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PASTURE AND FORAGE UTILIZATION

Elephant grass silage with addition of regional by-products

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ABSTRACT. This study examines the effect of adding coffee husks (CH), cacao by-product (CBP) and passion fruit by-product (PBP) (fresh-matter basis) in the silage of elephant grass cv. Napier on nutritional characteristics. The experiment was laid out in a completely randomized design with a 3 × 4 factorial arrangement represented by three additives (CH, CBP or PBP) and four inclusion levels (0, 12, 24 or 36%). Four replicates were used per treatment. The material was ensiled in experimental mini-silos that were opened 60 days later for chemical analysis of the produced silages. The dry matter content of the silages with CH and PBP included at levels greater than 25% was adequate. The silage with PBP inclusion showed the highest crude protein levels and the best results for *in vitro* dry matter digestibility. In the silage containing CH, the neutral detergent fiber content decreased linearly with increasing inclusion of the husks. The silage with CBP showed the lowest dry matter and crude protein levels and the highest pH. In conclusion, the inclusion of up to 36% PBP in the ensiling of elephant grass is recommended, as the resulting material has potential for use in ruminant feeding at times of forage scarcity.

Keywords: coffee husks; passion fruit peel; silage fermentation; *Theobroma cacao* by-products.

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Introduction

Forage production in Brazil has a direct impact on the nutritional status of herds, since the growth and quality of these plants are compromised in dry periods. The making of silage from the preservation of forages produced during the rainy period is an alternative to overcome the deficit encountered at times of food scarcity, periods of drought and summer. Elephant grass is one of the main tropical grasses used for this purpose, due to its high dry matter yield per cultivated area, from several harvests throughout the year; soluble carbohydrate content, which is higher than that of other grasses; perenniality; lower cost per kilogram of dry matter; low risks of loss; and greater flexibility at harvest (Pereira, Ribeiro & Oliveira, 2013).

However, the high moisture content of elephant grass at the stage when its nutritional value is considered ideal constitutes an obstacle to its use in the form of silage, as it leads to unsatisfactory fermentations that culminate in high quantitative and qualitative losses. A recommended practice to offset this effect is adding products with a high dry matter content or eliminating excess moisture from the forage through appropriate treatments such as wilting (Carvalho et al., 2008; Teixeira, Veloso, Pires, Silva & Nascimento, 2008; Santos et al., 2010). It is important to emphasize that the use of elephant grass in the form of silage should be prioritized at the time of best nutritional value and greatest growth (Gusmão, Danés, Casagrande, & Bernardes, 2018).

Regional by-products such as those from agriculture or agribusiness have the potential to be used as ingredients in animal feed, where they can be supplied fresh or as additives in silage (Ferreira et al., 2019).

Coffee husks have hygroscopic properties and can benefit the fermentation process by increasing the dry matter percentage of grass silages (Bernardino et al., 2009; Pires et al., 2009). The cacao by-product consists of its shell, which represents, on average, 80% of the fruit weight. This by-product is highly fibrous and, according to Valadares Filho, Magalhães, Rocha Júnior and Capelle (2006), its crude protein, neutral detergent fiber, acid detergent fiber, lignin and gross energy contents are 7.47, 57.98, 50.70, and 20.60% and 4.28 Mcal kg^{-1}, respectively. The passion fruit by-product originates in agribusiness and has potential for use in ruminant feeding thanks to its pectin, mineral, vitamin and considerable protein content, which enables it to improve the nutritional value of the produced silage (Cruz et al., 2011; Alves et al., 2015; Bonfá et al., 2015). It is supplied by some industries for the production of compost.

In several regions of Brazil, these by-products are available in considerable quantities, but information is still lacking on their nutritional quality, levels of inclusion in the animal diet, best form of supply, among other factors. Considering that the feed cost influences the profitability of most production systems, as it accounts for over 60% of total production costs, especially for small family farmers, it is particularly important to use feed alternatives by taking advantage of local potential, at lower costs.

Therefore, this study was conducted to examine the inclusion of coffee husks, cacao by-product and passion fruit by-product on the chemical characteristics of silages of elephant grass cv. Napier.

Material and methods

The experiment was carried out at the Experimental Farm of the Espirito Santo Institute of Research, Technical Assistance and Rural Extension - Incaper, located in the municipality of Linhares, state of Espírito Santo (ES), Brazil, in February 2016. According to the Köppen classification, the climate of the municipality is an Af (humid tropical) type, with dry winters and rainy summers. Precipitation in the period was less than 800 mm. The soils in the area are classified as dystric alluvial.

The elephant grass (*Pennisetum purpureum* Schum) used for silage making originated from a pre-established crop, from which it was harvested at 90 days, at 15 cm from the ground, with an average height of 1.50 m. This material was chopped in a stationary chopper to 2-cm particles and wilted for 12h in the shade. The experimental treatments consisted of four levels of inclusion (0, 12, 24 or 36%; fresh matter basis) of coffee husks (CH), cacao by-product (CBP) or passion fruit by-product (PBP) in the ensiling of elephant grass cv. Napier. Coffee husks and CBP were obtained from farmers in the region of Linhares/ES, and from the Executive Committee of the Cacao Plantation Plan (CEPLAC - ES). The CBP consisted of shells that were chopped and dried in the sun for 12h. The PBP used was also obtained in the region of Linhares/ES, and was composed of peels and seeds, which were subjected to the same drying and chopping process.

Table 1 shows the chemical composition of the ingredients used in the making of the silages.

Table 1. Chemical composition (g kg^{-1}) of elephant grass (EG) and coffee (CH), cacao (CBP) and passion fruit (PBP) by-products wilted before ensiling.

Parameter (%DM)	EG	CH	CBP	PBP
Dry matter	268.00	903.80	289.00	310.00
Mineral matter	107.90	82.50	76.70	97.10
Crude protein	50.00	111.80	47.60	135.50
Neutral detergent fiber	638.50	482.70	527.10	603.60
Acid detergent fiber	460.40	384.20	428.60	492.70
Lignin	82.00	175.20	179.80	95.00
IVDMD	500.00	415.50	330.00	534.80

IVDMD = *in vitro* dry matter digestibility.

The material was chopped in a stationary chopper, weighed and ensiled in its respective proportions in experimental mini silos made from PVC tubes (10 cm wide × 40 cm high), at an average compaction density of 600 kg m^3. Then, the mini silos were closed with a lid equipped with Bunsen valves and sealed with adhesive tape. One kilogram of sand was placed at the bottom of each mini silo, which was separated from the forage by a thin plastic and cotton fabric, to capture the effluent from the ensiled forage. After 60 days of ensiling, the mini-silos were opened and sensory and sanitary assessment of the silages was carried out according to the methodology of Meyer, Bronsch, and Leibetseder (1989). Subsequently, the first 10 cm were discarded, the material was homogenized and samples were collected to determine the pH values from the extraction of the silage juice. Samples were pre-dried in a forced-air oven at 55°C for 72h (Silva & Queiroz, 2006), ground in a stationary mill with a 1-mm sieve and packed in plastic jars for later chemical analysis following the Association of Official Analytical Chemists [AOAC] (1995). The cell wall components were determined sequentially, using the method proposed by Van Soest, Robertson and Lewis (1991). *In vitro* dry matter digestibility (IVDMD) was measured according to the first phase of the method described by Tilley and Terry (1963), at the P2S2 laboratory (Florestal/MG).

The experiment was laid out in a completely randomized design with a 3 × 4 factorial arrangement represented by three additives (CH, CBP or PBP) and four inclusion levels (0, 12, 24 or 36%). Four replicates were used per treatment. Tukey's test was applied at the 5% probability level for mean comparison. To evaluate the results, the Assistat statistical program of SAS software was used.

Results and discussion

The DM content of the silages of elephant grass cv. Napier enriched with CH and PBP increased linearly. In these silages, the addition of 24% of these by-products was sufficient to achieve the minimum DM value of 30% recommended by McDonald, Henderson and Heron (1981) to produce high-quality silage (Table 2). According to these authors, this level would adequately favor the fermentation process, providing stability and reduced undesirable bacterial activity (*Clostridium*) and thereby reducing nutrient losses via effluents and gases.

The high DM content of CH (Table 1) and its hygroscopic property may have contributed to this result. The passion fruit by-product, on the other hand, was subjected to the wilting process, which induced a reduction in the moisture content of the produced silages. Both the grass and these two by-products were subjected to the wilting process. Wilting increases the DM content and consequently improves the environment for lactic acid-producing bacteria, favoring fermentation and ensuring silage quality. The same effect is obtained with feedstuffs with a high DM content and absorbent capacity.

In the silage with CBP, the DM content was below 30% at all inclusion levels assessed. Each percentage unit of CBP added to the unenriched elephant grass silage resulted in a 0.13% decrease in its DM content.

The high moisture of by-products from crops or juice industries tends to limit their use on farms located far from the site where they will be used for silage-making. This is due to their difficult transport and storage as well as the possibility of fungal proliferation. Lira Junior et al. (2018) reported that fresh PBP caused a decrease in the DM content of the produced grass silages. Likewise, Bonfá et al. (2015) reported a decrease in DM content after adding up to 50% of fresh passion fruit peel in the ensiling of elephant grass. These authors also pointed out that the use of dried passion fruit peel resulted increased the DM content of the silages, which the present findings corroborate.

Table 2. Dry matter (DM), crude protein (CP) and mineral matter (MM) contents of silages of elephant grass cv. Napier with cacao (CBP), coffee (CH) and passion fruit (PBP) by-products.

	CBP	CH	PBP
DM	$Y = -0.13X + 24.19$ $R^2 = 0.94$	$Y = 0.46X + 23.40$ $R^2 = 0.96$	$Y = 0.38X + 23.64$ $R^2 = 0.94$
MM	Y = NS	$Y = 0.007X^2 - 0.34X + 10.93$ $R^2 = 0.99$	$Y = -0.004X^2 + 0.07X + 11.10$ $R^2 = 0.82$
CP	$Y = -0.0018X^2 + 0.09X + 3.93$ $R^2 = 0.99$	$Y = 0.13X + 4.35$ $R^2 = 0.95$	$Y = -0.012X^2 + 0.65X + 4.37$ $R^2 = 0.93$

NS = not significant.

The mineral matter (MM) content of the silages with the addition of CH and PBP showed a quadratic behavior according to their inclusion level. In the silage with CH, the maximum MM content was 6.81%, achieved at 23.31% inclusion of this by-product. For PBP, the inclusion of 9.49% of the by-product provided the maximum percentage of 11.44% of minerals in the produced silages (Table 2). Mineral matter levels were highest in the silage with PBP because of the additive effect, since, like elephant grass, this by-product also has a high mineral content, as shown in other studies (Cruz et al., 2011; Lira Junior et al., 2018). In these silages, the lowest MM value was reached at 29.91% inclusion of the by-product. When the silage was enriched with CH, the highest MM value was achieved at 9.49% inclusion of the product. Lastly, in the silages with CBP, the MM content did not differ between the inclusion levels tested.

The CP content of the silages containing PBP and CBP responded quadratically to the by-product inclusion levels (Table 2). To achieve the highest CP percentage in the silages with PBP (12.89%), the by-product inclusion level was 26.22%. For CBP, the inclusion of 25.58% of this by-product provided a maximum CP content of 5.10% in the produced silages, which is a lower value than the minimum of 6 to 8% (DM basis) necessary to meet the CP requirements of the ruminal microbiota (Mertens 1994). For CH, the CP levels increased linearly, by 0.13%, with each unit of CH added to the silage. In this silage, the maximum CP (9.03%) was achieved at 36% inclusion of this by-product.

The CP contents were thus higher in the silage with the addition of PBP as compared with the other by-products, as also evidenced by other authors (Cruz et al., 2011; Alves et al., 2015; Lira Junior et al., 2018). Of all three evaluated by-products, CBP provided the lowest CP levels in the silage. The CP composition of PBP and CH was responsible for the additive effect on the silages produced with these by-products, when compared with elephant grass (50.00, 111.80 and 135.50 g kg^{-1}, respectively).

Cruz et al. (2011) found 4.80 to 11.90% CP, 77.50 to 58.90% NDF and 45.50 to 48.00% ADF resulting from the addition of increasing levels of dried passion fruit peel (0, 10, 20 and 30%) in elephant grass silage. In the present study, the CP, NDF and ADF levels ranged from 4.36 to 12.83%, 62.19 to 41.89% and 45.41 to 33.22%, respectively, at 24% inclusion of PBP in the silage. Mertens (1994) reported that 6 to 8% CP (DM basis) are necessary, together with the energy available in the rumen environment, for microbial protein of high biological value to be produced for ruminant animals. Accordingly, the silages produced with PBP and CH would be able to meet the minimum CP requirement. The silage containing increasing levels of CBP, in turn, would not able to provide the minimum protein content required by the ruminal microbiota, given the reduced content of this nutrient in this feedstuff and possible unavailability of part of this protein.

The silage with PBP had the lowest NDF content, followed by the silage with CH. In the former, the NDF content showed a quadratic response to the inclusion levels. In the silage with CBP, the inclusion of this by-product did not influence the NDF contents of the produced material. The lowest percentage of this nutrient was 41.35%, which was achieved at the PBP inclusion level of 28.59% (Table 3). In the silage produced with CH, the NDF content decreased by 0.44% per unit of CH added, and the maximum level of inclusion of this by-product (36%) resulted in the lowest percentage of NDF (47.48%) ($p < 0.05$).

Table 3. Neutral detergent fiber content (NDF), acid detergent fiber content (ADF), *in vitro* dry matter digestibility (IVDMD), lignin content and pH of silages of elephant grass cv. Napier with cacao (CBP), coffee (CH) and passion fruit (PBP) by-products.

	CBP	CH	PBP
NDF	Y = NS	$Y = -0.43X^2 + 63.16$ $R^2 = 0.74$	$Y = 0.025X^2 - 1.46X + 62.19$ $R^2 = 0.83$
ADF	Y = NS	Y = NS	$Y = 0.026X^2 - 1.13X + 45.41$ $R^2 = 0.91$
IVDMD	$Y = 0.014X^2 - 0.56X + 52.49$ $R^2 = 0.94$	$Y = 0.014X^2 - 0.68X + 52.94$ $R^2 = 0.81$	$Y = -0.048X^2 + 2.08X + 51.8$ $R^2 = 0.98$
Lignin	$Y = 0.007X^2 - 0.15X + 8.47$ $R^2 = 0.88$	$Y = -0.013X^2 + 0.49X + 8.28$ $R^2 = 0.99$	$Y = 0.009X^2 - 0.27X + 7.87$ $R^2 = 0.84$
pH	$Y = 0.03X + 3.94$ $R^2 = 0.92$	$Y = 0.02X + 4.09$ $R^2 = 0.98$	$Y = -0.001X^2 + 0.06X + 4.14$ $R^2 = 0.71$

NS = not significant.

The NDF content of the CH silage decreased linearly with its increasing inclusion levels. This was likely an effect of the addition of the husks, since the concentration of this chemical component in the ingredient was 15% lower than that of elephant grass at the time of ensiling. Carvalho et al. (2007) also described similar results, with a reduction in the NDF contents with increasing addition of CH to elephant grass silage. Faria et al. (2007) reported a linear decrease in NDF and a linear increase in ADF in response to increasing levels of CH added to elephant grass silage.

From the nutritional point of view, fiber is the slow and incompletely digestible fraction of feed that has a filling effect on the gastrointestinal tract of animals (Mertens, 1997). Neutral detergent fiber values above 60% correlate negatively with voluntary DM intake by animals and with the net energy content. Tylutki et al. (2008) suggested that the NDF intake ability of ruminants from forage is 1% of their live weight. Nonetheless, NDF is of great importance due to the balance provided in the rumen environment through rumination.

In the silage with PBP, the ADF content responded quadratically to the increasing by-product inclusion levels. To obtain the minimum ADF value of 33.11% in the silage, 21.88% inclusion of PBP was necessary (Table 3). In the silages with the other by-products, the ADF content was not changed by their inclusion. The passion fruit by-product had a higher concentration of this compound than elephant grass before ensiling (49.27 vs. 46.04%, respectively), which is due to the amount of seeds present in it. The ADF content was not influenced by the fermentation inside the silo.

According to Tilley and Terry (1963), ADF values above 40% negatively influence the digestibility of DM. In the present experiment, the silage produced with PBP showed NDF and ADF contents that ranged from 42.75 to 48.37% and 35.61 to 38.23% (DM basis), on average, respectively. These values may favor the consumption of this roughage, as they are within the desirable range for animal feed. Similar results were found by Cruz et al. (2010), who evaluated elephant grass silage with the addition of dried passion fruit peel (10, 20 and 30%) and found increases in the DM and CP levels and a reduction in the concentrations of fibrous compounds.

The IVDMD of the silages responded quadratically to the increasing levels of PBP, CH and CBP (Table 3). In the silage containing PBP, the maximum digestibility value (75.74%) was achieved at 21.96% inclusion of this by-product. The CH inclusion level of 25.16% provided a silage IVDMD value of 44.33%. In the case of CBP, 20.75% of this by-product were necessary to obtain the highest IVDMD value, of 46.67%. Along with the nutritional values of DM, CP and NDF found in the silages containing the three evaluated by-products, these results suggest that minimum inclusion levels of 24 to 36% for the PBP and CH by-products in the ensiling of elephant grass cv. Napier produce silages with satisfactory nutritional chemical quality for ruminant feeding. For CBP, the values found for these nutrients demonstrate the nutritional limitation of this by-product when ensiled with elephant grass cv. Napier.

The silage with PBP showed the highest IVDMD values among the by-products, at all inclusion levels. These highly desirable IVDMD values found in this treatment are likely due to the amount of soluble carbohydrates present in this ingredient, which results in better utilization of the produced silage. *In vitro* dry matter digestibility is related to the residence time of forage in the rumen. As such, it directly influences voluntary intake, due to the physical fil of the rumen. In the silages with CH and CBP, the IVDMD values were lower due to the high ADF values and also to the lignin fraction present in these feedstuffs.

Carvalho et al. (2007) described that IVDMD was significantly affected, decreasing linearly as CH was added to elephant grass silage, due to the high lignin content of CH, which is 187.5% higher than that of elephant grass. Carvalho Junior et al. (2010) concluded that nutrient digestibility decreased with the inclusion of CH. In the present study, the CH inclusion level for the best IVDMD was 25.16%.

Lignin showed a quadratic behavior with all evaluated by-products. For CBP and PBP, the minimum lignin contents of 7.64 and 5.93% were achieved at the inclusion levels of 10.91 and 14 % of these by-products, respectively. For CH, the maximum lignin level in the silage with this by-product (13.03%) was attained with 19.25% inclusion of the husks (Table 3).

The lignin contents of CH and CBP before ensiling were similar and much higher than that of elephant grass (Table 1). As previously demonstrated, the presence of high levels of lignin negatively influenced the digestibility of the silages produced with these by-products. These results reveal the importance of knowing the nutritional quality of alternative feedstuffs available locally, since, in a condition of feed scarcity, these are used as an option for feeding small herds by many producers who develop agricultural activity in integration with livestock or even for those who have them available regionally. The pH of the silages produced with CH and CBP increased linearly with the inclusion of these by-products, and the increase in its inclusion level from 12 to 36% caused the pH to rise to values above the recommended ideal (4.2) (McDonald et al., 1981). In the silage with PBP, the pH responded quadratically, with a maximum value detected at 20% inclusion of the by-product (Table 3).

The pH change in the silages without and with the addition of by-products was from 3.94 to 5.00. The silages with 10% inclusion of CBP and CH showed pH values within the optimal range of 3.8 to 4.2 recommended by McDonald et al. (1981). In the silage with PBP, the pH values were higher than 4.2 at only 1% addition of the by-product. Sensory and sanitary analysis of the silages (Meyer et al., 1989) revealed adequate fermentation, as they did not have an unpleasant odor or sticky consistency and had few losses due to deterioration. In addition, their color was similar to that of the original material and they had a characteristic acidic odor, which suggests adequate amounts of desirable acids for good fermentation. Moreover, Jobim, Nussio, Reis and Schmidt (2007) reported that silages of wilted forages, such as those evaluated in the present study, usually have pH values above 4.2, due to the lower intensity of the fermentation process. According to these authors, there is an influence of increased osmotic pressure that leads to less acid production, indicating that these silages can reach aerobic stability values with higher pH values.

At present, there is an imperative search for foods that reach the consumer's table while preserving animal health and welfare. Particularly with respect to the silages, it is important to ensure their hygienic quality through production methodologies that minimize the proliferation of microorganisms, besides lessening the environmental impact on their production and reducing nitrogen losses in the soil and atmosphere. Therefore, when using high-moisture ingredients, the DM content should be increased through wilting or the addition of feedstuffs or by-products so silage of nutritional and sanitary quality can be produced.

The silages produced with the three by-products (PBP, CH and CBP) had a characteristic acidic odor and the typical smell of fruit in the original form, at all tested levels of inclusion, which suggests adequate amounts of desirable acids for good fermentation. They also showed a typical greenish-yellow or brownish color, due to the presence of CH, and were free of strange odors that suggest heating (roast smell) or yeast (intense burning smell), with few losses caused by deterioration. These results are related to the adequate ensiling process achieved with the recommended particle size, compaction and sealing, in addition to intrinsic characteristics of the evaluated by-products that contributed positively to the fermentation process in the silages.

In conclusion, greater information is necessary about the fermentation profile of the silages produced with the inclusion of the evaluated by-products at the tested levels. In this way, important results can be obtained that might confirm the action of the by-products also on this parameter.

Conclusion

The inclusion of up to 36% passion fruit by-product or 24% coffee husks in silage of elephant grass cv. Napier improves the nutritional value of the silage, constituting an option for periods of forage scarcity.

The cacao by-product has nutritional limitations when ensiled with elephant grass cv. Napier for animal feed purposes.

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