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Effects of additives on silage African oil palm forage waste and its acceptability in sheep

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ABSTRACT

Objective: The objective was to evaluate the effects of different levels of microbial inoculum (MI; 0, 3 and 6%), molasses (0, 3 and 6%), and ground corn (GC; 0 and 3%) on the fermentation and chemical composition of silage made from African oil palm forage waste (APFW), as well as its acceptability in sheep.
Design/methodology/approach: A total of 54 micro-silos were used in a completely randomized design with a 3×3×2 factorial arrangement and three replications. Additionally, 0.1% urea was added to all treatments. The variables evaluated were pH, lactic acid (LA), dry matter (DM), crude protein (CP), ash, neutral detergent fiber (NDF), and acid detergent fiber (ADF). Significant interactions were analyzed using SLICE in SAS. Acceptability was evaluated using a cafeteria test with four Pelibuey sheep.
Results: Treatments with MI ≥3% and molasses ≥3% reduced pH (from 4.9 to 3.7; $p \leq 0.05$) and increased LA concentration, indicating stable fermentation. MI at 6% decreased NDF and ADF ($p \leq 0.05$), whereas molasses increased DM ($p \leq 0.05$). GC (3%) increased ($p \leq 0.05$) pH and LA concentration when combined with molasses at 3-6%, while maintaining indicators consistent with adequate fermentation. Sheep showed greater preference ($p \leq 0.05$) for the silage, coinciding with higher DM and CP, and lower NDF and ADF.
Limitations/Implications: The study was conducted in laboratory-scale micro-silos, with a limited animal sample size (n=4) and without evaluation of productive parameters. Therefore, it is recommended to validate these results under field conditions, including the assessment of aerobic stability, performance, and cost-benefit.
Findings/conclusions: The combination of MI (3-6%) with molasses (3-6%) improved the fermentation of APFW, reduced NDF and ADF, and increased its acceptability in sheep, supporting its potential as a feed resources for small ruminants in tropical regions.

Keywords: Silage, agroindustrial waste, microbial inoculum, African oil palm, acceptability.

INTRODUCTION

African oil palm (*Elaeis guineensis* Jacq.) is an agroindustrial crop of great global importance due to its high oil (Pasiecznik, 2022). In Mexico, its cultivation is concentrated in the states of Chiapas, Veracruz, Campeche, and Tabasco, where large amounts of residual biomass —particularly leaves— are generated during harvesting and agronomic

management (SIAP, 2024). Despite their potential as a resource for ruminant feeding, these leaves are often underutilized and remain in the field as agricultural waste.

African oil palm leaves can be incorporated into ruminant diets as a non-conventional forage (Ebrahimi *et al.*, 2013; Syamsuddin *et al.*, 2024). However, their use in fresh form is limited by their short shelf life, attributed to rapid deterioration and oxidation processes when the material remains exposed to the environment (Ang, 2017). From a nutritional perspective, agricultural residues can contribute to ruminant diets; nevertheless, their adoption is often low due to logistical and preservation constraints, as well as variability in their quality, which limits their effective use in production systems (Alkhtib *et al.*, 2017). In the particular case of African oil palm forage waste (APFW), these materials are characterized by a neutral detergent fiber (NDF) fraction ranging from 69.5 to 78.05% and an acid detergent fiber (ADF) content of 50.9 to 56.9% (Wilson *et al.*, 2020). This composition may restrict ruminal degradation and, consequently, their intake and utilization potential if conservation and technological improvement strategies are not implemented.

Ensiling is a viable alternative for valorizing PFW, as it allows the material to be preserved for prolonged periods under anaerobic conditions, reducing losses and minimizing deterioration associated with storage or exposure to environmental conditions (Da Silva *et al.*, 2019). The production of high-quality silage depends on the occurrence of predominantly lactic fermentation, characterized by a rapid decline in pH. In this process, water-soluble carbohydrates (WSC) are essential because they serve as fermentable substrates for lactic acid bacteria (LAB), which are responsible for lactic acid production and the acidification that inhibits undesirable microorganisms (Oladosu *et al.*, 2016; Aguirre *et al.*, 2024). When the material to be ensiled is low in WSC or presents characteristics that hinder acidification, fermentation may be slow and unstable, increasing the risk of proteolysis and undesirable fermentations. Therefore, the use of additives is considered a key technological strategy to direct the fermentation process.

The incorporation of additives during ensiling can improve the fermentative quality and nutritional value of the material, promoting its acceptance by animals and their productive response (Diogénes *et al.*, 2023). In particular, the use of microbial inoculum aims to ensure a sufficient population of lactic acid bacteria (LAB) with high acidification capacity, while energy sources such as molasses provide rapidly fermentable water-soluble carbohydrates (WSC), and ground corn can contribute to the dry matter content and energy density of the silage, with potential effects on its fermentation profile and acceptability. Therefore, the objective of this study was to evaluate the effects of different levels of microbial inoculum, molasses, and ground corn on the fermentative quality, chemical composition, and acceptability of African oil palm forage residue silage in Pelibuey sheep.

The hypothesis was that the combination of microbial inoculum, molasses, and ground corn at increasing levels would improve the fermentation process and nutritional value of silage made from African oil palm forage waste, thereby increasing its acceptability in sheep.

MATERIALS AND METHODS

Collection of African oil palm forage waste

APFW were collected at Rancho La Esperanza, located in Colonia El Arenal (15° 10' 19" N, 92° 42' 00" W), in the municipality of Acapetahua, Chiapas, Mexico. The leaflets were manually separated from the rachis, and the material was chopped to a particle size of 2-3 cm using a 13 HP Honda® hammer mill. The material was transported to the Animal Science Laboratory (Colegio de Postgraduados, Campus Tabasco; Cárdenas, Tabasco) and processed on the same day for the preparation of micro-silos.

Experimental design and treatments

For the fermentative and chemical variables, a completely randomized design with a 3×3×2 factorial arrangement was used: MI (0, 3, and 6%), molasses (0, 3, and 6%), and GC (0 and 3%), expressed on a fresh basis (w/w). A total of 18 treatments (Table 1) with three replications were evaluated (n=54 micro-silos). Each micro-silo consisted of a 2.5-L hermetic polycarbonate jar with a screw cap. In all treatments, 0.1% urea was added on a fresh basis (1 g kg^{-1} of fresh mixture) to ensure a minimum of 10% CP in the mixture.

Statistical Analysis

An analysis of variance was performed for each measured variable. The model included the fixed effects of MI, molasses, and GC, as well as their interactions. Mean comparisons

Table 1. Percentage inclusion of ingredients in the experimental treatments on a fresh basis.

Treat	APFW (%)	MI (%)	Molasses (%)	GC (%)	Urea (%)
T1	99.9	0	0	0	0.1
T2	96.9	0	0	3	0.1
T3	96.9	0	3	0	0.1
T4	93.9	0	3	3	0.1
T5	93.9	0	6	0	0.1
T6	90.9	0	6	3	0.1
T7	96.9	3	0	0	0.1
T8	93.9	3	0	3	0.1
T9	93.9	3	3	0	0.1
T10	90.9	3	3	3	0.1
T11	90.9	3	6	0	0.1
T12	87.9	3	6	3	0.1
T13	93.9	6	0	0	0.1
T14	90.9	6	0	3	0.1
T15	90.9	6	3	0	0.1
T16	87.9	6	3	3	0.1
T17	87.9	6	6	0	0.1
T18	84.9	6	6	3	0.1

Treat: treatment; APFW: African oil palm forage waste; MI: microbial inoculation; GC: ground corn.

were conducted using Tukey's multiple comparison test. When significant interactions were detected, simple effects were evaluated using the SLICE option in PROC MIXED (SAS, 2013), following the approach described by Maxwell and Delaney (1990). Specifically, the effect of factor A was evaluated within each combination of factors B and C, the effect of B within each combination of A and C, and the effect of C within each combination of A and B.

The linear model including all main effects and interactions was:

$$Y_{ijkl} = \mu + A_i + B_j + C_k + (AB)_{ij} + (AC)_{ik} + (BC)_{jk} + (ABC)_{ijk} + \varepsilon_{ijkl}$$

where: μ is the overall mean; A_i, B_j, and C_k are the main effects; $(AB)_{ij}$, $(AC)_{ik}$ and $(BC)_{jk}$ are the two-way interaction effects; $(ABC)_{ijk}$ represents the three-way interaction effect; and ε_{ijkl} is the experimental error term. The assumptions of normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test) were verified using the model residuals. When any of the assumptions were not met, the data were transformed using the Box-Cox procedure, and subsequent analyses were performed on the transformed scale.

Preparation of micro-silos

Ground APFW was mixed with MI, molasses, and GC according to the treatments (Table 1), and a sample (200 g) was taken to determine the initial moisture content. The mixture was placed in polycarbonate jars (2.5 L), compacted in a standardized manner (recording the net filling weight and minimizing headspace) to promote anaerobic conditions, and then hermetically sealed. The micro-silos were incubated for 30 days at ambient temperature in a cool area, without direct exposure to light.

Preparation of the microbial inoculum

The microbial inoculum, also known as Vitafert® (Iraola *et al.*, 2019), was produced by submerged liquid fermentation following the method described by Ramos *et al.* (2021). The following ingredients were mixed in a 20-L plastic bucket: 4% soybean meal, a source of proteins and essential amino acids for bacterial growth (Zhu *et al.*, 2022); 4% rice bran, which provides carbohydrates and fiber as an energy substrate (Lovegrove *et al.*, 2020); 15% molasses, rich in readily fermentable sugars that promote microbial multiplication (Zentou *et al.*, 2017); 0.5% mineral salts, necessary to maintain basic metabolic functions (Elliott & Sharp, 2020); 0.5% urea, used as an additional nitrogen source (Dos *et al.*, 2016); 0.3% magnesium sulfate, which provides magnesium as an enzymatic cofactor (Li *et al.*, 2025); 5% natural yogurt (Yoplait®), used as a starter inoculum of lactic acid bacteria (Kandola, 2018); and 7.7 L of water, required for the dissolution of the components and cellular activity. The mixture was allowed to ferment for three days and was stirred six times per day for three minutes on each occasion. At the end of fermentation, the inoculum had a pH of 4, 81.1% moisture, 24.9% crude protein, and concentrations of 8.5 and 4.7 $\log_{10}$ CFU mL^{-1} of lactic acid bacteria and yeasts, respectively.

Fermentative variables

At the end of the fermentation period, a 10 g sample was taken from the center of the micro-silo and placed in a 125 mL Erlenmeyer flask, to which 90 mL of distilled water was added. The mixture was placed on an orbital shaker (VWR®, model DS-500E) at 180 rpm for 30 minutes. Subsequently, the samples were filtered through sterile gauze. The pH of the filtrate was immediately measured using a potentiometer (HANNA HI 2210) previously calibrated (pH 4.0 and 7.0). Lactic acid (LA) concentration in the filtrate was determined according to the method described in the *Diario Oficial de la Federación* (2010).

Chemical variables

A 400 g sample was taken from the central portion of each micro-silo and placed in paper bags for drying in a forced-air oven at 60 °C (Tecsa®, model HDT-28) in the Animal Science Laboratory at Colegio de Postgraduados, Campus Tabasco. When the samples reached constant weight, the percentages of moisture, ash, and CP were determined following the methodology described by AOAC (2012). Dry matter was calculated as 100 minus the moisture percentage. NDF and ADF were determined according to the method described by Van Soest *et al.* (1991).

Acceptability test

A cafeteria test with sheep was conducted at the Experimental Field of Colegio de Postgraduados, Campus Tabasco, to evaluate feeding preference, following the methodology described by Wamatu *et al.* (2017). Silage from treatment 16 (6% MI, 3% molasses, 3% GC; Table 1) was used. The trial lasted 15 days (10 days for adaptation and 5 days for measurement). Four male Pelibuey sheep (average BW 29.25 kg; similar body condition) were used and housed individually.

The experimental unit consisted of 12 feeders arranged in four pens (blocks), with one sheep per pen. The data were analyzed using a mixed model (PROC MIXED, SAS, 2013) under a randomized complete block design with repeated measures (days). Treatments were considered fixed effects, animal was included as a random effect, and day was treated as the repeated factor. Means were compared using Tukey's test when appropriate ($p \leq 0.05$).

Animals confined in their pens were simultaneously offered, ad libitum, three treatments (T): T1, fresh giant grass forage (*Pennisetum purpureum* Schumach); T2, fresh APFW; and T3, APFW silage. The position of the feeders was randomized daily to avoid habit bias associated with feed location.

Animals were managed in accordance with the institutional regulations for the use and care of animals for research at Colegio de Postgraduados. Prior to the beginning of the trial, the sheep were supplemented with vitamins and dewormed according to their body weight. Each animal was housed in an individual pen (2 m^2) with *ad libitum* access to drinking water. The amount of each feed offered and refused was recorded daily to calculate intake (fresh basis), and DM was determined to express intake on a dry matter basis. The feeds offered were analyzed for moisture, CP, and ash content following the methodology previously described.

RESULTS AND DISCUSSION

A significant three-way interaction (MI×molasses×GC) was found for pH, LA, CP, and ash, indicating that the effect of the microbial inoculum depends on the availability of soluble carbohydrates provided by molasses and on the inclusion of ground corn. For this reason, the effects of MI were interpreted using the SLICE procedure in SAS within each combination of molasses and GC.

Regarding pH, with 0% MI and without molasses or GC, the highest pH value (4.97) was recorded. The inclusion of molasses at 3 and 6% significantly reduced pH ($p \leq 0.05$) to values of 3.76 and 3.77, respectively. A similar pattern was observed with 3% MI, where pH was 3.80 without molasses or GC and decreased to 3.71 and 3.67 with 3 and 6% molasses, respectively, with no statistical differences between these levels. With 6% MI, pH was 3.79 without molasses or GC and remained stable (3.70-3.73) when molasses was added at 3 and 6%, with no significant differences (Table 2).

In the absence of GC, the inclusion of molasses at all MI levels maintained the pH below 4.0 (Table 2), indicating adequate silage fermentation and consistent with the findings reported by Wang *et al.* (2021) for silages with high availability of soluble carbohydrates.

The inclusion of 3% GC tended to increase silage pH. With 0% MI, pH increased significantly ($p \leq 0.05$) in all combinations with molasses. In treatments with 3 and 6% MI,

Table 2. Effect of microbial inoculum, molasses, and ground corn levels on pH, lactic acid, crude protein, and ash in African oil palm forage waste silages.

MI (%)	M (%)	GC (%)	pH	AL (%)	CP (%)	Ash (%)
0	0	0	4.97^{b}	6.54^{b}	10.71^{c}	13.56^{c}
		3	5.56^{a}	6.96^{a}	11.73^{b}	15.09^{a}
	3	0	3.76^{d}	6.90^{a}	12.29^{b}	14.90^{a}
		3	4.01^{c}	6.90^{a}	11.88^{b}	14.10^{bc}
	6	0	3.77^{d}	6.90^{a}	12.07^{b}	14.71^{ab}
		3	3.98^{c}	6.96^{a}	12.89^{a}	13.89^{c}
3	0	0	3.8^{bc}	6.72^{a}	12.26^{b}	13.32^{bc}
		3	4.0^{a}	6.84^{a}	13.30^{a}	13.36^{bc}
	3	0	3.71^{c}	6.84^{a}	10.80^{c}	12.85^{c}
		3	3.90^{ab}	6.96^{a}	10.53^{c}	14.59^{a}
	6	0	3.67^{c}	6.78^{a}	11.76^{b}	13.98^{ab}
		3	3.79^{bc}	6.90^{a}	10.82^{c}	13.54^{bc}
6	0	0	3.79^{bc}	6.78^{b}	12.14^{a}	14.43^{a}
		3	4.07^{a}	6.96^{ab}	11.58^{a}	13.46^{bc}
	3	0	3.70^{c}	6.78^{b}	10.56^{b}	13.39^{c}
		3	3.92^{ab}	7.20^{a}	10.75^{b}	14.15^{ab}
	6	0	3.73^{c}	6.96^{ab}	10.72^{b}	13.62^{bc}
		3	3.85^{bc}	7.20^{a}	10.61^{b}	13.15^{c}
SE±			0.06	0.10	0.19	0.23

[abc] Means with different superscript letters within the same column, for each Molasses×GC combination, indicate statistical differences among MI levels ($P \leq 0.05$). SE: standard error; MI: microbial inoculation; M: molasses; GC: ground corn; LA: lactic acid; CP: crude protein.

pH increased with 0 and 3% molasses; however, with 6% molasses no significant changes were observed (Table 2).

Overall, MI contributed to reducing pH under all scenarios, with more consistent effects when molasses was included at 3-6% and in the absence of GC. This behavior suggests that the soluble carbohydrates provided by molasses promote rapid and sustained acidification of the silage. Final pH values $\leq$3.9 observed in treatments with MI are consistent with adequate fermentations for high-quality silages (Ferreira *et al.*, 2015). Previous studies have documented that the incorporation of microbial additives and sources of simple sugars favors pH reduction and improves silage stability (Ling *et al.*, 2022). The slight increase in pH observed with the inclusion of GC could be attributed to the fact that molasses constitutes the main source of rapidly fermentable carbohydrates, whereas corn starch undergoes slower fermentation during the initial stages of the process (Araiza *et al.*, 2015).

Regarding lactic acid (LA) content, the treatment without MI, molasses, or GC showed the lowest value (6.54%), with significant differences ($p\leq0.05$) compared with the rest of the evaluated combinations (Table 2). The inclusion of molasses, regardless of the level, increased LA content compared with the treatment without additives.

In treatments with 3% MI, the addition of molasses and GC did not significantly modify LA content, with similar values observed among all evaluated combinations. In contrast, with 6% MI, the inclusion of GC showed a tendency to increase LA, particularly when combined with 3 and 6% molasses, where the highest LA values (7.20%) were recorded, although without consistent differences among all treatments (Table 2).

These results are consistent with those reported by Da Silva *et al.* (2019), who indicated that the addition of microbial inoculants and sources of fermentable carbohydrates promotes lactic fermentation in high-fiber forages.

The higher LA production observed in treatments with MI and molasses is desirable, as it promotes rapid and stable silage fermentation. Inoculation provides lactic acid bacteria (LAB), which promote the conversion of soluble sugars into lactate and accelerate the decline in pH, reflecting the widely documented inverse relationship between pH and LA (Ghimire and Raya, 2022). Similarly, Kim *et al.* (2021) reported that the addition of LAB is a key factor in stabilizing pH and improving the preservation of ensiled forage. Alhaag *et al.* (2019) highlighted that species such as *Lactobacillus plantarum* and *Pediococcus acidilactici* efficiently convert soluble carbohydrates into LA, accelerating silage acidification. Likewise, Bohórquez and Mena (2024) noted that molasses, as a source of fermentable substrate, enables efficient lactic fermentation in materials with low soluble carbohydrate content.

Regarding crude protein (CP), the treatment without MI, molasses, or GC showed the lowest value (10.71%; Table 2). In treatments with 0% MI, the inclusion of molasses increased CP compared with the control, with the highest value observed at 6% molasses and 3% GC (12.89%; $p\leq0.05$), while the remaining combinations showed intermediate values. When 3% MI was included, CP reached its highest value when molasses was not added and 3% GC was included (13.30%; $p\leq0.05$). At this MI level, the inclusion of molasses (3 or 6%) was associated with lower CP concentrations, particularly when combined with GC, where the lowest values were recorded (10.53-10.82%; Table 2).

With 6% MI, CP was higher in the absence of molasses (12.14 and 11.58% for 0 and 3% GC, respectively; p≤0.05), with no differences between both GC levels. In the presence of molasses (3 and 6%), CP remained around 10.56-10.75% and 10.61-10.72%, respectively (Table 2), suggesting a modulatory effect of molasses on the final CP percentage.

The variations observed in CP are expected, since the addition of energy sources (molasses and/or corn) may modify the relative percentage of CP due to dilution effects and changes in fermentative dynamics and nitrogen conservation during the ensiling process. Overall, the final CP values obtained are considered compatible with ruminant diets, in which moderate CP concentrations favor nitrogen supply for microbial protein synthesis in the rumen (Pashayan and Vunsh, 2024).

Regarding ash content, significant differences were observed among treatments, determined by the combination of MI, molasses, and GC (Table 2). In the absence of MI, molasses, and GC (0-0-0), the silage presented an intermediate ash content (13.56%). At this same MI level (0%), the inclusion of 3% GC without molasses significantly increased ash content to the highest value observed (15.09%; p≤0.05). Likewise, with 0% MI and the addition of molasses (3 or 6%) without GC, ash remained high (14.90 and 14.71%, respectively); in contrast, when molasses was combined with 3% GC, lower values were recorded (14.10 and 13.89%).

When 3% MI was included, treatments without molasses showed the lowest ash contents (13.32–13.36%). The combination of 3% molasses and 3% GM significantly increased ash content (14.59%; p≤0.05), whereas with 6% molasses the values remained within an intermediate range (13.98 and 13.54% for 0 and 3% GM, respectively).

With 6% MI, ash content was higher in the absence of molasses (14.43% with 0% GM) and decreased when 3% GM was included (13.46%). In the presence of 3% molasses, ash values were low (13.39 and 14.15% with 0 and 3% GM, respectively), whereas with 6% molasses intermediate values were observed (13.62 and 13.15% with 0 and 3% GM, respectively).

Ash content in forages represents the total mineral fraction and constitutes an indicator of the mineral contribution of the material for ruminant feeding (Block, 2022). This component is essential for maintaining animal health, productive efficiency, and metabolic balance (Fawaiq, 2022), and may vary depending on the supplements or additives incorporated during the ensiling process (Dilaga, 2024).

Regarding final dry matter (FDM), a significant interaction between microbial inoculum (MI) and ground maize (GM) levels was observed (p≤0.05); therefore, the effects of this combination were interpreted using the SLICE procedure (Table 3).

With 0% MI, the addition of GM significantly reduced the FDM content, with values of 57.21 and 55.51% for 0 and 3% GM, respectively (p≤0.05). In contrast, with 3% MI, the inclusion of GM significantly increased FDM, rising from 54.67% without GM to 56.59% with 3% GM (p≤0.05). When 6% MI was used, no significant differences in FDM were observed between the evaluated GM levels, with values of 56.25 and 56.01% for 0 and 3% GM, respectively (Table 3).

These results agree with those reported by Kung *et al.* (2018), who indicate that the objective of ensiling is to preserve the original nutrients of the forage while maintaining

Table 3. Effect of microbial inoculum and ground corn levels on the final dry matter content of African oil palm forage waste silages.

Microbial inoculation (%)	Ground corn (%)	Final dry matter (%)
0	0	57.21[a]
	3	55.51[b]
3	0	54.67[b]
	3	56.59[a]
6	0	56.25[a]
	3	56.01[a]
SE±		0.38

[ab] Means with different superscript letters in the same column indicate differences between levels of the GC factor (P≤0.05) for each MI level. SE: Standard error; FDM: Final dry matter.

adequate dry matter that allows the quality of the material to be conserved and ensures its availability during periods of forage scarcity.

With respect to initial dry matter (IDM), neutral detergent fiber (NDF), and acid detergent fiber (ADF), no significant interactions were detected among the evaluated factors (MI×molasses×GM; Table 4); therefore, the main effects were analyzed.

For IDM, the levels of MI and GM did not show significant differences (P≥0.05). However, the level of molasses did influence this variable, with a significant increase (P≤0.05) observed at 3% molasses compared with 0% (53.93 and 51.10%, respectively), whereas the 6% level showed intermediate values (Table 4).

Table 4. Effect of microbial inoculum, molasses, and ground corn levels on initial dry matter, neutral detergent fiber, and acid detergent fiber in African oil palm forage waste silages.

Factor	Variables		
	IDM (%)	NDF (%)	ADF (%)
MI (%)			
0	51.45[a]	76.81[a]	67.02[a]
3	52.80[a]	74.90[a]	64.65[b]
6	52.57[a]	69.64[b]	61.82[c]
EE±	0.42	2.14	1.50
Molasses (%)			
0	51.10[b]	73.51[a]	64.70[a]
3	53.93[a]	73.90[a]	65.03[a]
6	51.78[ab]	73.94[a]	63.75[a]
EE±	0.85	0.14	0.38
Ground corn (%)			
0	51.49[a]	74.27[a]	64.70[a]
3	53.05[a]	73.30[a]	64.29[a]
SE±	0.78	0.49	0.21

[ab] Means with different superscripts in the same column within each factor indicate significant differences (P≤0.05). SE: Standard error; MI: Microbial inoculation; IDM: Initial dry matter; NDF: Neutral detergent fiber; ADF: Acid detergent fiber.

Regarding NDF, no significant differences were observed between 0 and 3% MI; however, the inclusion of 6% MI significantly reduced ($P \leq 0.05$) the NDF content, with values of 76.81, 74.90, and 69.64% for 0, 3, and 6% MI, respectively. The levels of molasses and GM did not have a significant effect on this variable (Table 4).

Similarly, ADF showed a progressive reduction as the level of MI increased, with a significant decrease ($P \leq 0.05$) from 67.02 to 61.82% when MI increased from 0 to 6%. In contrast, the levels of molasses and GM did not significantly modify the ADF content (Table 4).

The reduction in NDF and ADF associated with increasing MI suggests a possible partial solubilization and/or structural disruption of the cell wall, as a consequence of more efficient lactic fermentation. This reduction in the fibrous fraction is relevant from a productive standpoint, since it is associated with greater potential digestibility and, therefore, with a higher expected intake of the silage by ruminants (Alves *et al.*, 2016).

Overall, the results indicate that the inclusion of microbial inoculum (MI) at levels of 3 to 6%, in combination with molasses between 3 and 6%, favors the establishment of a stable acidic environment, characterized by low pH values and higher concentrations of lactic acid, in addition to preserving crude protein in relative terms. In particular, the addition of 6% MI reduced neutral detergent fiber by 7.17 percentage units (from 76.81 to 69.64%) and acid detergent fiber by 5.20 percentage units (from 67.02 to 61.82%), results consistent with silage of African oil palm forage waste of adequate quality. The inclusion of 3% ground maize caused a slight increase in pH; however, this effect did not alter the overall fermentative profile when combined with MI and molasses.

Our results are consistent with the findings of Syamsuddin *et al.* (2024), who reported fermentative improvements when applying inoculants and sources of WSC to palm residues. However, other authors report variable effects of MM depending on its proportion and the type of forage (Alkhtib *et al.*, 2017), so its inclusion should be evaluated according to the production system.

Regarding the feeds offered during the cafeteria test, significant differences in chemical composition were observed among treatments ($P \leq 0.05$; Table 5). Green forage (T1) presented the lowest values of DM and CP, whereas APFW silage (T3) showed higher concentrations of DM, CP, and ash, as well as lower contents of NDF and ADF compared with fresh APFW (T2) and grass (Table 5).

For the variables intake index (II) and total intake (TI), statistical differences were observed only for the treatment factor ($P \geq 0.05$). The sheep showed a marked preference for the silage (T3), with higher II and TI on a dry matter basis compared with fresh APFW (T2) and grass (T1) ($P \leq 0.05$; Table 6). This response may be associated with the nutritional profile of the silage, characterized by lower fiber concentration (NDF and ADF) and greater DM and CP density, in addition to the effect of fermentation metabolites (*e.g.*, lactate and organic acids) that provide aroma and acidity and may improve palatability (Siqhny and Irfandy, 2024).

Due to the small sample size (4 sheep), these results should be interpreted with caution and require validation at a larger scale, incorporating productive variables and an economic

Table 5. Chemical composition of the diets offered to Pelibuey sheep during the cafeteria test.

Trat	DM (%)	Ash (%)	PC (%)	NDF (%)	ADF (%)
T1	18.63^{c}	11.47^{b}	7.10^{c}	77.89^{a}	55.95^{a}
T2	43.92^{a}	8.52^{c}	8.16^{b}	73.65^{b}	51.27^{b}
T3	44.31^{a}	13.65^{a}	10.50^{a}	62.72^{c}	45.14^{c}
EE±	8.11	1.50	1.01	4.52	5.43

^{abc} Means with different letters in the same column are significantly different (P≤0.05). Trat: Treatment; T1: fresh giant grass forage; T2: fresh African oil palm forage waste; T3: African oil palm forage waste silage. DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber.

Table 6. Total intake and intake index on a dry matter basis in sheep during the cafeteria test.

Treatment	Intake index	Total intake (%)
T1	0.19^{b}	11.90^{c}
T2	0.13^{b}	12.70^{b}
T3	2.11^{a}	75.40^{a}
EE±	0.03	0.09

^{abc} Means with different superscripts in the same column are different (P≤0.05). T1: Giant grass fresh forage; T2: Fresh African oil palm forage waste; T3: African oil palm forage waste silage.

feasibility analysis to quantify the zootechnical impact of using APFW silage in tropical production systems.

Overall, the data suggest that APFW silage is an alternative with high acceptability and a more favorable nutritional profile than fresh material and green forage, with potential to help sustain intake during periods of forage scarcity in African oil palm producing regions.

CONCLUSIONS

The combined application of microbial inoculum (IM) between 3 and 6% and molasses between 3 and 6% significantly improved the fermentative quality of African oil palm forage waste (APFW) silage, as evidenced by a reduction in pH, an increase in lactic acid, higher dry matter content, and reductions in NDF and ADF. The use of ground corn at 3% showed minimal impact on the evaluated variables. Treatments with IM and molasses also increased the acceptability of the silage in Pelibuey sheep, which preferentially consumed this material compared with fresh APFW and grass. However, these results should be interpreted with caution due to the limited animal sample size (n=4) and the absence of productive performance metrics. APFW silage treated with IM and molasses represents a viable alternative for feeding small ruminants in tropical regions. Nevertheless, validation under field conditions is required, considering aerobic stability, productive response, and economic analysis to estimate its technical and financial feasibility.

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REFERENCES

Aguirre García, YL, Nery Flores, SD, Campos Muzquiz, LG, Flores Gallegos, AC, Palomo Ligas, L., Ascacio-Valdés, JA, Sepúlveda Torres, L., & Rodríguez-Herrera, R. (2024). Fermentación Ácida Láctica en la Industria Alimentaria y Bioconservación de Alimentos. *Fermentación*. https://doi.org/10.3390/fermentation10030168

Alhaag, H., Yuan, X., Mala, A., Bai, J. y Shao, T. (2019). Características de la fermentación de especies de *Lactobacillus Plantarum* y *Pediococcus* aisladas de ensilaje de sorgo dulce y su aplicación como inoculantes de ensilaje. *Applied Sciences, 9*(6), 1247. https://doi.org/10.3390/APP9061247

Alkhtib, A., Wamatu, J., Kaysi, Y., Mona, M. y Rischkowsky, B. (2017). Subproductos de pistacho (*Pistacia vera*) como alimento para rumiantes: una revisión sobre producción, gestión y utilización en zonas áridas y semiáridas de Oriente Medio. *Journal of Experimental Biology and Agricultural Sciences, 5*(6), 718-729. https://doi.org/10.18006/2017.5(6).718.729

Alves, AR, Pascoal, LAF, Cambuí, GB, Trajano, J. da S., Silva, CM da y Gois, GC (2016). Fibra para rumiantes: Aspecto nutricional, metodológico y funcional. 10(7), 513-579. https://doi.org/10.22256/PUBVET.V10N7.568-579

Ang, CH (2017). Actividades antioxidantes de las hojas de *Elaeis guineensis*. *Revista de Investigación de la Palma Aceitera*, 343-351. https://doi.org/10.21894/JOPR.2017.2903.06

AOAC (2012) Official Methods of Analysis. 19th Edition. Association of Official Analytical Chemists. Gaithersburg, Mary Land, USA. Chapter 4: 1-44.

Araiza Rosales, EE, Delgado Licon, E., Carrete Carreón, FO, Medrano Roldán, H., Solís Soto, A., Rosales Serna, R., & Haubi Segura, CU (2015). Calidad fermentativa y nutricional de ensilajes de maíz complementados con manzana y melaza. 2(6), 255-267. http://www.scielo.org.mx/pdf/era/v2n6/v2n6a2.pdf

Block , W. (2022). Estimación del contenido mineral en forrajes (pp. 133-146). https://doi.org/10.1007/978-981-19-6020-8_11

Bohórquez Vargas, J. A., & Mena Quinteros, K. A. (2024). Fermentación láctica en la conservación de forrajes tropicales: ventajas frente al ensilado tradicional. *Revista PRISMA Amazónico, 1*(1), 28-33. https://prismaamazonico.com/index.php/revista-prisma

Da Silva, AL, dos Santos, BRC, Perazzo, AF, Neto, JMC, Santos, FN de S., Pereira, DM y Santos, EM (2019). Heno: una alternativa de conservación de forrajes. *Núcleo Animalium, 11*(1), 73-80. https://doi.org/10.3738/21751463.3560

Diario Oficial de la Federación (2010). Norma Oficial Mexicana NOM-181-SCFI-2010. Yogurt-Denominación, especificaciones fisicoquímicas y microbiológicas, información comercial y métodos de prueba. Secretaría de Economía. http://www.dof.gob.mx/normasOficiales/4209/seeco/seeco.html [Links]

Dilaga, S. (2024). Los minerales esenciales para el metabolismo ruminal. *Jurnal Biologi Tropis*. https://doi.org/10.29303/jbt.v24i1.6373

Diogénes, LV, Filho, JMP, Edvan, RL, de Oliveira, JPF, do Nascimento, RR, Santos, EM, Alencar, EJS, Mazza, PHS, Oliveira, RL, & Bezerra, LR (2023). Efecto de diferentes aditivos sobre la calidad del ensilaje de grano de maíz rehidratado: una revisión sistemática. *Rumiantes*. https://doi.org/10.3390/ruminantes3040035

Dos Santos, KC, de Carvalho, FFR, Carriero, MM, Magalhães, ALR, Batista, AMV, Fagundes, GM y Bueno, IC da S. (2020). Uso de diferentes fuentes de carbohidratos asociadas con la urea e implicaciones para la fermentación *in vitro* y las poblaciones microbianas ruminales. *Animal Production Science*, *60*(8), 1028–1038. https://doi.org/10.1071/AN18633

Ebrahimi, M., Rajion, MA, Goh, YM, Sazili, AQ, Soleimani, AF y Schonewille, JT (2013). Palma aceitera (*Elaeis guineensis* Jacq.) Alimentación con frondas de cabras en el trópico húmedo. *Revista de avances animales y veterinarios, 12*(4), 431-438. http://psasir.upm.edu.my/id/eprint/29281/

Elliott, R. y Sharp, P. (2023). Minerales y oligoelementos. Oxford University Press. https://doi.org/10.1093/hesc/9780198866657.003.0016

Fawaiq, M. (2022). Componentes de la calidad del forraje (pp. 17-32). https://doi.org/10.1007/978-981-19-6020-8_4

Ferreira, D. de J., Zanine, A. de M., Santos, EM, de Oliveira, JS y Pinho, RMA (2015). Bacterias de ácido láctico con potencial como medio para inhibir microorganismos indeseables en ensilajes de pasto de estación cálida. *Revista estadounidense de agricultura experimental, 8*(1), 1-11. https://doi.org/10.9734/AJEA/2015/14281

Ghimire, A. y Raya, N. (2022). Cinética de la fermentación del ácido láctico durante la preparación de dahi. 16-22. https://doi.org/10.3126/tujfst.v1i1.49932

Iraola, J., Rodríguez, R., Elías, A., García, Y., & Hernández, JL (2019). Evaluación del peso vivo de toros en pastoreo, suplementados con ensilado de Cenchrus, Moringa, una fuente amilácea y VITAFERT®. *Revista Cubana de Ciencias Agrícolas, 53*(1), 29-34.

Kandola, S. (2018). Evaluación de la compatibilidad de iniciadores de yogur con aislados autóctonos de Lactobacillus acidophilus para el desarrollo de yogur simbiótico mediante la comprobación de diferentes atributos como la inhibición por contacto, la acidez titulable, el recuento de microorganismos viables y el pH. *Revista Internacional de Microbiología y Ciencias Aplicadas Actuales, 7*(07), 3743-3751. https://doi.org/10.20546/IJCMAS.2018.707.433

Kim, D. H., Lee, K. D., Choi, K. C., & Choi, K. C. (2021). Role of LAB in silage fermentation: Effect on nutritional quality and organic acid production —An overview. 6(1), 216-234. https://doi.org/10.3934/AGRFOOD.2021014

Kung, L. (2018). Fermentación de ensilaje y aditivos. *Archivos Latinoamericanos de Producción Animal, 26*(3), 61-66. https://ojs.alpa.uy/index.php/ojs_files/article/view/2677

Li, H., Yang, J., Kuang, S., Fu, H., Li, H. y Peng, B. (2025). El magnesio modula el metabolismo de los fosfolípidos para promover la resistencia fenotípica bacteriana a los antibióticos. *eLife,* 13. https://doi.org/10.7554/elife.100427.3

Ling, W.-C., Zhang, L., Feng, Q., Degen, AA, Li, J.-W., Qi, Y., Li, Y., Zhou, Y., Liu, Y., Yang, F. y Zhou, J. (2022). Efectos de diferentes aditivos sobre la calidad de la fermentación, las comunidades microbianas y la degradación ruminal del ensilaje de alfalfa. *Fermentación, 8*(11), 660. https://doi.org/10.3390/fermentation8110660

Lovegrove, A., Kosik, O., Bandonill, E., Abilgos-Ramos, R., Romero, M., Sreenivasulu, N. y Shewry, PR (2019). Mejora del contenido y la composición de la fibra dietética del arroz para la salud humana. *Revista de Ciencias de la Nutrición y Vitaminología,* 65. https://doi.org/10.3177/JNSV.65.S48

Maxwell, S. E., & Delaney, H. D. (1990). Designing experiments and analyzing data: A model comparison perspective. Wadsworth/Thomson Learning.

Oladosu, Y., Rafii, MY, Abdullah, N., Magaji, U., Hussin, G., Ramli, A. y Miah, G. (2016). Calidad de la fermentación y aditivos: Un caso de ensilado de paja de arroz. *BioMed Research International,* 2016, 7985167. https://doi.org/10.1155/2016/7985167

Pashayan, SA y Vunsh, B. (2024). Metabolismo proteico en el rumen de vacas lecheras. *Vestnik Krasnoârskogo Gosudarstvennogo Agrarnogo Universiteta, 0*(10), 90-95. https://doi.org/10.36718/1819-4036-2024-10-90-95

Pasiecznik, NM (2022). *Elaeis guineensis* (palma africana). Compendio CABI. https://doi.org/10.1079/fc.20295.20210113788

Ramos Juárez, J.A., Martínez-Urbina, E., Izquierdo Reyes, F., Aranda Ibañez, E.M., Vargas-Villamil, L.M., Hernández-Sánchez, D. y Joaquín-Torres, B.M. (2021). Efecto de suplementos fermentados con pollinaza sobre el consumo y degradación del pasto cuba ct-115. *Revista Fitotecnia Mexicana, 44*(4A), pp.773-780. https://doi.org/10.35196/rfm.2021.4-A.773

SAS. SAS User's Guide: Statistics (version 9.4). Cary NC, USA: SAS Institute Inc. 2013.

SIAP (2024) Cierre de producción agrícola. Anuario estadístico de la producción agrícola. https://nube.siap.gob.mx/cierreagricola/ Fecha de consulta: 14 noviembre de 2024.

Siqhny, ZD, e Irfandy, F. (2024). Ácidos orgánicos en la fermentación y producción de pasta de camarón y pescado: Formación, funciones y estándares de concentración regulatorios. *Revista Internacional de Ciencias Químicas y Bioquímicas, 26*(20). https://doi.org/10.62877/32-ijcbs-24-26-20-32

Syamsuddin, S., Bain, A., Asminaya, NS y Saili, T. (2024). Análisis del potencial y la capacidad de carga de subproductos de plantaciones de palma aceitera (*Elaeis guineensis* Jacq.) y plantas de sagú (*Metroxylon* sp.) como alimento para ganado en el sureste de Sulawesi. *Transacciones de la Sociedad China de Maquinaria Agrícola , 55*(9). https://doi.org/10.62321/issn.1000-1298.2024.09.01

Van Soest P.J., Robertson J.P., Lewis B.A. 1991. Symposium: carbohydrate methodology, metabolism, and nutritional implications in dairy catlle. *J. Dairy Sci.* 74:3583-3597.

Wamatu, J., Louhaichi, M., Rubanza, C., Khatib, A., Alkhtib, A. y Rischkowsky, B. (2017). Preferencia estacional de las ovejas Awassi por arbustos atriplex adecuados para pastizales mediterráneos. *Journal of Experimental Biology and Agricultural Sciences*, 5, 76-85. https://doi.org/10.18006/2017.5(SPL-1-SAFSAW).S76.S85

Wang, C., Hongyan, H., Sun, L., Na, N., Xu, H., Chang, S., Jiang, Y. y Xue, Y. (2021). Patrón de sucesión bacteriana durante la fermentación en ensilaje de maíz de planta entera procesado en diferentes zonas geográficas del norte de China. 9(5), 900. https://doi.org/10.3390/PR9050900.

Wilson, A. B., Mestra-Vargas, L. I., Portilla-Pinzon, D., & Mejía-Luquez, J. A. (2020). Efecto de subproductos de palma africana en la producción y calidad de leche bovina en el sur del departamento del Atlántico, Colombia. *Revista Ciencia y Tecnología Agropecuaria, 21*(2).

Zentou, H., Abidin, ZZ, Zouanti, M. y Greetham, D. (2017). Efecto de las condiciones de operación en la fermentación de melaza para la producción de bioetanol. *Revista Internacional de Investigación en Ingeniería Aplicada, 12*(15), 5202-5206. https://pure.hud.ac.uk/en/publications/effect-of-operating-conditions-on-molasses-fermentation-for-bioet

Zhu, S., Zhang, Y., Wang, J., Zhang, C. y Liu, X. (2022). Investigación de genes de expresión diferencial de *Limosilactobacillus reuteri* LR08 regulados por proteína y péptidos de soja. *Foods, 11*(9), 1251. https://doi.org/10.3390/foods11091251