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Chemical composition and fermentative parameters of heart of palm waste produced from Alexander Palm ensiled with chemical additives

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ABSTRACT - The objective of this study was to evaluate the chemical composition and the fermentative parameters of heart of palm waste produced from Alexander Palm, ensiled with chemical additives. Treatments consisted of silage of the sheath with or without calcium oxide. In the silage without calcium oxide, we evaluated the control silage (without additive) and the silage enriched with 5.0 g kg^{-1} urea (urea). In the silage with calcium oxide, we evaluated the silage enriched with 5.0 g kg^{-1} calcium oxide (control) and the silage enriched with 5.0 g kg^{-1} urea and 5.0 g kg^{-1} calcium oxide (urea). Experimental silos were distributed in a completely randomized design in a 2 × 2 factorial arrangement (inclusion or lack of lime × inclusion or lack of urea), with four replicates. Crude protein concentration was greater in the silages that received urea, whereas in the case of neutral detergent fiber and acid detergent fiber, the lowest levels were found in the control silage. Control silage had the lowest pH (3.75) and the silages that received lime displayed the lowest lactic acid content. Effluent losses were greater in the control silage and in the silage with lime (56.1 kg t^{-1} and 58.4 kg t^{-1}, respectively). Silages prepared with waste from heart of palm production and enriched only with urea showed a better chemical composition and improved fermentation parameter estimates. We recommend the use of this waste only with additives that can improve the chemical characteristics of the forage. Without additives, unwanted fermentation processes may occur and compromise the quality of the silage.

Key Words: fermentation, forage conservation, organic acids, silage

Introduction

The world production of heart of palm has shifted from extractivist to cultivated, due mainly to the ban on its extraction in forests, resulting from demands of the consumer market for sustainable products and the reduction of the natural palm reserves. There are approximately 39 palm tree species in the Atlantic Forest (Fermino et al., 2014) and, of the cultivated species, production of heart of palm from Alexander palm (*Archontophoenix alexandrae*) has increased due to the high commercial value and favorable production characteristics of this species.

Processing of Alexander Palm for heart of palm production discards the leaves, sheath, and part of stems, which are considered waste without commercial value for the agroindustry (Bayão et al., 2014). The processing of one plant yields approximately 0.4 kg of commercial heart of palm and generates approximately 13 kg of waste, including leaves, stipe, and sheaths (Fermino et al., 2014), which correspond to 96.9% of waste per plant and also represent a source of contamination. The degradation of these organic wastes in nature depends on factors like the carbon:nitrogen ratio, physicochemical and biological characteristics, as well as the temperature and moisture of the soil (Figueiredo et al., 2012). These factors lengthen the time necessary for their full deposition, resulting in large occupied areas that could be used for production.

Waste from heart of palm production can be used for silages to feed ruminants; these animals possess specialized gastrointestinal characteristics that enable optimal use of roughages. Thus, coupled with the low or

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zero cost of acquiring this waste, farmers can optimize their profit margin in the production system and minimize environmental impact.

Data related to the ensiling of waste from heart of palm production refer to peach palm (*Bactris gasipaes*); however, only a few studies exist so far (Rodrigues Neto et al., 2001; Oliveira et al., 2010; Schmidt et al., 2010).

The use of alkaline additives in silage causes hydrolyzation of ester bonds between lignin, cell walls, cellulose, and hemicellulose, making them more available for rumen microorganisms (McDonald et al., 2011). Thus, the ensilage of high-fiber forages, together with lime and urea, has the potential to improve their nutritive value and optimize animal production.

Based on the knowledge that the sheath of the heart of palm from Alexander Palm is characterized by a high lignin and low protein content, this study aimed to evaluate the chemical composition and fermentation parameters of silage from heart of palm sheath with the addition of lime and urea.

Material and Methods

Waste, consisting of the leaf sheaths that surround the heart of palm, produced from Alexander Palm was provided by Real Palm® in Cajuri, Minas Gerais, Brazil.

Treatments consisted of silage of the sheath with or without calcium oxide. In the silage without calcium oxide, we evaluated the control silage (without additive) and the silage enriched with 5.0 g kg^{-1} urea (Urea). In the silage with calcium oxide, we evaluated the silage enriched with 5.0 g kg^{-1}calcium oxide (Control) and the silage enriched with 5.0 g kg^{-1} urea and 5.0 g kg^{-1} calcium oxide (Urea). All treatments were tested on a fresh matter basis. Before ensilage, we analyzed the chemical composition of sheath using subsamples (Table 1). Sheaths were cut with knife mills to particles of 2 to 3 cm and inserted in 16 experimental 15-L silos (buckets) equipped with a Bunsen valve to allow fermentation gases to escape. Two kilograms of washed sand were placed in the silos inside a fabric bag to estimate effluent losses. The roughage was compressed manually to obtain a fixed density of 600 kg/m^3. The silos were weighed and sealed with adhesive tape.

Table 1 - Chemical composition of sheath of heart of palm produced from Alexander Palm

Variable	Value
Dry matter (g kg^{-1} as fed)	194.1
Organic matter (OM)[1]	959.1
Crude protein (CP)[1]	25.4
Neutral detergente fiber (NDFap)[1]	672.1
Acid detergente fiber (ADFap)[1]	530.9
Non-fiber carbohydrates[1,3]	251.8
Lignin[1]	123.0
Ether extract (EE)[1]	9.8
Neutral detergent insoluble protein[2]	326.2
Acid detergent insoluble protein[2]	235.7

ap - corrected for ash and protein.
[1] g kg^{-1} of the dry matter.
[2] g kg^{-1} of crude protein.
[3] Non-fibrous carbohydrates = OM – (EE + NDFap + CP).

After 60 days, the silos were weighed again and opened and losses through dry matter, effluent, and gases were determined by gravimetric differences. Dry matter losses, effluent production, and gases were estimated according to the methodology described in Jobim et al. (2007).

Fermentation acids (lactate, acetate, propionate, and butyrate) and pH values were determined from the silage extract. The pH of the final solution was measured. One milliliter of 20% metaphosphoric acid was added to 2 mL of the filtrate and centrifuged at 3,000 rpm for 15 min. Subsequently, 5 mL of the supernatant was transferred to 10-mL test tubes containing 1 mL of formic acid (pa) and 1 mL of the solution was filtered through a Millex filter (0.45 μm) and stored at –10 °C until analysis. Fermentation acids were determined using high-performance liquid chromatography following the recommendations of Wilson (1971).

Samples of fresh sheath and sheath silages were dried in a forced-air oven at 65 °C for 72 h, ground in a knife mill (1 mm), kept in plastic containers, and evaluated for dry matter (DM), organic matter, crude protein, ether extract, and lignin contents, following the methodology described in Detmann et al. (2012). Neutral detergent fiber (NDF) contents were measured according to Mertens (2002), using heat-stable α-amylase and without the use of sodium sulfide. Corrections of NDF and acid detergent fiber (ADF) for ash and protein were carried out according to Mertens (2002) and Licitra et al. (1996), respectively.

Dry matter content was corrected for losses of volatile compounds according to Weißbach et al. (2008), using the following equation:

$$DMc = DMu + VR \times SCa + 0.08\ LA + 0.77 \times (PD) + 0.87 \times (BD) + 1.00\ (OA),$$

in which DMc = corrected DM; DMu = uncorrected DM; VR = volatilization rate (%) expressed by VR = (1.05 − 0.059pH); SCa = short-chain acids (C_2-C_6), which were acetic, butyric, and propionic acids; LA = lactic acid; PD = 1,2-propanodiol; BD = 2,3-butanodiol; and OA = total other alcohols (C_2-C_4). 1,2-propanodiol, 2,3-butanodiol, and total other alcohols were detected by gas chromatography using a flame ionization detector. Concentrations for all individual compounds were expressed as g per kilogram fresh matter. For 1,2-propanodiol, 2,3-butanodiol, and total other alcohols, the obtained values were either zero or not significant.

The experimental design was completely randomized in a 2 × 2 factorial design (inclusion or lack of lime × inclusion or lack of urea) with four replicates, totaling 16 mini-silos. The model of the experimental design followed the equation:

$$Y_{ij} = \mu + u_i + l_i + (ul)_{ij} + \varepsilon_{ij},$$

in which Y_{ij} = experimental response to treatment i at the j-th replicate; μ = overall constant; u_i = effect of treatment i with urea; l_i = effect of treatment i with lime; ul_{ij} = effect of urea × lime interaction i; and ε_{ij} = experimental error. Data were analyzed using the SAS statistical software (Statistical Analysis System, version 9.0) and the means were compared by Tukey's test at a significance level of 5%.

Results and Discussion

In the silage without calcium oxide, the control showed a lower DM content; in the silage with calcium oxide, the silage enriched with urea also had a lower DM content (P<0.05) (Table 2). According to Jobim et al. (2009), the DM content of an ensiled plant forage should be between 280.0 g kg^{-1} and 400.0 g kg^{-1} and values below this range may lead to the development of microorganisms, compromising forage quality and facilitating effluent losses, while values above 400.0 g kg^{-1} hamper proper compression. Thus, silages made of Alexander Palm sheath, irrespective of the treatments, have DM values that may compromise the silage quality.

Compared with fresh forage (Table 1) with the control silage without calcium oxide (Table 2), there were no alterations in the DM content during the ensiling process. On the other hand, the silages with urea or calcium oxide had a higher DM content, possibly related to effluent losses. Pre-wilting of the sheath prior to ensiling might be an alternative to increase silage DM content and prevent or minimize losses during ensilage.

Crude protein content was higher (P<0.05) in the silages enriched with urea (Table 2), which was expected, given the high protein equivalent of this additive. In the control silage, protein content was 30.3 g kg^{-1} without calcium oxide and 32.4 g kg^{-1} with calcium oxide; this difference was not significant at P>0.05. These protein concentrations are considered low and may compromise animal growth, since crude protein contents below 80.0 g kg^{-1} are considered deficient to the use of fibrous components by the rumen microbiota (Lazzarini et al., 2009).

The use of alkaline additives in silages is aimed at enhancing nutritional properties as these additives may cause expansion of the cellulose and hemicellulose fibers, improving neutral detergent fiber digestion (Klopfenstein, 1980). Thus, the higher content of NDF and ADF corrected for ash and protein of the enriched silages is related to the greater intake by microorganisms that ferment non-fibrous carbohydrates (NFC) with the use or additives and/or also to the solubilization by alkaline effect of NDF, especially in the treatments with lime, given that a dilution effect occurred because the estimates of the chemical components were in percentage.

Lignin contents were significantly lower in the treatment without the addition of calcium oxide (P<0.05) (Table 2). During fermentation processes, lignin content does not change (Van Soest, 1994) and a variation in the percentage values is related to NFC intake, characterizing

Table 2 - Chemical composition of silages of Alexander Palm waste with or without additives

Variable	Without calcium oxide		With calcium oxide		P-value			CV%
	Control	Urea	Control	Urea	Urea	Calcium oxide	Interaction	
DM (g kg^{-1} as fed)	192.2b	201.7a	197.5A	185.2B	0.138	0.001	0.001	0.89
OM[1]	951.1a	951.9a	926.1B	940.2A	0.001	0.001	0.001	0.22
CP[1]	30.3b	106.1a	32.4B	114.9A	0.001	0.763	0.756	2.39
NDFap[1]	699.1b	728.2a	741.8A	735.7A	0.126	0.002	0.020	1.79
ADFap[1]	513.6b	574.1a	576.2A	549.3A	0.052	0.032	0.001	2.72
NFC[1,3]	209.1a	165.7b	135.9A	147.3A	0.028	0.001	0.001	7.78
LIG[1]	135.2a	139.4a	149.1A	146.8A	0.689	0.001	0.096	2.24
EE[1]	14.1a	10.2b	16.4A	10.1B	0.001	0.307	0.215	10.30
NDIP[2]	333.8a	140.4b	370.3A	148.9B	0.001	0.067	0.264	9.11
ADIP[2]	275.6a	106.2b	297.3A	95.7B	0.001	0.464	0.070	7.91

DM - dry matter; OM - organic matter; CP - crude protein; NDFap - neutral detergent fiber corrected for ash and protein; ADFap - acid detergent fiber corrected for ash and protein; NFC - non-fibrous carbohydrates; EE - ether extract; NDIP - neutral detergent insoluble protein; ADIP - acid detergent insoluble protein; CV - coefficient of variation.
[1] g kg^{-1} of the dry matter.
[2] g kg^{-1} of crude protein.
[3] NFC = OM – (EE + NDFap + CP).
a-b - Means followed by different lowercase letters (without calcium oxide) in the same row are significantly different (P<0.05) by Tukey's test.
A-B - Means followed by different uppercase letters (with calcium oxide) in the same row are significantly different (P<0.05) by Tukey's test.

it as a similar dilution effect to that occurred with the NDF contents. Because the NFC intake in the treatments with calcium oxide was higher, this resulted in an increased lignin content in these treatments.

In the silage without calcium oxide, the control silage had lower ($P<0.05$) pH levels (Table 3) because of the alkalinity of the added substances. In the silage with calcium oxide, we found no differences in pH levels between treatments (Table 3).

The pH of the silages that received urea or lime was above the range of 3.8 to 4.2 recommended by McDonald et al. (1991) and Tomich et al. (2004). These silages probably showed an increase in their buffer capacity with the additives, reducing the acidification potential of the organic acids produced during the fermentation process, in addition to the lower NFC content. Schmidt et al. (2010) analyzed the silages of peach palm meal and found pH values of 4.0, 4.1, and 4.4 in the silage of sheath, silage enriched with 10.0 g kg^{-1} urea (fresh matter basis), and silage with 10.0 g kg^{-1} lime (fresh matter basis), respectively. These values are similar to the ones observed in our experiment.

The control silage without the addition of calcium oxide showed a lower ($P<0.05$) ammoniacal nitrogen (NH_3) content in relation to the silage enriched with urea (Table 3), which indicates greater hydrolysis of the latter. We found no difference in NH_3 in silages with calcium oxide, with concentrations of 84.87 g kg^{-1} (Table 3). The pH values of the enriched silages might have led to the development of microorganisms that break down urea, thereby having an effect on NH_3 concentrations. However, the silages displayed ammoniacal nitrogen contents below 100.0 g kg^{-1} of the total nitrogen, which is the acceptable limit (Van Soest, 1994).

The high pH observed in the enriched silages with calcium oxide or urea (Table 3) might compromise the fermentation quality due to the proliferation of undesirable bacteria, which results in increased butyric acid content. However, we did not observe this effect and all silages showed a concentration of this fatty acid lower than 0.5 g kg^{-1} on a dry matter basis (Table 3).

The silages that received lime had a lower ($P<0.05$) lactic acid content (Table 3). Lactic acid bacteria can be homofermentative, able to produce only lactic acid, whereas the heterofermentative lactic acid bacteria produce lactic and acetic acids (Lopes and Evangelista, 2010). The addition of lime probably influenced the development of heterofermentative lactic acid bacteria, increasing the acetic acid contents. It is desirable that the concentration of lactic acid be predominant, since it rapidly decreases the silage pH (Umana et al., 1991). Acetic acid, in contrast, assists in aerobic stability of the silage (Danner et al., 2003), thus maintaining its quality.

The addition of urea to the silage decreased ($P<0.05$) effluent losses (Table 3). The dry matter content of the sheaths of Alexander Palm was lower than what is usually recommended for ensilage and the fact that they were not subjected to pre-wilting might have contributed to the effluent values observed in the control silage. In a similar study on the silage of sheath from Alexander Palm, Coitinho (2013) found effluent losses of 34 kg t^{-1} of fresh mass, which was lower than the values found in the present study. Because it promotes the rupture of the cell wall and the release of the cellular content, lime may lead to increased effluent production (Schmidt et al., 2010), influencing the production of effluents in the silage enriched with lime.

Gas losses (DM) were lower ($P<0.05$) in the silage enriched with urea in treatments with calcium oxide (Table 3). Although the combination of urea and lime decreased gas losses, the DM losses (Table 3) in this

Table 3 - Qualitative characteristics of silage of heart of palm waste produced from Alexander Palm

Variable	Without calcium oxide		With calcium oxide		P-value			CV%
	Control	Urea	Control	Urea	Urea	Calcium oxide	Interaction	
pH	3.75b	4.90a	4.75B	4.89A	0.001	0.001	0.001	1.35
Ammonia (NH_3)[1]	31.43a	23.28b	84.74	84.87	0.012	0.001	0.012	4.89
Acetic acid[2]	26.03a	23.04b	31.09A	27.24B	0.004	0.004	0.886	6.88
Proprionic acid[2]	02.43	02.28	02.87	03.04	01.74	0.001	0.183	3.38
Butyric acid[2]	0.37	0.44	0.51	0.49	07.55	0.094	0.567	6.90
Lactic acid[2]	49.4	51.4	32.3	32.6	0.325	0.001	0.661	3.83
Efluent[3]	56.1a	48.2b	58.4A	49.6B	0.041	0.614	0.904	13.66
Gas production[4]	115.3a	136.2a	137.9A	70.3B	0.556	0.001	0.001	9.17
Loss of dry matter (%)	8.4a	3.5b	6.9B	11.2A	0.556	0.001	0.001	12.33

CV - coefficient of variation.
[1] g kg^{-1} of total nitrogen.
[2] g kg^{-1} of the dry matter.
[3] kg t^{-1} of natural matter.
[4] g kg^{-1} of the dry matter.
a-b - Means followed by different lowercase letters (without calcium oxide) in the same row are significantly different ($P<0.05$) by Tukey's test.
A-B - Means followed by different uppercase letters (with calcium oxide) in the same row are significantly different ($P<0.05$) by Tukey's test.

treatment were higher (P<0.05). Although we expected DM losses to be lower for this treatment, since gas and effluent losses were smaller and could lead to a lower dry matter loss, our study did not confirm this.

Conclusions

Silage prepared with waste from heart of palm production and enriched with 5.0 g kg^{-1} urea have a better chemical composition and improves fermentation parameters. We, therefore, do not recommend using waste from heart of palm production without adding urea to improve chemical characteristics of the forage and to prevent unwanted fermentation processes.

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