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Elephant Grass Silage with Pelleted Citrus Pulp: Chemical Composition, Digestibility, and Feedlot Costs

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ABSTRACT

This study aimed to assess the effects of including pelleted citrus pulp (PCP) in BRS Capiaçu elephant grass silage on its chemical composition and digestibility and the production costs of feedlot diets for beef cattle. A completely randomized experimental design in a 2×5 factorial scheme was used considering 90- and 120-day harvesting intervals for ensiling and five inclusion levels of PCP (0%, 3%, 6%, 12%, or 24% as fed). The dry matter (DM) content of the silages increased with regrowth interval (p<0.01) and there was a quadratic response to the inclusion level of PCP (p<0.01). Total digestible nutrients of the silages decreased with increasing Capiaçu regrowth interval (p<0.01) but increased linearly with increasing inclusion levels of PCP during ensiling (p<0.01). The *in vitro* DM digestibility of silage increased linearly with the inclusion of PCP (p<0.01) and with increasing regrowth interval (p<0.01). The inclusion of PCP and grass regrowth interval linearly increased DM recovery from silage (p<0.01). Adding up to 24% PCP during the ensiling of Capiaçu improves the fermentation profile and nutritional value of the silage and digestibility parameters. Based on economic analysis, we recommend the use of silage prepared from Capiaçu harvested at 120 days and containing 6% to 12% PCP because of its lower cost per unit of gain ($/arroba produced), cost per animal, and total feedlot costs compared to the other treatments.

Keywords: chemical composition; economic analysis; fermentation characteristics; in vitro digestibility; ruminant

INTRODUCTION

Seasonality in forage production represents a significant challenge for livestock farming in tropical climates, particularly during the dry season when the quality and availability of natural pasture are limited (Moselhy *et al.*, 2022). This seasonal variation can lead to insufficient nutrients for livestock animals, affecting their growth, reproductive performance, and overall productivity. To mitigate this problem, preserving surplus forage during the rainy season in the form of silage has proven to be an effective strategy for maintaining uniform production throughout the year (Figueiredo *et al.*, 2022).

Elephant grass cv. BRS Capiaçu (*Pennisetum purpureum* Schum.) is an alternative for forage supplementation during the dry season and periods of forage deficiency. The dry matter (DM) yield of Capiaçu exceeds 49.9 tons per year (Pereira *et al.*, 2017). Despite its high productivity, the neutral detergent fiber (NDF) content of Capiaçu is high (71.5%) because of its stalk production capacity; in addition, the average crude protein (CP) content (9.1%) is satisfactory, and its production costs are lower than those of other crops used for silage production (Pereira *et al.*, 2017).

The harvest period of the grass for silage production is an important factor since advancing the phenological stage increases DM content and directly influences the chemical composition of the forage to be ensiled (Oliveira *et al.*, 2015; Silva *et al.*, 2021). However, the high moisture content of elephant grass at the stage when its nutritional value is considered optimal can increase effluent losses and compromise the fermentation process in the silo (Figueiredo *et al.*, 2022).

Pelleted citrus pulp (PCP), a by-product of the orange juice industry, is an excellent alternative to grass silage (Grizotto *et al.*, 2020). After processing, the pulp is pelleted and commercialized (Pacheco *et al.*, 2021). Moreover, PCP is characterized by a high hygroscopic power, a high soluble carbohydrate content, an excellent nutritional value, and good acceptability by animals, rendering it an ideal material for elephant grass ensiling (Salami *et al.*, 2020; Grizotto *et al.*, 2020; Anjos *et al.*, 2022).

The ensiling of Capiaçu grass during its peak biomass production, combined with the inclusion of PCP, offers a promising strategy to optimize silage production, particularly in regions where PCP is abundant and economically accessible. Despite the known benefits of Capiaçu and PCP, no studies have investigated their combined use for ensiling high-yielding elephant grass cv. BRS Capiaçu. This study hypothesizes that the inclusion of PCP during Capiaçu ensiling enhances the fermentation profile and digestibility of the silage while reducing the production costs of feedlot diets. Accordingly, the objective was to evaluate the effects of PCP inclusion during the ensiling of Capiaçu at two distinct regrowth intervals on the chemical composition and *in vitro* digestibility of the silage and the production cost of diets for feedlot-finished Nellore bulls.

MATERIALS AND METHODS

The experiment was conducted at the Forage Farming sector of the School of Veterinary Medicine and Animal Science (FMVZ), Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP; 22º51'01" south latitude and 48º25'27" west longitude, altitude of 800 m). According to the Köppen classification, the predominant climate type in the region is Cwa, a tropical high-altitude climate with dry winters and hot and rainy summers. The average temperature is 21.04 ºC, with 69.8% relative humidity and an annual cumulative average precipitation of 1,521.76 mm. The soil in the experimental area is classified as dystrophic Red Latosol (Oliveira *et al.*, 2020), with sand, silt, and clay concentrations of 280 g, 90 g, and 630 g kg^{-1}, respectively.

Capiaçu (*P. purpureum* Schum.) was the forage species used, which has been established (planted) since April 2020. The experiment was conducted in a completely randomized design in a 2×5 factorial scheme considering two regrowth intervals (90 and 120 days) and five inclusion levels of PCP (0%, 3%, 6%, 12%, and 24% as fed). At the beginning of the experimental period (October 2021), a uniformization cut close to the ground was performed, followed by fertilization with 250 kg ha^{-1} of NPK 20-05-20. The harvesting intervals were chosen considering the high growth of Capiaçu and the better ratio between nutritional composition and DM content (Monção *et al.*, 2019).

At the defined harvesting intervals (90 and 120 days), Capiaçu was manually cut to a residual height of 5 cm. The material was chopped in a stationary forage grinder until 2 to 3 cm particles were obtained. PCP was purchased from a local store (Botucatu, São Paulo, Brazil). For each forage mass obtained at the two regrowth intervals, the percentages of PCP (0%, 3%, 6%, 12%, or 24% as fed) were manually homogenized. A sample of approximately 400 g was collected from each experimental unit before the ensiling of the material and the addition of PCP. The samples were pre-dried in a forced air circulation oven at 55 ºC for 72 hours and analyzed for the content of DM (934.01), CP (978.04) and ether extract (EE; 920.39) according to AOAC (1995), mineral matter (MM; 942.05) (AOAC, 2005), and NDF, acid detergent fiber (ADF) and lignin according to Van Soest *et al*. (1991). Cellulose content was calculated as the difference between NDF and lignin. Hemicellulose levels were determined as the difference between NDF and ADF content. Total digestible nutrients (TDN) were estimated using the equations proposed by Weiss and adopted by the National Research Council (2001).

For silage preparation, we used 40 experimental silos made of polyvinyl chloride (10 treatments and four replicates), each measuring 40 cm in height and 10 cm in diameter. The silos had a capacity of approximately 2.5 kg of ensiled material (density of 600 kg/m^3 of fresh forage). The silos were equipped with a lid with a Bunsen valve. A TNT (tissue-non-tissue) bag of known weight containing sterilized sand was placed at the bottom of the silos to drain the effluents produced and to determine effluent losses according to the equation proposed by Jobim *et al*. (2007). First, the silo, lid, sand, and bag were weighed to determine the weight of the empty silo. The material to be ensiled was then homogenized according to the proportions of each treatment, transferred to the appropriate silos, and compacted with a hydraulic press while maintaining pressure for 5 minutes. After ensiling, the silos were sealed with adhesive tape, weighed, and kept at room temperature.

The experimental silos were opened 60 days after ensiling and weighed for DM quantification. Fermentation losses were determined as the difference between the weight of the mass obtained at ensiling and silo opening, multiplied by the respective DM content and transformed to the percentage of the initial mass and of the bags with sand. The loss of DM by effluents was calculated according to Andrade *et al.* (2010):

$$EP= [(Wop-Wen)/FMef] \times 100$$

where EP was effluent production (kg/t of fresh mass); Wop was the weight of the set (silo + sandbag) at opening (kg); Wen was the weight of the set (silo + sandbag) at ensiling (kg), and FMef was a fresh mass of ensiled forage (kg).

After weighing, the sealed silos were opened, and approximately 10 cm of the upper and lower portions were discarded. The remaining silage was homogenized, and forage samples were obtained for subsequent analysis. Two samples weighing approximately 400 g were collected from each experimental unit after silo opening. The first sample was used for the measurement of pH (100 g) with a benchtop digital pH meter for aqueous solutions (Mpa-210) (Silva & Queiroz, 2002) and ammoniacal nitrogen ($N\text{-}NH_3$). The second silage sample was transferred to a paper bag and pre-dried in a forced air circulation oven at 55 ºC to constant weight. A portion of the pre-dried silage was ground in a stationary Wiley mill with a 1-mm mesh sieve for chemical analysis, while the remaining sample was ground using a 2-mm mesh sieve to assess digestibility.

The chemical composition of the silage samples was analyzed following previously described procedures (AOAC, 1995; Van Soest *et al.*, 1991). The TDN content was estimated according to the NRC (2001). *In vitro* DM digestibility (IVDMD) was determined in a DAISYII incubator (ANKOM® Technology) following the protocol of the manufacturer (McDougall, 1948; Van Soest & Wine, 1968). Briefly, a buffer solution was prepared to mimic the composition of ruminant saliva, ensuring an optimal environment for microbial activity, and maintained at 39 °C prior to use. Silage samples (0.5 g) were ground to 1-mm particle size, sealed in F57 filter bags, and pre-soaked in the buffer solution to standardize hydration. Rumen fluid, collected from fistulated cattle fed a basal diet, was filtered and combined with the buffer at a 2:1 ratio in digestion jars. The jars were purged with CO_2 to maintain anaerobic conditions and incubated at 39 °C for 48 hours under continuous agitation to simulate rumen fermentation. Following incubation, the filter bags were rinsed to remove fermentation residues, dried at 105 °C for 24 hours, and weighed to determine residual DM. The IVDMD was calculated as the difference in DM weight before and after incubation.

The results were analyzed in terms of homogeneity of variances and normality of residuals. The data were presented as means with their respective standard errors. Differences between treatment means were compared by the Dunnett test using the PROC Mixed procedure of SAS 9.4. In addition to the effect of the inclusion of PCP (0%, 3%, 6%, 12%, or 24%) and Capiaçu regrowth interval (90 and 120 days), the model included the interaction of these factors and can be written as follows:

$$Yijk = \mu + Ti + Cj + T*Cij + eijk$$

where, Yijk is the trait of interest; μ is the overall mean; Ti is the effect of inclusion of PCP; Cj is the effect of regrowth interval; T*Cij is the interaction effect, and eijk is random error. Least squares means were compared by the Dunnett, adopting an error probability of 5%. Differences were considered significant when $p\leq0.05$, and trends were considered when $0.05<p<0.10$. The regrowth interval was analyzed as a repeated measure over time, with differences being considered significant when $p<0.05$ and trends when $0.05<p<0.10$.

The RLM Corte v.3.3 software (available at https://rlm.app.br/principal) was used for predicting the productive performance and for economic analysis of the finishing diets for feedlot Nellore bulls fed Capiaçu silages (ensiled at two harvesting intervals) containing PCP. The diets were formulated using the Tropicalized NRC system (Andrade *et al.,* 2023). Simulations were performed to evaluate the total daily cost ($/animal/day), weight gain cost ($/@), daily price ($/animal/day), cost per animal ($/animal), feedlot cost ($), and cost of diet ($/ton), following the procedures described by Costa *et al*. (2023). The costs associated with the original material ($/ton) of the ingredients were adjusted based on quotes obtained in the state of São Paulo in February 2024. Operating costs (non-feed; fixed and variable costs) were obtained from the monthly bulletin of production costs of feedlot cattle in February 2024, provided by the Economic Analysis Laboratory of the University of São Paulo (https://www.lae-fmvz-usp.com/).

RESULTS

Table 1 describes the pre-ensiling chemical composition of PCP and the BRS Capiaçu forage at the two regrowth intervals. The interaction between increasing regrowth interval and PCP inclusion level quadratically increased ($p<0.01$) the DM content of the silage (Table 2). Likewise, there was an interaction effect between PCP inclusion and Capiaçu regrowth interval on MM ($p<0.01$) and cellulose ($p<0.01$) content, which increased linearly (Table 2).

There was an interaction effect between increasing Capiaçu regrowth interval and PCP addition on CP content ($p<0.01$). The CP content decreased linearly with increasing regrowth interval ($p<0.05$) and inclusion of PCP in the silages ($p<0.01$; Table 2). Likewise, the interaction between regrowth interval and PCP inclusion level increased ($p<0.01$) EE content (Table 2). There was no interaction effect between cutting interval and PCP level in the silage on CP or EE content. However, the NDF and ADF fractions increased linearly with increasing Capiaçu regrowth interval ($p<0.01$) and decreased linearly with increasing PCP inclusion ($p<0.01$). There was also a linear decrease in hemicellulose and lignin ($p<0.05$) with inclusion of PCP during ensiling (Table 2). However, TDN decreased linearly ($p<0.05$) with increasing Capiaçu regrowth interval and increased linearly ($p<0.01$) with increasing inclusion level of PCP in the silages. The addition of PCP promoted a linear increase in IVDMD ($p<0.01$), while this parameter decreased linearly with increasing regrowth interval of Capiaçu ($p<0.01$; Table 2).

An increase in the regrowth interval of Capiaçu and the addition of PCP quadratically increased ($p<0.05$) silage pH. The concentrations of $N\text{-}NH_3$ decreased linearly in response to the addition of PCP ($p<0.01$) and increasing regrowth interval ($p<0.01$). There was an interaction effect between PCP inclusion and Capiaçu regrowth interval on effluent losses, with a quadratic reduction ($p<0.01$) in this parameter that was more pronounced in silages with the inclusion of 24% PCP (Table 2). Likewise, an interaction effect was observed between the addition of PCP and Capiaçu regrowth interval on DM recovery from silages, which increased linearly ($p<0.01$).

Simulations of the use of Capiaçu in feedlot finishing diets and prediction of productive

Table 1. Chemical composition of elephant grass cv. BRS Capiaçu (*Pennisetum purpureum* Schum.) at 90 and 120 days of age and of pelleted citrus pulp

Item (%)	Pelleted citrus pulp	Capiaçu 90 days	Capiaçu 120 days
Dry matter[1]	88.50	22.36	28.16
Crude protein[2]	7.62	10.20	8.10
Ether extract[2]	2.41	2.97	2.86
Neutral detergent fiber[2]	26.53	65.81	70.29
Acid detergent fiber[2]	20.14	42.38	45.25
Cellulose[2]	12.70	37.00	37.45
Hemicellulose[2]	6.39	23.43	25.04
Lignin[2]	6.24	4.11	5.60
Total digestible nutrients[2]	73.35	66.07	63.24

Note: [1] % as fed; [2] dry matter basis.

performance of Nellore bulls showed that grass ensiled at 90 or 120 days with 24% PCP worsens feed conversion (kg dry matter intake [DMI]/kg live weight gain) by the animals compared to the other diets (Table 3). Increasing the regrowth interval of Capiaçu and PCP inclusion in the silage altered the costs of the simulated feedlot diets (Table 4). The diet containing Capiaçu silage ensiled at 90 days of regrowth with 24% PCP was associated with lower costs per arroba produced (@; one unit of weight equivalent to 15 kg of saleable meat), lower daily costs, and lower costs per ton of DM when compared to the other diets containing Capiaçu ensiled at 90 days. In this simulation, reductions of 4.32% ($/@ produced), 7.29% ($/animal/day), and 7.91% ($/ton), respectively, were observed. On the other hand, in the case of diets containing Capiaçu ensiled at 120 days of regrowth, lower costs per arroba produced ($/@) were observed for diets containing 6% or 12% PCP. The lowest daily cost ($/animal/day) and cost per ton of DM ($/ton) were found for diets containing Capiaçu ensiled at 120 days and inclusion of 24% PCP. However, it should be noted that this diet was associated with the worst feed conversion, a fact that may compromise profitability. The following cost reductions were observed in these simulations: 8.01% in the total cost per arroba produced ($/arroba) for diets with 6% PCP, and 5.52% in daily cost ($/animal/day) and 6.02% in the cost per ton of DM ($/ton) for diets with 24% PCP.

DISCUSSION

The silages harvested at 90 days that contained 24% PCP and all silages of the second harvest (120 days) met the DM content (28% to 40%) recommended in the literature (Villa *et al.*, 2020; Amorim *et al.*, 2020; Macêdo *et al.*, 2021). A low DM content of silages can cause fermentation problems and losses by gases and effluents, with consequent leaching of nutrients, which reduces the nutritional value and increases the fibrous fraction of the ensiled material (Borreani *et al.*, 2018; Alves *et al.*, 2022). On the other hand, a high DM content (> 40%) of the forage mass compromises compaction, resulting in a high rate of residual oxygen and providing an environment for undesirable fermentations (Macêdo *et al.*, 2021).

The CP content of silages from the first (90 days) and second cut (120 days) containing 0% and 3% PCP was above the minimum recommended level (7%) for maintaining microbial growth (Hoffmann *et al.*, 2014), suggesting that the difference in regrowth interval and PCP inclusion in silage may be an alternative for ruminant feeding. Likewise, the regrowth interval and PCP inclusion levels increased EE content, possibly affecting the energy density of the silage. The PCP used in the present study had a higher TDN content and lower NDF and ADF concentrations than fresh Capiaçu (Table 1). These characteristics of the by-product promote improvements in the silage due to the increase in the content of non-fibrous carbohydrates (Ülger *et al.*, 2020).

NDF and ADF are components of the cell wall of the plant. The increase observed in these fractions

Table 2. Chemical composition, pH, effluent production, *in vitro* dry matter digestibility, N-NH_3, and dry matter recovery of elephant grass cv. BRS Capiaçu (*Pennisetum purpureum* Schum.) ensiled at different harvesting intervals (90 or 120 days) with pelleted citrus pulp (0%, 3%, 6%, 12%, or 24%)

Variables*	90 days					120 days					SEM*	p-value				
	0%	3%	6%	12%	24%	0%	3%	6%	12%	24%		TR	DAY	TR*DAY	L	Q
DM, %	22.360^{e}	21.750^{e}	23.750^{e}	27.148^{d}	34.000^{c}	28.155^{d}	29.787^{cd}	31.495^{c}	35.920^{b}	40.335^{a}	0.579	<.0001	<.0001	0.028	<.0001	0.001
MM, %	6.025^{cd}	6.147^{bcd}	6.495^{bc}	5.937^{cd}	6.452^{bc}	5.835^{d}	6.150^{bcd}	6.302^{bc}	6.713^{ba}	7.037^{a}	0.225	0.004	0.039	0.003	<.0001	0.924
CP, %	10.142^{a}	9.625^{b}	9.403^{b}	8.385^{c}	7.457^{d}	7.970^{d}	7.552^{d}	6.840^{de}	6.312^{e}	5.585^{f}	0.204	0.014	0.021	<.0001	0.001	0.665
EE, %	2.927^{cbd}	2.955^{cbd}	2.975^{cbd}	3.042^{cb}	3.207^{a}	2.903^{d}	2.93^{cd}	2.970^{cbd}	3.020^{cbd}	3.047^{b}	0.041	0.036	0.001	0.003	0.003	0.285
NDF, %	65.762	61.387	57.135	53.737	47.687	68.300	64.807	59.185	50.605	50.035	1.260	<.0001	0.024	0.094	<.0001	0.511
ADF, %	41.455	40.575	38.070	35.135	30.812	43.332	42.385	38.332	34.570	32.877	1.015	<.0001	0.009	0.087	<.0001	0.379
Cellulose, %	36.313^{c}	35.187^{cd}	33.072^{de}	30.072^{fe}	27.155^{g}	37.825^{b}	38.635^{a}	39.003^{a}	26.887^{g}	28.840^{fg}	0.649	<.0001	0.001	<.0001	<.0001	0.001
Hemicellulose, %	23.557	20.812	19.065	18.602	16.875	23.920	22.173	18.792	18.532	17.157	0.891	<.0001	0.759	0.877	<.0001	0.148
Lignin, %	4.042	4.297	3.640	3.235	2.637	5.507	3.752	3.177	6.365	4.037	1.135	0.012	0.088	0.109	0.008	0.535
TDN, %	67.503^{e}	67.913^{cd}	69.388^{bcd}	71.339^{ba}	73.205^{a}	65.223^{e}	67.873^{cd}	69.736^{bcd}	67.735^{ecd}	70.125^{bc}	1.545	<.0001	0.011	0.113	<.0001	0.863
IVDMD	60.600^{de}	61.575^{dc}	64.950^{c}	67.500^{b}	70.325^{a}	53.975^{h}	55.200^{g}	56.850^{f}	58.500^{fe}	57.525^{f}	0.350	<.0001	<.0001	0.021	<.0001	0.270
pH	3.325	3.350	3.425	3.722	3.870	3.840	3.880	3.895	3.943	4.020	0.031	<.0001	<.0001	0.874	<.0001	0.042
N-NH_3	10.487^{e}	6.737^{d}	4.425^{c}	2.730^{ab}	2.307^{a}	12.330^{e}	9.465^{d}	5.647^{d}	3.685^{c}	3.300^{bc}	0.277	<.0001	<.0001	0.205	<.0001	0.193
Effluent, kg/t	78.867^{g}	78.325^{g}	56.935^{f}	29.887^{e}	10.620^{ba}	20.642^{d}	19.322^{cd}	18.272^{c}	9.617^{b}	7.832^{a}	2.451	<.0001	<.0001	0.059	<.0001	<.0001
DM recovery, %	92.275^{f}	93.400^{e}	94.175^{d}	97.525^{b}	99.175^{a}	92.475^{f}	93.525e	94.125^{d}	95.36^{c}	97.225^{b}	0.318	<.0001	0.014	<.0001	<.0001	0.409

Note: $^{a\text{-}g}$= Means in the same row followed by different letters differ significantly ($p<0.05$). * DM= dry matter; MM= mineral matter; CP= crude protein; EE= ether extract; NDF= neutral detergent fiber; ADF= acid detergent fiber; TDN= total digestible nutrients; IVDMD= *in vitro* dry matter digestibility; SEM= standard error of the mean.

Table 3. Predicted performance of Nellore bulls fed feedlot finishing diets containing elephant grass cv. BRS Capiaçu (*Pennisetum purpureum* Schum.) ensiled at different harvesting intervals (90 or 120 days) with pelleted citrus pulp (0%, 3%, 6%, 12%, or 24%)

Variables*	90 days					120 days				
	0%	3%	6%	12%	24%	0%	3%	6%	12%	24%
Average daily gain (ADG), kg/d	1.74	1.74	1.74	1.73	1.71	1.73	1.74	1.74	1.71	1.66
Fasted ADG, kg/d	1.66	1.65	1.65	1.65	1.62	1.64	1.65	1.65	1.62	1.57
Dry matter intake (DMI), kg/d	9.93	9.94	9.94	9.95	9.99	9.96	9.94	9.94	9.99	10.08
DMI, % final body weight	2.26	2.26	2.26	2.26	2.27	2.27	2.26	2.26	2.27	2.29
Feed conversion (kg dry matter/ kg live weight gain)	6.0	6.0	6.0	6.0	6.2	6.1	6.0	6.0	6.2	6.4

Note: *Variables predicted using software to formulate and evaluate beef cattle diets (RLM Corte v.3.3, ESALQ Tropicalized NRC system - https://en.rlm.app.br/home).
Feedlot finishing diets for Nellore cattle (100 uncastrated males with an initial fasted body weight of 373 kg and final fasted body weight of 506 kg; mean feedlot period of 80 days).

Table 4. Production costs[1] (total and feed) of Nellore bulls fed feedlot finishing diets containing elephant grass cv. BRS Capiaçu (*Pennisetum purpureum* Schum.) ensiled at different harvesting intervals (90 or 120 days) with pelleted citrus pulp (PCP; 0%, 3%, 6%, 12%, or 24%)

Treatments	Cost per ingredient ($/animal/day)							Cost of gain ($/ arroba)		Daily cost ($/ animal/day)		Cost per animal ($/ animal)		Feedlot cost ($)		Cost (original material, $/ton)	Cost (dry matter, $/ ton)
	Silage	PCP	Soybean hulls	Corn grain	Soybean meal	Urea	Mineral mix	Total	Feed	Total	Feed	Total	Feed	Total	Feed		
90 days																	
0%	3.41	-	1.44	5.93	2.73	0.21	0.30	231.56	194.77	16.88	14.03	1,334.40	1,122.40	133,440.00	112,240.00	765.61	1,384.24
3%	3.45	0.37	1.44	5.58	2.73	0.22	0.30	233.28	196.36	16.75	14.10	1,339.70	1,127.70	133,970.40	112,770.40	764.44	1,389.26
6%	3.16	0.74	1.44	5.22	2.73	0.22	0.30	229.26	192.36	16.47	13.82	1,317.23	1,105.23	131,723.20	110,523.20	783.16	1,361.75
12%	2.77	1.47	1.44	4.52	2.74	0.22	0.30	224.85	187.85	16.10	13.45	1,304.46	1,089.81	130,445.64	108,980.64	812.36	1,325.04
24%	2.22	2.96	1.45	3.10	2.75	0.22	0.31	221.60	184.08	15.65	13.00	1,283.22	1,065.92	128,321.80	106,591.80	862.36	1,274.72
120 days																	
0%	2.67	-	1.44	5.95	2.74	0.22	0.30	223.58	186.48	15.97	13.32	1,293.61	1,078.96	129,361.05	107,896.05	814.43	1,310.75
3%	2.52	0.37	1.44	5.58	2.73	0.22	0.30	220.34	183.42	15.82	13.17	1,265.22	1,053.22	126,521.60	105,321.60	826.82	1,297.43
6%	2.38	0.74	1.44	5.22	2.73	0.22	0.30	218.09	181.24	15.68	13.03	1,254.65	1,042.65	125,464.80	104,264.80	838.99	1,285.17
12%	2.10	1.48	1.45	4.53	2.75	0.22	0.31	219.12	181.61	15.48	12.83	1,269.49	1,052.19	126,949.12	105,219.12	867.19	1,258.49
24%	1.88	2.97	1.45	3.11	2.76	0.22	0.31	219.71	181.76	15.34	12.69	1,273.32	1,053.37	127,331.96	105,336.96	895.16	1,240.56

Note: [1]RLM Corte v.3.3, ESALQ Tropicalized NRC system - https://en.rlm.app.br/home. Feedlot finishing diets for Nellore bulls (100 animals with an initial fasted body weight of 373 kg and final fasted body weight of 506 kg).

was probably due to the greater thickness of the plant cell wall and the reduction in cellular lumen and content with increasing regrowth interval of Capiaçu, which leads to an increase in the content of these fractions (Monção *et al.,* 2020). Although these cell wall components are essential for the structural integrity of the plant, particularly the stem that supports the leaf blade for optimal sunlight exposure (Li *et al.,* 2021), their increase can have a negative impact on fiber digestibility. Higher NDF and ADF levels slow the passage of digesta through the rumen, reducing DMI and animal performance (Ball *et al.,* 2015). The reduction in NDF and ADF content with increasing PCP inclusion might be related to the presence of lower concentrations of these fractions in PCP when compared to the levels found in Capiaçu (Table 1).

A possible explanation for the linear decrease in hemicellulose and lignin with the inclusion of PCP during ensiling is that PCP serves as a diluting agent for these compounds in the silage (Gomes *et al.,* 2017). Regarding regrowth interval, we expected an increase in lignin content with increasing regrowth interval of Capiaçu as a result of DM accumulation and enhanced lignification of the cell wall (Monção *et al.,* 2020); however, our results did not show such effect despite the observation of a trend ($p<0.10$), which may be related to limitations of the method used for lignin quantification. Ensiling of Capiaçu has been recommended so that the harvest can occur between 90 and 110 days of regrowth, not exceeding 120 days, to prevent the loss of nutritional value (Monção *et al.*, 2019; Alves *et al.*, 2022). Estimation of the TDN content of the silages in the present study revealed no interaction between cutting interval and PCP level (Table 2).

The linear increase in IVDMD with the inclusion of PCP in grass silage can be attributed to the reduction in the fibrous fraction and the presence of more digestible substrates in PCP. In contrast, other studies (Gomes *et al.,* 2017; Monção *et al.,* 2020) found that increasing the regrowth intervals of Capiaçu tends to increase this cell wall fraction.

Only silages made from grass harvested at 90 days containing 24% PCP and all silages from the second cut (120 days of regrowth) had pH values within the optimal range of 3.8 to 4.2, as recommended by Tolentino *et al*. (2016), indicating effective fermentation. This result is attributed to the higher DM content and the abundance of fermentable substrates. Within this context, $N\text{-}NH_3$ is an important parameter for determining silage quality because it represents the extent of protein degradation during the fermentation process; this degradation produces nitrogenous compounds that reduce the DM content and conservation quality of the forage (Jobim *et al.*, 2007). The concentrations of $N\text{-}NH_3$ decreased in response to the addition of PCP and increasing regrowth interval. This observation can be explained by an increase in DM content as well as higher concentrations of soluble carbohydrates; both are used by lactic acid bacteria during the fermentation process. According to the literature, this microbiological activity reduces the degradation of proteins by plant enzymes, inhibiting the growth of undesirable microorganisms such as *Clostridium* spp. (Okoye *et al.,* 2023; Jiang *et al.,* 2024). Other factors can also influence the fermentation characteristics of silage, such as particle size, additives, silo hygiene and type, compaction, and silo sealing (Oliveira *et al.,* 2017; Lustosa *et al.,* 2022; Dentinho *et al.,* 2023; Costa *et al.,* 2023). However, in the present study, the lack of inclusion of PCP in Capiaçu silage harvested after 90 days of regrowth worsened the fermentation profile. In contrast, the addition of 24% PCP was found to be a viable strategy for promoting adequate fermentation, consequently providing better-quality silages.

The reduction in effluent losses can be attributed to the increase in DM content with increasing grass regrowth interval and inclusion of PCP. This finding can be explained by the high hygroscopic power of citrus pulp, whose weight can increase by up to 145% when in contact with moist grass, thus preserving the nutrients that would be leached as effluents and/or used for secondary fermentation (Grizotto *et al.,* 2020). This reduction is an advantage since a high moisture content of grass silage favors effluent losses and compromises the fermentation of the ensiled material (Figueiredo *et al.,* 2022). Likewise, the influence of PCP inclusion and regrowth interval of Capiaçu on DM recovery from silages highlights the effectiveness of PCP addition and increasing the regrowth interval of Capiaçu. The highest DM recovery was observed in silages prepared with 24% PCP and Capiaçu harvested at 90 days, indicating lower losses throughout the fermentation process. However, all silages exhibited DM recovery higher than 92%, with rates considered excellent (Alves *et al.,* 2022). Therefore, the changes observed in the fermentation characteristics and nutritional value of the silages confirm the hypothesis that PCP and Capiaçu regrowth interval affect the quality of grass silage.

Simulations of the use of Capiaçu in feedlot finishing diets and prediction of productive performance of Nellore bulls showed that higher inclusion levels of PCP led to a reduction in the predicted gain of approximately 2% to 3%, most notably for Capiaçu ensiled at 120 days with 24% PCP. This finding is consistent with the study by Steen and Kilpatrick (2000), which found a decrease in the DMI of Simmental x Holstein steers as the percentage of concentrate increased in diets containing grass silage. On the other hand, Huuskonen *et al*. (2020) observed an increase in the DMI of Hereford and Charolais bulls with increasing the concentrate levels in diets containing grass silage. This suggests that the inclusion of supplements in grass silage diets may elicit different responses, as the response is linked to silage quality.

The evaluation of animal performance and production costs associated with the experimental diets demonstrated that using Capiaçu ensiled at 120 days of regrowth and including 6% or 12% PCP can promote satisfactory performance and reduce the production costs of feedlot-finished Nellore bulls. The variations in productive performance and diet costs confirm the hypothesis that the inclusion of PCP and the regrowth interval of Capiaçu influence animal performance and the production costs of feedlot finishing diets for Nellore bulls. A lower cost per arroba indicates more efficient production, whereas a higher cost per arroba suggests higher expenses, which may affect profitability.

CONCLUSION

Increasing the regrowth interval of Capiaçu increases DM content and pH values, with a reduction in the production of silage effluents. The addition of up to 24% PCP during the ensiling of Capiaçu improves the fermentation profile and nutritional value of the silage, increasing DM, TDN, and pH, reducing the fibrous fraction (less NDF and ADF), and improving digestibility parameters. Based on the analysis of simulated animal performance and production costs of the experimental diets, the use of Capiaçu ensiled at 120 days of regrowth with 6% or 12% PCP may be a more profitable alternative for the feedlot finishing of Nellore bulls. These findings suggest that the incorporation of strategic regrowth intervals and PCP inclusion into feedlot management practices may be a potential alternative to enhance efficiency and profitability.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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