily feed intake (ADFI), the average daily gain (ADG), and the gain-to-feed (G/F) ratio, as well as the carcass traits, were evaluated. Guarana inclusion did not affect the apparent digestibility coefficients of dry matter, crude energy, or crude protein ($p > 0.05$). However, increasing dietary guarana levels significantly affected growth performance, with linear reductions in ADFI and ADG ($p \leq 0.05$), while the G/F ratio increased linearly. Quadratic responses were observed for hot carcass yield, cold carcass yield, loin eye area, and fat-to-meat ratio. These results indicate that guarana supplementation influences the growth performance and carcass characteristics of finishing pigs, but does not improve the overall productive performance under the conditions evaluated.

KEYWORDS

digestibility, finishing pigs, growth performance, *Paullinia cupana*, phytogenic additive

1 Introduction

The finishing phase can correspond to the period of highest cost in pig production, accounting for up to 65% of the total production costs (López-Vergé et al., 2018). During this stage, pigs reach heavier body weights, accompanied by a reduced feed efficiency and an increased fat deposition in the carcass, which may result in poorer performance and higher production costs (Marcolla et al., 2017). Thus, the search for strategies to improve nutrient

utilization during the grow-finish period remains a constant objective in swine production (Jia et al., 2021).

Phytogenic feed additives, which include plant-derived bioactive compounds such as flavonoids, alkaloids, and tannins, have been identified as promising alternatives in animal nutrition due to their beneficial effects on intestinal health, antioxidant status, and nutrient digestibility (Moreira et al., 2002; Ntongota et al., 2025). These compounds have been associated with improvements in growth performance, animal health, reproductive outcomes, and product quality while also contributing to reductions in environmental emissions and toxicity (Moreira et al., 2002; Liu et al., 2026).

Guarana (*Paullinia cupana* var. *sorbilis*), a fruit native to the Amazon rainforest, has been reported in scientific studies as a plant-based food with health-promoting properties, particularly due to its antioxidant and anti-inflammatory effects (Silveira et al., 2018). It is characterized by high contents of methylxanthines, mainly caffeine, which is known for its potential effects on the central nervous system, as well as theobromine and theophylline (Teixeira de Azevedo et al., 2025). Guarana powder is also rich in polyphenols, mainly catechins and epicatechins, which exhibit strong antioxidant and anti-inflammatory properties (Teixeira de Azevedo et al., 2025). Majority of the guarana produced for commercial purposes is purchased by companies in the beverage, pharmaceutical, and cosmetic industries or exported to European and North American markets (Silva Junior et al., 2024).

Despite its richness in compounds with antioxidant, antimicrobial, anti-inflammatory, and neurostimulant properties, its application in animal production, particularly in swine nutrition, remains largely unexplored. Although guarana has been traditionally used and widely applied in the food and pharmaceutical industries, its use as a functional additive in pig nutrition is still limited. Considering its bioactive compounds and their potential effects on animal metabolism and performance, it becomes relevant to investigate its inclusion in finishing diets. Therefore, the present study aimed to evaluate the effects of dietary supplementation with guarana powder (*P. cupana* var. *sorbilis*) on finishing pigs through analysis of the digestibility, the zootechnical performance, and the economic feasibility of the use of this additive.

2 Materials and methods

The Animal Ethics Committee of Federal University of Fronteira Sul approved the study (approval no. 23205.001024/2018-12). All animal manipulations were performed according to the Brazilian Code for the Care and Use of Animals for Scientific Purposes and reported in proportion to the guidelines and regulations of Animal Research: Reporting of *In Vivo* Experiments (ARRIVE).

2.1 Digestibility trial

The digestibility trial was conducted at the Laboratory of Animal Nutrition (LANA), Center for Nuclear Energy in Agriculture,

University of São Paulo (CENA/USP), Piracicaba, São Paulo, Brazil. The facilities were equipped with metabolic cages, thermometers for temperature monitoring, fans, precision scales, greenhouses, freezer, and a water and electrical energy structure.

A total of 20 barrows of high genetic potential from the commercial Topigs® strain were used, with an average age of 110 days and an initial average live weight (LW) of 61.8 ± 1.9 kg. The animals were individually housed in metabolic cages and distributed in a randomized block design, with blocks defined according to the initial body weight of the animals. Four dietary treatments were evaluated (0%, 1%, 2%, and 4% guarana inclusion), with five replicates (blocks) and one animal per experimental unit (cage).

The guarana used in this research contained 5% caffeine in its composition and was purchased from the Linea Verdes Alimentos Ltd., CNPJ 03. 291.625/0001-48, headquartered in the city of Curitiba-PR (Brazil). The method of total collection of feces was adopted (Sakomura and Rostagno, 2016) using 2% ferric oxide (Fe_2O_3) as a marker of the beginning and end of the collection period. The aforementioned experiment lasted 12 days, 7 days for the animal's adaptation to the experimental environment (metabolic cages) and experimental diets and 5 days for the total collection of feces. The diets used were formulated following the recommendations of Rostagno et al. (2024). Experimental diets were fed twice a day (0800 and 1600 hours), and water was given *ad libitum*.

On the first day of the digestibility experiment, after housing, the 20 pigs received 500 g of the experimental feed according to each treatment. From day 1 to day 7 of adaptation, water was supplied *ad libitum* and the feed provided gradually, always following the voluntary consumption of each animal within each block, as the controlled consumption was aimed at estimating the restricted consumption for total collection of feces. In the days following the completion of the adaptation phase, the animals received their feed twice a day at 8:00 a.m. and at 4:00 p.m. and a water supply *ad libitum*.

The feed was weighed daily in plastic bags and supplied according to the consumption of each animal in each block. After 1 h of feeding the diet, each metabolic cage was checked for any leftovers; if so, the leftovers were collected from the feeder with the help of a sponge to ensure total removal and were placed in plastic bags, identified according to the cage number and treatment, weighed on a precision scale, and then registered. At the end of the adaptation phase, from the record of the average feed consumption of each animal in the period, it was possible to estimate the amount of daily feed that the animals would receive in the following 5 days, i.e., the total collection of feces phase. The index (*I*) was calculated for all animals; however, the lowest value of *I* found for the calculation of restricted ration consumption (RRC) (Equation 1) was adopted. The following calculation was performed:

$$\text{RRC} = \frac{\text{Average Consumption} \times 5 \text{ days (kg)}}{(\text{LiveWeight})^{0.75}} \quad (1)$$

On day 8 of the digestibility experiment, the animals started to receive the amount of feed to meet the restricted consumption according to each block (Table 1). The amount of feed was divided into two portions and provided daily at 8:00 a.m. and at 3:00 p.m.

TABLE 1 Apparent digestibility coefficients of dry matter, gross energy, and crude protein in finishing pigs fed diets containing increasing levels of powdered guarana.

Dietary guarana level (%)	Variable		
	DC-DM (%)	DC-GE (%)	DC-CP (%)
0	88.16	88.36	88.24
1	87.08	86.62	84.90
2	87.72	88.86	85.98
4	86.66	87.40	82.62
CV (%)	3.75	2.25	3.12
<i>p</i> -value ^a	NS	NS	NS
Effect ^b	NS	NS	NS

DC-DM, digestibility coefficient of dry matter; DC-GE, digestibility coefficient of gross energy; DC-CP, digestibility coefficient of crude protein; CV, coefficient of variation.

^aProbability of the effect of dietary guarana levels (significant at $p \leq 0.05$). Not significant (NS) ($p > 0.05$).

^bEffect denotes the linear (L) or quadratic (Q) effect of the guarana inclusion levels.

during the 5 days for total collection of feces. During the collection period, feces were collected twice a day (8:30 a.m. and at 3:30 p.m.) using two spatulas, paper towels, and plastic bags. After each collection, the material was placed in a plastic bag, identified, quantified on a precision scale, and frozen.

At the end of the feces collection period, the volume produced per animal was placed in a plastic bucket, thawed, individually homogenized according to each repetition of each treatment, placed in an aluminum tray, identified, and then placed in an oven with forced circulation air for drying at a temperature of 65°C for a period of 72 h. After a period of 72 h, the samples were removed from the oven and weighed again on a precision scale, obtaining the dry weight of the samples. Afterward, the dried samples were finely ground in a Wiley mill, passed through a 1-mm diameter sieve, and sent for laboratory analysis. Samples were collected from the four experimental rations (0%, 1%, 2%, and 4% inclusion of guarana) and guarana for analysis similar to those for fecal samples carried out according to the Association of Official Analytical Chemists (AOAC, 2019).

With the results of the chemical analysis, it was possible to calculate the digestibility coefficient (DC) for the total collection method using Equation 2.

$$DC = \frac{\text{Nutrient intake} - \text{Nutrient} \in \text{feces}}{\text{Nutrient intake}} \times 100 \quad (2)$$

From the results of the total feed intake based on dry matter (DM) and chemical analysis, it was also possible to calculate the apparent digestible energy of the feed using the equation proposed by Matterson et al. (1965).

It is important to note that the digestibility trial included a maximum guarana level of 4%, whereas the performance trial evaluated inclusion levels up to 3%. The use of a higher level in the digestibility assay was aimed at exploring the potential effects of a broader range of guarana inclusion on nutrient utilization under controlled intake conditions. However, for the performance trial, the maximum inclusion level was limited to 3% to avoid excessive reductions in voluntary feed intake that could compromise animal welfare and growth performance. Therefore, caution should be exercised when extrapolating the digestibility results obtained with the 4% diet to the performance outcomes observed at the 3% inclusion level.

2.2 Performance trial and carcass traits

For the evaluation of performance, a total of 96 pigs (Topigs[®]) with a starting weight of 73.3 ± 1.40 kg were used for a 30-day feeding trial. Finishing pigs were allocated randomly to four treatment groups consisting of six replicate pens per treatment with four pigs (two barrows and two gilts) per pen. The average daily feed intake (ADFI), the average daily gain (ADG), and the gain-to-feed (G/F) ratio were evaluated and calculated. The animals were weighed weekly, from the beginning to the end of the experimental period (73.3–95 kg/LW). The ADFI data were obtained by daily recording of each repetition during the entire experimental period (4 weeks). The G/F ratio was calculated from the data on total intake and weight gain in the period considered.

At the end of the performance experiment period, the last weighing of the animals was performed. Animals with LW closest to the average of the blocks were selected, with a total of six animals from each treatment (three males and three females), totaling 24 animals, which were later transported to the inspected commercial slaughterhouse in an appropriate vehicle. In the slaughterhouse, following all slaughter procedures, the animals were stunned, bled, depilated, eviscerated, and cut in half lengthwise. Subsequently, in the slaughter line, weighing of the carcasses was carried out on a conveyor scale, thus obtaining the weight of the hot carcasses. Subsequently, the half-carcasses were kept in a cold chamber at 4°C for 24 h.

Analyses of the carcass traits were carried out according to the carcass evaluation method (ABCS, 2014). The carcass length (CL) was measured with the use of a tape measure, the average backfat thickness (BT) was measured with the use of a caliper, and the loin eye area (LEA) was obtained through a drawing made by outlining the area of the longissimus dorsi muscle using appropriate material. Similarly, a drawing was made to obtain the fat-to-meat ratio (F/MR) of the animal carcass.

2.3 Statistical analysis

Data were submitted to analysis of variance, considering a randomized block design experiment, using the GLM procedure of SAS (2011). All data were tested for normality, homogeneity of residual variances, and outliers. The degrees of freedom of the

dietary guarana levels were decomposed into individual components (linear and quadratic) using orthogonal polynomials. The alpha level for the determination of significance was ≤ 0.05 .

3 Results

3.1 Digestibility

The chemical composition of the experimental diets and the calculated nutritional values are presented in Table 2. The apparent DCs of DM, crude energy (CE), and crude protein (CP) are shown in Table 1. The inclusion of guarana powder at levels of 0%, 1%, 2%,

and 4% did not affect ($p > 0.05$) the apparent digestibility of nutrients in finishing pigs. No significant differences were observed among treatments for the DCs of dry matter (DC-DM), crude energy (DC-CE), or crude protein (DC-CP).

Regression analysis also indicated that increasing dietary guarana levels did not produce significant linear or quadratic responses for the digestibility variables evaluated. Therefore, the apparent digestible energy (apDE) and the apparent digestible protein (apDP) of the diets remained unchanged across treatments.

The mean DCs observed were approximately 87%–88% for DM, 86%–89% for CE, and 82%–88% for CP, indicating that the inclusion of guarana powder did not impair nutrient utilization by the animals. The absence of statistical effects suggests that

TABLE 2 Composition and calculated values of diets containing guarana (at 0%, 1%, 2%, and 4% levels) as an additive for finishing pigs in the digestibility trial.

Ingredients	Control	1% of guarana	2% of guarana	4% of guarana
Control diet				
Corn (%)	81.41	81.11	80.31	77.73
Soybean meal, 45% (%)	14.95	14.25	14.05	14.02
Vitamin supplement ^a (%)	0.10	0.10	0.10	0.10
Dicalcium phosphate (%)	2.77	2.77	2.77	2.77
Guarana powder (%)	0.00	1.00	2.00	4.00
Salt (%)	0.36	0.36	0.36	0.37
L-Lysine, 78% (HCl) (%)	0.31	0.31	0.31	0.30
Mineral supplement ^b (%)	0.10	0.10	0.10	0.10
Soybean oil (%)	0.00	0.00	0.00	0.61
Total	100	100	100	100
Calculated values				
Linoleic acid (%)	1.60	1.60	1.60	1.90
Caffeine (%)	0	0.05	0.10	0.20
Calcium (%)	0.76	0.76	0.76	0.76
ME (kcal/kg)	3100	3100	3100	3100
ADF (%)	3.84	3.84	3.84	3.81
NDF (%)	11.06	11.06	11.06	10.89
Crude fiber (%)	2.41	2.41	2.41	2.39
Available phosphorus (%)	0.60	0.60	0.60	0.60
Total phosphorus (%)	0.79	0.79	0.79	0.79
Fat (%)	2.92	2.92	2.92	3.46
Total lysine (%)	0.86	0.86	0.86	0.86
Total methionine + cystine (%)	0.48	0.48	0.48	0.48
Total methionine (%)	0.23	0.23	0.23	0.23
Crude protein (%)	13.83	13.83	13.83	13.83
Sodium (%)	0.18	0.18	0.18	0.18
Total threonine (%)	0.52	0.52	0.52	0.52
Total tryptophan (%)	0.14	0.14	0.14	0.14

ME, metabolizable energy; ADF, acid detergent fiber; NDF, neutral detergent fiber.

^aAmount per kilogram of feed: vitamin A, 2,520 IU; vitamin D₃, 540 IU; vitamin E, 9.9 IU; vitamin K₃, 0.72 mg; thiamine, 404 µg; riboflavin, 1.98 mg; pyridoxine, 404 µg; vitamin B₁₂, 8.1 µg; folic acid, 225.2 µg; pantothenic acid, 6.3 mg; niacin, 12.6 mg; growth promoter, 10 mg; selenium (Se), 0.24 mg.

^bAmount per kilogram of feed: copper (Cu), 9 mg; iron (Fe), 81 mg; iodine (I), 0.9 mg; manganese (Mn), 54 mg; zinc (Zn), 135 mg.

guarana supplementation, within the levels evaluated, does not interfere with the digestive processes of finishing pigs.

3.2 Growth performance

The performance and the carcass characteristics of finishing pigs fed increasing levels of guarana powder are presented in Table 3. Increasing dietary levels of guarana significantly influenced the feed intake and growth performance variables. The ADFI showed a quadratic response ($p \leq 0.05$), decreasing as the dietary guarana levels increased: $ADFI = 0.1533x^2 - 0.6984x + 3.5069$ ($R^2 = 0.9878$).

Similarly, the ADG was significantly affected ($p \leq 0.05$) by guarana inclusion, presenting a decreasing linear trend. Animals that received the control diet showed an ADG of 1.20 kg day^{-1} , whereas pigs fed the diet containing 3% guarana exhibited an ADG of 0.91 kg day^{-1} . The regression equation describing the response of ADG was: $ADG = -0.2299x + 1.3334$ ($R^2 = 0.72$).

In contrast, the G/F ratio increased linearly ($p \leq 0.05$) with increasing guarana levels, reaching the highest value (3.00) in pigs that received the diet with 3% inclusion. The regression equation describing this relationship was: $G/F = 0.0308x + 2.893$ ($R^2 = 0.8365$).

Regarding the carcass traits, significant quadratic responses ($p \leq 0.05$) were observed for hot carcass yield (HCY), cold carcass yield (CCY), LEA, and the F/MR. HCY showed a quadratic response to guarana inclusion according to the equation: $HCY = 3.0059x^2 - 8.9307x + 80.251$ ($R^2 = 0.88$).

This response indicates that intermediate inclusion levels resulted in lower carcass yield, while the highest inclusion level (3%) promoted a recovery in this parameter, reaching values close to those observed in the control treatment. CCY also showed a quadratic response: $CCY = 2.4477x^2 - 7.0922x + 77.914$ ($R^2 = 0.94$).

The highest mean value (78.92%) was observed in pigs fed the diet containing 3% guarana. LEA was significantly affected by guarana

supplementation and presented a quadratic response described by the equation: $LEA = 3.719x^2 - 11.104x + 48.431$ ($R^2 = 0.9936$). The mean LEA values were 48.27, 41.43, 40.71, and 48.72 cm^2 for the diets containing 0%, 1%, 2%, and 3% guarana, respectively.

Finally, the F/MR also showed a quadratic response according to the regression equation: $F/MR = -0.0223x^2 + 0.0436x + 0.3853$ ($R^2 = 0.9208$). These results indicate that, although increasing guarana levels reduced the feed intake and weight gain, the additive influenced the carcass composition variables.

4 Discussion

Several factors influence pig performance from growth to slaughter, including management, nutrition, health, genetics, and environmental conditions (Heck, 2009). In this context, the evaluation of alternative feed additives has become increasingly relevant in swine production. However, studies investigating the use of guarana powder (*P. cupana* var. *sorbilis*) as a dietary additive in pig nutrition are still scarce. The present study demonstrated that increasing levels of guarana inclusion significantly affected the performance and carcass parameters, with linear and quadratic responses observed among the evaluated variables.

The ADFI showed a quadratic decrease as the dietary guarana levels increased. This response suggests that the incorporation of guarana powder in the diets may have influenced the palatability of the feed or the metabolic regulation of intake. Guarana is characterized by a complex chemical composition that includes several bioactive compounds such as methylxanthines (caffeine, theophylline, and theobromine), tannins, gallic acid, saponins, catechins, and epicatechins (Seidemann, 1998; Heard et al., 2006). Many of these compounds can influence the sensory characteristics of feed, particularly the bitterness and astringency.

TABLE 3 Growth performance and carcass traits of finishing pigs fed diets containing increasing levels (0%, 1%, 2%, and 3%) of powdered guarana.

Variable	Dietary guarana level (%)				P-value ^a	Effect ^b	CV (%)
	0	1	2	3			
IBW (kg)	67.30	70.99	70.77	71.08	–	–	9.36
FBW (kg)	97.50	95.99	94.23	93.85	NS	NS	9.10
ADFI (kg/day)	3.52	2.91	2.77	2.77	0.01	L	11.96
ADG (kg/day)	1.20	1.00	0.94	0.91	0.01	L	13.27
G/F	2.91	2.91	2.94	3.00	0.01	L	2.44
HCY (%)	79.69	75.73	73.01	80.98	0.01	Q	4.72
CCY (%)	77.61	74.03	72.76	78.92	0.01	Q	3.83
CL (cm)	96.00	98.00	96.00	96.00	NS	NS	9.65
BT (mm)	13.00	13.10	12.10	12.30	NS	NS	2.18
BT-P2 (mm)	6.00	10.00	7.50	7.00	NS	NS	9.64
LEA (cm ²)	48.27	41.43	40.71	48.72	0.01	Q	9.6
F/MR	0.38	0.42	0.37	0.32	0.01	Q	9.64

IBW, initial body weight; FBW, final body weight; ADFI, average daily feed intake; ADG, average daily gain; G/F, gain-to-feed ratio; HCY, hot carcass yield; CCY, cold carcass yield; CL, carcass length; BT, average backfat thickness; BT-P2, backfat thickness at point P2; LEA, loin eye area; F/MR, fat-to-meat ratio; CV, coefficient of variation.

^aProbability of the effect of dietary guarana levels (significant at $p \leq 0.05$). Not significant (NS) ($p > 0.05$).

^bEffect denotes the linear (L) or quadratic (Q) effect of the guarana inclusion levels.

Phenolic compounds are known to contribute to the sensory properties of foods, especially the flavor and astringency (Lesschaeve and Noble, 2005). Therefore, the presence of these compounds in guarana may have negatively affected the feed palatability, leading to reduced voluntary feed intake by pigs. Swine possess a well-developed gustatory system capable of detecting subtle changes in feed flavor, which may result in reduced consumption when diets contain bitter or astringent substances.

In addition to the sensory effects, the presence of tannins in guarana may also have contributed to the observed reduction in feed intake. Tannins are considered anti-nutritional compounds because they can interact with proteins and other nutrients, reducing their digestibility and availability (Tocchini et al., 1977). Furthermore, salivary proteins can bind tannins and represent a physiological defense mechanism against their negative dietary effects (Skopec et al., 2004; Shimada, 2006). High dietary concentrations of tannins have been associated with reduced feed intake and impaired performance in several animal species.

Another factor that may explain the reduction in feed intake is the high caffeine content of guarana. According to Edwards et al. (2005), guarana has substantially higher caffeine concentrations than several commonly consumed products, such as coffee, tea, and cocoa. Caffeine is known to exert physiological effects on the metabolism and energy expenditure. Previous studies have shown that guarana supplementation can stimulate lipid metabolism and promote body weight reduction in both humans and animals (Boozar et al., 2001; Bérubé-Parent et al., 2005; Lima et al., 2005). Epidemiological studies have also suggested that regular guarana consumption may be associated with a lower risk of obesity in human populations (Krewer et al., 2011). In addition, caffeine has been reported to increase the basal metabolic rate, which may contribute to greater energy expenditure (Ruxton et al., 2007).

In the present study, the reduction in ADFI was accompanied by a linear decrease in ADG, indicating that the lower feed consumption directly affected growth performance. Despite this reduction, the final body weight remained within the expected range for finishing pigs. The reduction in the growth rate observed in animals that received guarana may be partially explained by the metabolic effects of caffeine. Caffeine inhibits phosphodiesterase activity, resulting in increased intracellular concentrations of cyclic adenosine monophosphate (cAMP), which stimulates lipolysis and increases the availability of free fatty acids as energy substrates.

Several studies have reported that caffeine intake can increase the energy expenditure and stimulate the sympathetic nervous system, thereby modifying energy metabolism and promoting greater lipid oxidation (Acheson et al., 1980, 2004; Graham, 2001; Leblanc et al., 1985). These physiological effects may partly explain the reduction in growth performance observed in pigs receiving diets containing guarana powder.

Despite the reduction in feed intake and weight gain, the G/F ratio increased linearly with increasing levels of guarana inclusion. This result indicates that animals receiving guarana consumed less feed per unit of body weight gain, suggesting an improvement in feed efficiency. One possible explanation for this effect is the

potential influence of the bioactive compounds in guarana on nutrient partitioning. According to Moser et al. (1986), lean tissue deposition requires less energy than fat deposition, which may result in improved feed conversion efficiency under certain metabolic conditions.

In conventional swine production systems, G/F ratios typically range between 2.5 and 3.0 when animals are fed corn-soybean meal diets. The values observed in the present study are therefore consistent with those reported under commercial production conditions. Although no studies evaluating guarana supplementation in pig diets were identified in the literature, similar responses have been reported when alternative feed ingredients containing caffeine-like compounds were used. Oliveira (1999), for example, reported reductions in the feed intake and weight gain when coffee husks were included in finishing pig diets. Similar findings were also described by Parra et al. (2008), who evaluated the inclusion of coffee by-products in swine diets. These similarities suggest that the presence of caffeine and other secondary metabolites in plant-derived ingredients may influence the feed intake and growth performance in pigs. Nevertheless, the metabolic effects of these compounds may also influence the carcass composition and nutrient utilization.

Regarding the carcass characteristics, significant quadratic responses were observed for HCY and CCY. The reduction observed at intermediate inclusion levels followed by recovery at the highest level suggests a nonlinear response of the carcass traits to guarana supplementation. Oliveira (2005) reported that higher carcass yields are often associated with increased fat deposition. However, this pattern was not observed in the present study, since animals with higher carcass yields did not necessarily present higher F/MR.

The potential influence of guarana on carcass traits may also be related to the metabolic effects of caffeine. Caffeine has been shown to stimulate lipolysis by increasing circulating catecholamines or by antagonizing the action of adenosine, which normally inhibits fatty acid oxidation (Goldstein et al., 2010). Furthermore, caffeine has been widely described as a nutritional ergogenic compound capable of influencing the energy metabolism and substrate utilization (Almeida et al., 2009).

CCY was also affected quadratically by guarana inclusion. Differences between HCY and CCY are expected due to evaporative and drip losses during carcass chilling. According to the Brazilian Association of Swine Breeders (ABCS, 2014, 2016), the cold carcass weight is generally 0.8%–2.3% lower than the hot carcass weight due to moisture loss during refrigeration. In the present study, the highest CCY values were observed in animals that received 3% guarana inclusion, which may reflect differences in the carcass composition and body fat deposition.

No significant differences were observed for CL, BT, or BT at the P2 point. These results suggest that guarana inclusion did not substantially affect the structural development of carcasses. However, the relatively low backfat values observed indicate reduced fat deposition, which may be associated with the metabolic effects of caffeine.

LEA was significantly affected by guarana inclusion, presenting a quadratic response. Animals that received the highest inclusion

level showed greater LEA values compared with those who had intermediate levels. Guarana contains several alkaloids that are structurally related to purines and xanthines, compounds that play important roles in metabolic regulation (Tavares and Sakata, 2012). These compounds are capable of modulating various physiological functions in animals (Guerra et al., 2000), which may influence nutrient utilization and muscle deposition.

In this context, the metabolic effects of the bioactive compounds in guarana may have contributed to the changes in carcass composition, particularly through mechanisms related to lipid mobilization and energy metabolism. Increased lipolysis and preferential utilization of fatty acids as energy substrates may favor lean tissue deposition, thereby contributing to greater LEA in pigs receiving higher levels of guarana supplementation.

Finally, the F/MR also presented a quadratic response, indicating that dietary guarana may influence fat deposition patterns in finishing pigs. These results suggest that, although guarana supplementation reduced the feed intake and growth rate, it may also influence the metabolic pathways related to energy utilization and carcass composition.

5 Conclusions

The inclusion of guarana powder in diets for finishing pigs did not affect the apparent digestibility of DM, CE, or CP. However, increasing dietary levels of guarana reduced the ADFI and ADG while increasing the G/F ratio. In addition, quadratic responses were observed for HCY, CCY, LEA, and F/MR. These results indicate that guarana supplementation alters the growth performance and carcass traits of finishing pigs, although it does not improve the overall productive performance under the conditions evaluated.

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 approved by Comitê de Ética de Uso de Animais. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

BB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration,

Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. FS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AA: Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. NM: Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. AB: Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. TP: Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. CM: Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing, Conceptualization. JF: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. NC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. HP: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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References

- Acheson, K. J., Gremaud, G., Meirim, I., Montigon, F., Krebs, Y., Fay, L. B., et al. (2004). Metabolic effects of caffeine in humans: lipid oxidation or futile cycling? *Am. J. Clin. Nutr.* 79, 40–46. doi: 10.1093/ajcn/79.1.40
- Acheson, K. J., Zahorska-Markiewicz, B., Pittet, P., Anantharaman, K., and Jequier, E. (1980). Caffeine and coffee: their influence on metabolic rate and substrate utilization in normal weight and obese individuals. *Am. J. Clin. Nutr.* 33, 989–997. doi: 10.1093/ajcn/33.5.989
- Almeida, C., Sangiovanni, D., and Liberali, R. (2009). Cafeína: efeitos ergogênicos nos exercícios físicos. *Rev. Bras. Nutr. Esportiva* 3, 198–209.
- Associação Brasileira dos Criadores de Suínos-ABCS (2014). *Produção de suínos: teoria e prática* (Brasília).
- Associação Brasileira dos Criadores de Suínos-ABCS (2016). *Mapeamento da suinocultura brasileira* (Brasília).
- Association of Official Agricultural Chemists-AOAC (2019). *Official methods of analysis of AOAC International. 21st ed* (Rockville, USA: AOAC).
- Bérubé-Parent, S., Pelletier, C., Doré, J., and Tremblay, A. (2005). Effects of encapsulated green tea and guaraná extracts containing a mixture of epigallocatechin-3-gallate and caffeine on 24-h energy expenditure and fat oxidation in men. *Br. J. Nutr.* 94, 432–436. doi: 10.1079/bjn20051502
- Boozer, C. N., Nasser, J. A., Heymsfield, S. B., Wang, V., Chen, G., and Solomon, J. L. (2001). An herbal supplement containing Ma Huang and guarana for weight loss: a randomized double-blind trial. *Int. J. Obes.* 25, 316–324. doi: 10.1038/sj.ijo.0801539
- Edwards, H. G. M., Farwell, D. W., Oliveira, L. F. C., Alia, J. M., Le Hyaric, M., and Almeida, M. V. (2005). FT-Raman spectroscopic studies of guarana and some extracts. *Anal. Chim. Acta* 532, 177–186. doi: 10.1016/j.aca.2004.10.055
- Goldstein, E. R., Ziegenfuss, T., Kalman, D., Kreider, R., Campbell, B., Wilborn, C., et al. (2010). International Society of Sports Nutrition position stand: caffeine and performance. *J. Int. Soc. Sports Nutr.* 7, 5. doi: 10.1186/1550-2783-7-5
- Graham, T. E. (2001). Caffeine and exercise: metabolism, endurance and performance. *Sports Med.* 31, 785–807. doi: 10.2165/00007256-200131110-00002
- Guerra, R. O., Bernardo, G., and Gutiérrez, C. (2000). Cafeína e esporte. *Rev. Bras. Med. Esporte* 6, 45–49. doi: 10.1590/S1517-86922000000200006
- Heard, C. M., Johnson, S., Moss, G., and Thomas, C. P. (2006). *In vitro* transdermal delivery of caffeine, theobromine, theophylline and catechin from extract of guarana (Paullinia cupana). *Int. J. Pharm.* 317, 26–31. doi: 10.1016/j.ijpharm.2006.02.042
- Heck, A. (2009). Fatores que influenciam o desenvolvimento dos leitões na recria e terminação. *Acta Sci. Vet.* 37, S211–S218.
- Jia, D., Wang, Y., Wang, J., Liu, J., Li, H., Liu, A., et al. (2021). Lactobacillus animalis pZL8a: a potential probiotic isolated from pig feces for further research. *3 Biotech.* 11, 132. doi: 10.1007/s13205-021-02681-3
- Krewer, C. C., Ribeiro, E. E., Ribeiro, E. A. M., Moresco, R. N., Rocha, M. I. U. M., Montagner, G. F. F., et al. (2011). Habitual intake of guaraná and metabolic morbidities: an epidemiological study of an elderly Amazonian population. *Phytother. Res.* 25, 1367–1374. doi: 10.1002/ptr.3437
- Leblanc, J., Jobin, M., Cote, J., Samson, P., and Labrie, A. (1985). Enhanced metabolic response to caffeine in exercise-trained human subjects. *J. Appl. Physiol.* 59, 832–837. doi: 10.1152/jappl.1985.59.3.832
- Lesschaeve, I., and Noble, A. C. (2005). Polyphenols: factors influencing their sensory properties and their effects on food and beverage preferences. *Am. J. Clin. Nutr.* 81, 330–335. doi: 10.1093/ajcn/81.1.330s
- Lima, W. P., Carnevali, L. C., Eder, R., Rosa, L. F. B. P. C., Bacchi, E. M., and Seelaender, M. C. L. (2005). Lipid metabolism in trained rats: effect of guaraná (Paullinia cupana Mart.) supplementation. *Clin. Nutr.* 24, 1019–1028. doi: 10.1016/j.clnu.2005.08.004
- Liu, L., Wang, P., Liu, S., Yan, M., Zhang, Q., Clark, E., et al. (2026). Meta-analyses of the global impact of non-antibiotic feed additives on livestock performance and health. *J. Adv. Res.* 79, 1–14. doi: 10.1016/j.jare.2025.03.009
- López-Vergé, S., Gasa, J., Farré, M., Coma, J., Bonet, J., and Solà-Oriol, D. (2018). Potential risk factors related to pig body weight variability from birth to slaughter in commercial conditions. *Transl. Anim. Sci.* 2, 383–395. doi: 10.1093/tas/txy082
- Marcolla, C. S., Holanda, D. M., Ferreira, S. V., Rocha, G. C., Serão, N. V. L., Duarte, M. S., et al. (2017). Chromium, CLA, and ractopamine for finishing pigs. *J. Anim. Sci.* 95, 4472–4480. doi: 10.2527/jas2017.1753
- Matterson, L. D., Potter, L. M., Stutz, M. W., and Singsen, E. P. (1965). The metabolizable energy of feed ingredients for chickens. *Res. Rep. Conn. Agric. Exp. Stn.* 7, 1–11. doi: 10.3382/ps.0390781
- Moreira, I., Marcos Junior, M., Furlan, A. C., Patricio, V. M. I., and Oliveira, G. C. (2002). Uso da levedura seca por spray-dry como fonte de proteína para suínos em crescimento e terminação. *Rev. Bras. Zootec.* 31, 962–969. doi: 10.1590/S1516-35982002000400020
- Moser, R. L., Dalrymple, R. H., Cornelius, S. G., Pettigrew, J. E., and Allen, C. E. (1986). Effect of cimaterol as a repartitioning agent in finishing pig diets. *J. Anim. Sci.* 62, 21–26. doi: 10.2527/jas1986.62121x
- Ntsongota, Z., Ikusika, O., and Jaja, I. F. (2025). The role of phytochemical feed additives in growth and immune response in livestock production: a global systematic review. *Front. Anim. Sci.* 6. doi: 10.3389/fanim.2025.1703112
- Oliveira, V. (1999). *Casca de café em rações isoenergéticas para suínos em crescimento e terminação: digestibilidade e desempenho* (Lavras (MG): Universidade Federal de Lavras). Master's thesis
- Oliveira, V., Fialho, E. T., Lima, J. A. F., Oliveira, A. I. G., and Freitas, R. T. F. (2000). *Substituição do Milho por Casca de Café em Rações Isoenergéticas para Suínos em Crescimento e Terminação*. Lavras, MG: Ciência e Agrotecnologia, 25 (2), 424–436.
- Parra, Â.R.P., Moreira, I., Furlan, A. C., Paiano, D., Scherer, C., and Carvalho, P. L. O. (2008). Utilização da casca de café na alimentação de suínos nas fases de crescimento e terminação. *Rev. Bras. Zootec.* 37, 433–442. doi: 10.1590/S1516-35982008000300008
- Rostagno, H. S., Albino, L. F. T., Calderano, A. A., Hannas, M. I., Sakomura, N. K., Costa, F. G. P., et al. (2024). *Brazilian tables for poultry and swine: food composition and nutritional requirements. 5th ed* (Viçosa, Brazil: UFV Press).
- Ruxton, C. H. S., Kirkwood, L., McMillan, B., St. John, D., and Evans, C. E. L. (2007). Effectiveness of a herbal supplement (Zotrin™) for weight management. *Br. Food J.* 109, 416–428. doi: 10.1108/00070700710753481
- Sakomura, N. K., and Rostagno, H. S. (2016). *Métodos de pesquisa em nutrição de monogástricos. 2nd Edn* (Jaboticabal, SP: FUNEP).
- SAS Institute (2011). *SAS user's guide: statistics* (Cary, NC: SAS Institute Inc). Version 9.1.
- Seidemann, J. (1998). Guaraná (Paullinia cupana H. B. K.): an active agent from the tropical rainforest. *Tropenlandwirt* 99 (1), 49–63.
- Shimada, T. (2006). Salivary proteins as a defense against dietary tannins. *J. Chem. Ecol.* 32, 1149–1163. doi: 10.1007/s10886-006-9077-0
- Silva Junior, A. L. S., Nascimento, M. M., Santos, H. M., Lôbo, I. P., de Oliveira, R. A., and de Jesus, R. M. (2024). Methylxanthine and flavonoid contents from guarana seeds

- (*Paullinia cupana*): comparison of different drying techniques and effects of UV radiation. *Int. J. Food Sci.* 2024, 7310510. doi: 10.1155/2024/7310510
- Silveira, A. K., Moresco, K. S., Gomes, H. M., Morrone, M. S., Grun, L. K., Gelain, D. P., et al. (2018). Guarana (*Paullinia cupana* Mart.) alters gut microbiota and modulates redox status, partially via caffeine in Wistar rats. *Phytother. Res.* 32, 2466–2474. doi: 10.1002/ptr.6185
- Skopec, M. M., Hagerman, A., and Karasov, W. H. (2004). Do salivary proline-rich proteins counteract dietary hydrolyzable tannin in laboratory rats? *J. Chem. Ecol.* 30, 1679–1692. doi: 10.1023/b:joec.0000042395.31307.be
- Tavares, C., and Sakata, R. K. (2012). Cafeína para o tratamento de dor. *Rev. Bras. Anesthesiol.* 62, 387–401. doi: 10.1590/S0034-70942012000300011
- Teixeira de Azevedo, G., Lima de Souza, G., Leonarski, E., Lotas, K. M., Barroso da Silva, G. H., Miguel Batista, F. R., et al. (2025). Valorization of Guarana (*Paullinia cupana*) production chain waste - a review of possible bioproducts. *Resources* 14, 98. doi: 10.3390/resources14060098
- Tocchini, R. P., Okada, M., and Angelucci, E. (1977). Extração do guaraná e sua aplicação em refrigerantes. *Coletânea Inst. Tecnol. Alimentos* 8, 391–407.