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Alternative Production of Mango Residue Silage (*Mangifera indica* L.) Var. Ataulfo Added with Poultry Waste

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ABSTRACT

The dry season reduces forage availability and quality, negatively affecting cattle production. Strategic supplementation with agro-industrial residues represents a sustainable alternative for livestock feeding. This study evaluated the ensiling process of Ataulfo mango residues (Mangifera indica L.) at three fruit maturity stages supplemented with poultry manure. A total of 648 kg of mango residues were collected and classified according to pulp firmness. Physicochemical analyses were performed during a 90-day fermentation period. Silages supplemented with poultry manure maintained stable pH values during the first 30 days of fermentation, reflecting favorable preservation conditions and limited ammonia formation ($p < 0.0001$). Fermentation temperatures averaged 27.3 °C, promoting lactic acid bacteria activity and organic acid production while reducing the risk of undesirable microbial growth. Under these conditions, lactic acid concentrations reached 2.8% ($p < 0.0001$). Moisture contents remained within the recommended range for quality silage. Treatments containing poultry manure showed higher moisture levels than controls, remaining stable between days 15 and 25. By day 30, moisture increased in control treatments, resulting in significant differences among treatments ($p < 0.0015$) and over time ($p < 0.0001$). Poultry manure supplementation also increased total nitrogen concentration, enhancing the nutritional value of the silage. Nitrogen levels in treatments containing 5% and 10% poultry manure were comparable to those reported for similar silage systems. The results demonstrate that Ataulfo mango residue silage supplemented with 5%, 10%, or 15% poultry manure achieved stable fermentation after 30 days and developed suitable physicochemical characteristics for ruminant nutrition and sustainable livestock production.

Keywords: *Silage, Mangifera indica L, Poultry waste, Cattle feeding, Fermentation*

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INTRODUCTION

The dry season is considered a problem due to its negative effects on cattle-raising activity. Pastures have a low nutritional value, having little digestibility and nitrogen that harms livestock feeding, which is why the use of waste is implemented to carry out strategic energy, protein, mineral, and vitamin supplementation.

The importance of livestock farming is to provide a secure source of protein for a rapidly growing world population to contribute to food security. Regarding Mexico, it is characterized as a livestock country; it has large areas where cattle farming is mainly developed (SIAP, 2018; Sergun *et al*., 2023), and it currently produces 35,653,619 heads of cattle on an area of 109.8 million hectares (SIAP, 2022).

In Chiapas, livestock farming is carried out on an area of 1,438,279 hectares, which contributes to 6.3% of the national cattle population with a total of 4,611,432 heads of cattle each year (SIAP, 2022) and ranks third with 217,395 tons. of meat (SIAP, 2016; Bona *et al*., 2023).

One of the main mango producers is Mexico, with 5%, since it has established itself as a mango producer, occupying sixth place worldwide with a production of 2,089,041 tons (SIAP, 2020). Chiapas ranks fourth nationally, generating 9% of production with 25,000 tons (SIAP, 2019). Currently, significant volumes of waste are generated, such as peels, fiber, pulp, seeds, or those with maturity and quality problems, which present a source of contamination.

Agroindustry waste in Chiapas is between 28 and 43% of the total processed mango (Rivas-Robles *et al*., 2020; Pakalapati *et al*., 2024). These wastes contain lignocellulosic tissue, which can be used to produce fermentation products, which are used as an alternative for the generation of food or protein-energy supplements in quality, low-cost, and environmentally sustainable silage form. Its use is limited due to its high moisture content, carbohydrates, and low protein content, which makes it necessary to add a non-protein nitrogen source such as poultry waste that is currently used in livestock feeding, which contains more than 50% of the nitrogen present. In uric acid, they can be used to partially replace conventional foods in

livestock diets (Aguirre & Apolo, 2016; Pham, 2024).
The addition of poultry waste in solid or liquid fermentation has been shown to improve its organoleptic characteristics. Therefore, the objective of the study is to evaluate the ensiling process of mango residues in three stages of maturation (*Mangifera indica* L.) variety Ataulfo, added with poultry waste for use as feed in cattle.

MATERIALS AND METHODS

Study site
The research was carried out in Huerta San Juan, Tapachula, Chiapas (14°54'32.6" N, 92°17'54.4" W), where mango fruit residues (*Mangifera indica L.*) variety Ataulfo were collected and the process of silage thereof.

Silage elaboration
To make the silage, mango residues (*Mangifera indica L.*) variety Ataulfo were used in different stages of ripening (green-ripe, firm-ripe, and over-ripe). 648 kg of mango waste were collected (72 kg from each ripening stage), classified by the firmness of the pulp using a LUZEREN penetrometer (kg/cm2). To which proximal chemical analysis was carried out at different stages of maturation, and the manure, which included total nitrogen, total sugars, neutral detergent fiber (NDF), ash, and humidity (955.04 of the AOAC, 1990). Next, transverse cuts were made to the mangoes, at a particle size of approximately 5cm, and humidity reduction to 20, 30, and 40% outdoors.
Once the humidity reduction was achieved, the treatments were prepared. The homogeneous mixture was placed in 324 transparent 60 x 90 caliber 600 plastic bags with a capacity of 2 kg. The air was removed from the bags by compression, and they were sealed with plastic string. All silos were made on the same day in a clean place at a room temperature of 30 °C.

Determination of the physicochemical characteristics of silage fermentation
The physicochemical analysis of the silage was carried out in the laboratory of the General Local Livestock Association of Tapachula A.C. (14°55'01" N,92°14'55" W). At 0, 5, 10, 15, 20, 25, 30, 35, and 90 days of fermentation, random samples were taken from the silos every 5 days until concluding on day 35.
pH was determined with a HANNA potentiometer, lactic acid by acidity determination (NOM-F-420-S-1982), temperature, and humidity with a digital hygrometer thermometer (NUODWELLE).
To determine the other characteristics of the 90-day silage, the samples corresponding to the time were taken, which were; lactic acid by acidity determination (NOM-F-420-S-1982), pH with a HANNA potentiometer, temperature with a digital hygrometer thermometer (NUODWELLE), reducing sugars by DNS method, total nitrogen by the Bradford method, humidity by the gravimetric method and ashes by the dry method, (Rodríguez *et al*., 2006; Thuy *et al*., 2023).

Experimental design
The experiment had a completely randomized design with a 4x3x3 factorial arrangement, 36 treatments with 9 repetitions: T1=ripe green mango + 5% poultry waste + 20% humidity, T2= firm ripe mango + 10% poultry waste + 30% humidity, T3= overripe mango + 15% poultry waste + 40% humidity and 3 controls: Control 1 = green-ripe mango + 0% poultry waste + 20% humidity, Control 2 = firm ripe mango + 0% poultry waste + 30% humidity and Control 3 = mango on mature + 0% poultry waste + 40% humidity.

Statistical analysis
An ANOVA and contrast of means by Tukey ($p<0.05$), as well as a principal components analysis (PCA), was performed. All analyses were performed with the InfoStat[MR]2020 statistical program.

RESULTS AND DISCUSSION

Proximal chemical analysis
The proximal chemical analysis of mango residues and poultry manure without application of treatments is shown in **Tables 1-4**. The mango residues presented total nitrogen content of 0.3, 0.4, and 0.5%, similar to that reported by Sumaya-Martínez *et al*. (2012), as well as the % humidity, in which there were differences in the percentage of neutral detergent fiber from what was reported in other articles. The chemical analyses of the poultry manure do not agree with previous articles (Aguirre & Apolo, 2016), which could be attributed to the different type of bedding or storage time.

Physicochemical characteristics of silage

pH
The pH results in the silage are presented in **Figure 1a**. Our results showed significant differences with respect to time in the treatments added with poultry manure ($p<0.0001$), which remained stable between days 0 and 30. On day 25, there was an increase in the pH value due to the presence of soluble carbohydrates as an energy supply for the growth of lactic acid bacteria (LAB), and then it decreased on day 30, which ended the fermentation. However, the pH value increased in all treatments after day 35, considering that under adequate conditions, the ensiled material achieved stabilization in a range of 4.0 to 4.5. The treatment with 10% manure had the highest values during the fermentation process, while the treatment with 5% manure increased from day 25.

Temperature
Figure 1b showed significant differences in the treatments ($p<0.0017$) and over time fermentation ($p<0.0001$). Time 0 of solid-state fermentation (SSF) is found at temperatures of 28.4 °C, after 35 days, it increased to 28.7 °C, which was attributed to the accumulation of metabolic heat derived from microbial activity, decreasing to 27.2°C for stability.

Lactic acid (%)
Highly significant differences were found between the treatments with respect to the time ($p<0.0001$). These results are shown in **Figure 1c**, at the beginning of FES (day 0), the control 3 (added with poultry manure) showed the highest production of lactic acid. However, on day 25 of FES, there was an increase in the production of lactic acid in the witness 1. At day 90, the production of lactic acid was marginal, which coincides with the phase of deterioration that begins at the end of the FES. All treatments presented a similar behavior, while on day 30, the highest acid production was obtained for lactic acid,

this increase in microbial biomass is favorable to produce organic acids that maintain low pH values and prevent the presence of undesirable microorganisms (Muck *et al*., 2018). Values of 2.8% lactic acid have been reported at temperatures of 28 °C (Weinberg, 2002), in which the highest acid production was obtained with lactic acid at a temperature of 27.3 °C. The values obtained in the study are like the ranges of lactic acid production in accordance with Cañaveral-Martínez *et al*. (2021), which can be attributed to obtaining minimum concentrations of $N\text{-}NH_3$, which indicates a low metabolism of lactic to butyric acid, explained by little activity of Enterobacteriaceae.

Humidity (%)

In the metabolic process of microorganisms, sugars (sucrose, fructose, and glucose) and starch, which generate water (Prada, 2012; Prada *et al*., 2024), are between 75-77% attributed to the microbial synthesis process (Riascos-Vallejos *et al*., 2018; Sakhnenkova *et al*., 2023). Less than 40% of the metabolic water available for the growth of lactic acid bacteria is limiting, therefore, the values in this study can be considered within the normal range for silage **(Figure 1)**. Considering that the highest values were obtained in the T2 treatment with 10% manure, during days 15 and 25 the values were maintained stable, while on day 30 there was an increase in the witnesses who presented significant differences between treatments ($p<0.0015$), and with respect to time ($p<0.0001$).

Ashes (%)

The % of silage ash presented a significant increase in the treatments added with chicken manure ($p<0.05$) due to the mineral content of the chicken manure 2.9% and of the different stages of mango ripening, with values of 3.33% of ashes in cassava byproducts (Arce *et al*., 2015). The highest was in Q3, with 15% manure at the end of the FES process, while T2, with 10% manure, presented the lowest value. Caceido W and Caicedo L (2021) reported 12.10% ash in the silage of mango inoculated with natural yogurt. Considering that the mineral composition is important for the metabolism of microorganisms and for achieving protein biomass.

Reducing sugars

Significant differences were observed in the concentration of reducing sugars in treatments with chicken manure ($p<0.05$). The stage of mango maturation was influenced by the concentration of reducing sugars in the silage **(Tables 2-4)**. Treatment T3 had the highest concentration due to its high content of carbohydrates represented by cellulose, hemicellulose, pectin and reducing sugars and not reducers, in addition to the protein contribution of the fruit that makes it a material with characteristics suitable for fermentations according to what was found by Mejía-Griraldo *et al.* (2007), while treatment T1 obtained the lowest concentration of reducing sugars due to its low concentration of carbohydrates. The highest value reported in this study was 3,132, while in studies of corn silage with 90 days of fermentation, they present values of 0.33, which contrast with the values found by Mier (2009).

Total nitrogen

Significant differences were found in the treatments added with chicken manure ($p<0.05$). The addition of chicken manure to the silage showed an increase in total nitrogen concentration, since there was a 1% change in the treatment with 5% manure, and treatment with 15% manure, having 1.5% total nitrogen. Arce *et al.* (2015) reported contents between 1.45% to 8.23% of total nitrogen for levels of chicken manure from 0 to 20%. The values reported in this study are low and can be attributed to the peel and seed of mango waste, which are extremely fibrous materials with low mineral and nitrogen content, according to Guzmán *et al.* (2013); Saadati *et al*. (2024).

Principal Component Analysis (PCA)

The main component that explains 59.7% of the behavior of the independent variables are lactic acid, moisture, and reducing sugars, which correspond to the control, indicating that a homolactic fermentation was carried out, attributing it to the degradation of glucose (sugar) present in mangoes and which is used by microorganisms present in the process, which gave lactic acid as the final product. And the humidity in which results between 75-77% were presented, which are the percentages adequate metabolic water to carry out the fermentation process, and do not possess 14 limiting factors for the development of microorganisms, while the main components that explain 15.7% of the behavior of the variables are temperature, ash, pH, and protein **(Figure 2)**.

Organoleptic characteristics

The effect of manure concentration on the organoleptic characteristics of silage **(Table 1)**. Treatment T1 presented the most appropriate organoleptic characteristics, attributable to its lower manure concentration. This is like what was reported by Citalán *et al.* (2016); Ahmed *et al*. (2023). The T3 treatment with 15% manure had unfavorable results despite being overripe mango with a higher percentage of reducing sugars like what was reported by Sánchez-Santana *et al.* (2021); Carita *et al*. (2025).

Table 1. Proximate chemical analysis of ripe-green mango

Total nitrogen	0.4%
Total sugars	0.4%
Neutral detergent fiber	0.8%
Ashes	0.65%
Humidity	87.5%

Table 2. Proximal chemical analysis of firm ripe mango

Total nitrogen	0.3%
Total sugars	1.6%
Neutral detergent fiber	1.8%
Ashes	0.4%
Humidity	79.3%

Table 3. Proximal chemical analysis of ripe mango

Total nitrogen	0.5%
Total sugars	15.4%
Neutral detergent fiber	0.8%
Ashes	0.36%
Humidity	83.5%

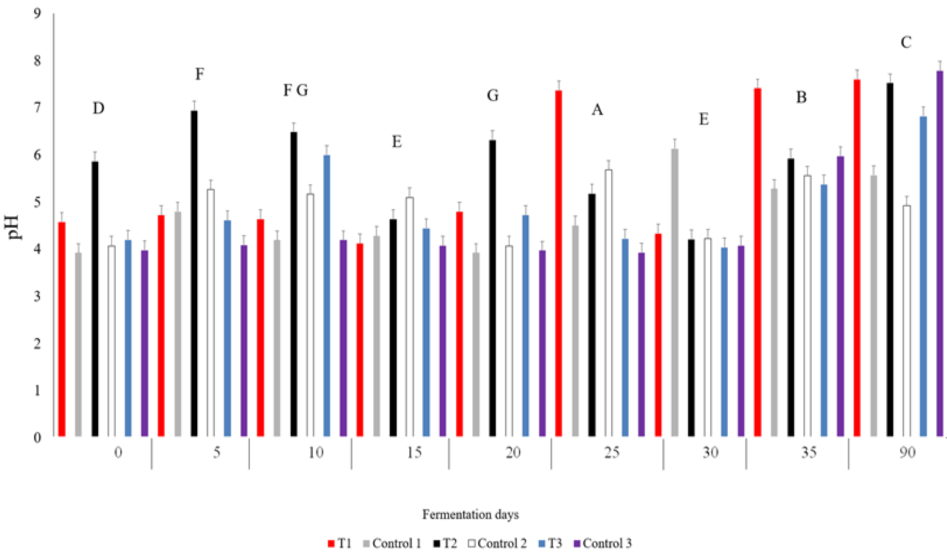
Table 4. Proximal chemical analysis of poultry waste

Total nitrogen	18.6%
Total sugars	1.7%
Neutral detergent fiber	19.1%
Ashes	2.9%
Humidity	88.3%

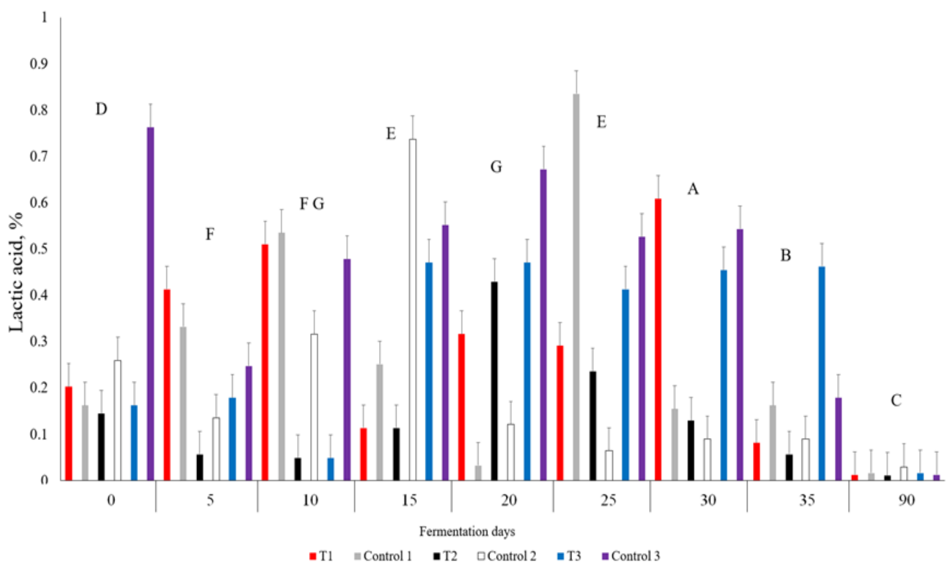
Table 5. Organoleptic characteristics of 90 – day silage.

Treatments	Color	Smell	Texture
T1	Olive green	Likable	Excellent
T2	Yellowish green	Slightly pleasant	Regular
T3	Dark green	Likable	Good
Control 1	Olive green	Likable	Excellent
Control 2	Yellowish green	Silightly pleasant	Regular
Control 3	Dark green	Likable	Good

T1= Green-ripe mango stage + 5% poultry waste + 20% humidity, **T2=** firm ripe mango stage + 10% poultry waste + 30% humidity, **T3=** overripe mango stage + 15% poultry waste + 40% humidity, **Control 1=** green-ripe mango stage + 0% poultry waste + 20% humidity, **Control 2=** firm ripe mango stage + 0% poultry waste + 30% humidity, and **Control 3=** overripe mango stage + 0% poultry waste + 40% humidity.



a)



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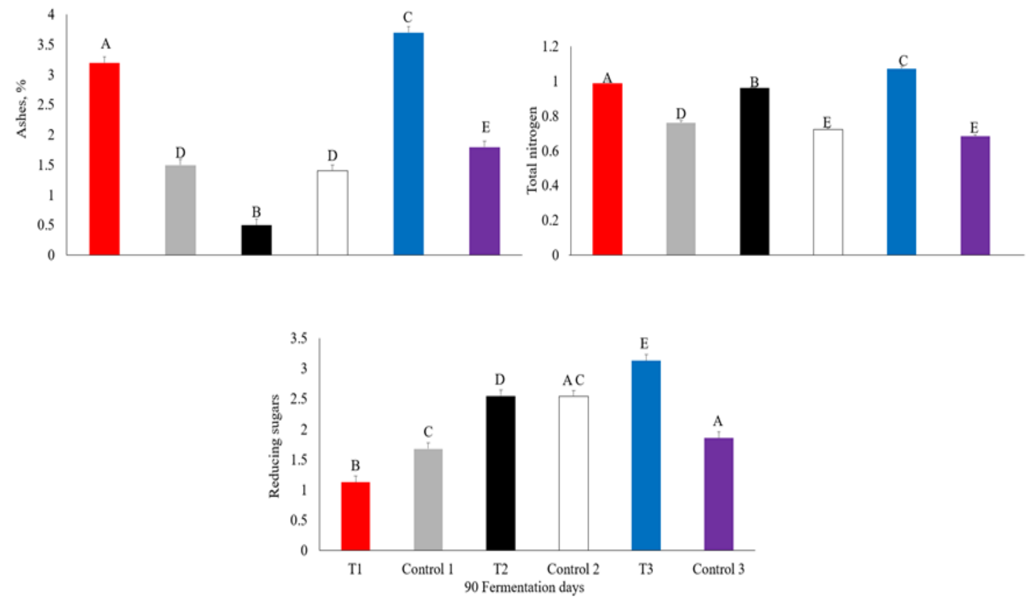

c)

Figure 1. Effect of poultry waste concentration and fermentation time on a) pH in silage, b) on lactic acid production in silage, and c) on the determination of physicochemical characteristics of 90-day silage. Different letters indicate significant differences according to Tukey's test ($p < 0.05$).

Proximal chemical analysis

The mango residues presented total nitrogen content of 0.3, 0.4, and 0.5%, like that reported by Sumaya-Martínez *et al.* (2012); Huata-Panca *et al*. (2025), as well as the % humidity, in which there were differences in the % detergent fiber neutral to what was reported in other articles. The chemical analyses of the poultry waste do not coincide with previous articles (Aguirre & Apolo, 2016), which was attributed to the different type of bedding or the storage time.

Physicochemical characteristics of silage

The pH results remained stable between days 0 and 30, similar behavior observed by Guzmán *et al.* (2013), where the silage had minimum pH values due to the low production of ammonia (NH_3), which favors the pH indicator; the NH_3 produced is retained in the substrate by the humidity of the waste. It was attributed to the use of available sugars by the prevailing microorganisms and to the non-protein nitrogen (NNP) present in the silage, for the formation of its cellular protoplasm (Aranda-Ibáñez *et al.*, 2016). On day 25, there was an increase in the pH value due to the presence of soluble carbohydrates as an energy supply for the growth of lactic acid bacteria (LAB), and then it decreased on day 30, which terminated the fermentation. However, the pH value increased in all treatments after day 35, considering that under adequate conditions the silage material achieved stabilization in a range of 4.0 to 4.5 **(Figure 1a)**. The treatment with 10% poultry waste had the highest values during the fermentation process, while the treatment with 5% manure increased from day 25. The temperature results could be attributed to the accumulation of metabolic heat from microbial activity, which decreased to 27.2 °C for stability. like what was reported by Sánchez Suárez. *et al.* (2018), since silage should not exceed 40 °C (Sánchez-Santana *et al.*, 2021). The values of this study agree with those of Borrás *et al*. (2020), who reported results below the control for elevated temperatures during solid-state fermentation of potato waste (*Solanum tuberosum*). On the other hand, all treatments presented a similar behavior in lactic acid production, observing the highest peak at day 30. This increase in microbial biomass is favorable to produce organic acids, which help maintain low pH and prevent the growth of undesirable microorganisms (Muck *et al.*, 2018). Values of 2.8% lactic acid have been reported at temperatures of 28 °C (Weinberg, 2002), in which the highest production of lactic acid was obtained with a temperature of 27.3 °C. The values obtained in the study are like the lactic acid production ranges reported by Cañaveral-Martínez *et al*. (2021), which can be attributed to the minimum $N\text{-}NH_3$ concentrations, indicating low metabolism. The conversion from lactic to butyric acid is explained by the low activity of enterobacteria.

In the metabolic process of microorganisms, sugars (sucrose, fructose, and glucose) and starch are used, which generate water (Prada, 2012), with 75-77% attributed to the microbial synthesis process (Riascos-Vallejos *et al*., 2018). Less than 40% of the metabolic water available for the growth of lactic acid bacteria is limiting, so the values in this study can be considered within the normal range for silage. According to the % of ash at the different stages of mango ripening, our results were like those reported in cassava (Arce *et al*., 2015); Caceido and Caicedo (2021) reported 12.10% ash in mango silage inoculated with natural yogurt. Thus, the mineral composition is important for the metabolism of microorganisms and achieving protein biomass. In addition, to the protein contribution of the fruit, which makes it a material with suitable characteristics for fermentations, according to what was found by Mejía-Giraldo *et al*. (2007), while treatment T1 obtained the lowest concentration of reducing sugars due to its low concentration of carbohydrates. The highest value reported in this study was 3.132, while in studies of corn silage with 90 days of fermentation, they present values of 0.33, which contrast with the values found by Mier (2009). On the other hand, the results of total nitrogen were like those of Arce *et al*. (2015), who reported contents between 1.45% to 8.23% of total nitrogen for poultry waste levels of 0 to 20%. Principal component analysis (PCA) explained 75.4% of the total variance, indicating that the evaluated variables effectively described the fermentation process **(Figure 2)**. The first principal component (59.7%) was mainly associated with lactic acid, moisture, and reducing sugars, highlighting their key role in silage quality through carbohydrate fermentation and organic acid production. The second component (15.7%) was related to temperature, ash, pH, and protein, reflecting the influence of mineral composition and nitrogen supplementation. Treatments supplemented with poultry waste were associated with higher protein content while maintaining stable fermentation, demonstrating that poultry waste improved the nutritional value of mango residue silage without compromising fermentation quality, consistent with previous studies on silage fermentation dynamics (Muck *et al*., 2018).

The values reported in this study are low and can be attributed to the fact that the peel and seed of mango waste are extremely fibrous materials, with little mineral and nitrogen content according to Guzmán *et al*. (2013). Finally, our organoleptic results were like those reported by Citalán *et al*. (2016) and Sánchez-Santana *et al*. (2021).

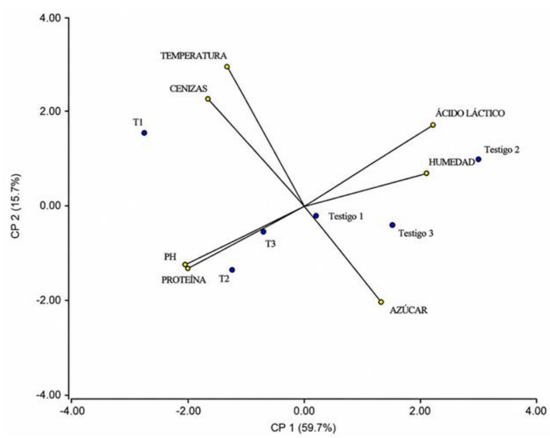

Figure 2. Principal component analysis (PCA) in 90-day silage.

CONCLUSION

Ataulfo mango residues supplemented with 5–15% poultry waste produced a stable silage after 30 days of fermentation, characterized by adequate pH, temperature, moisture, and lactic acid production. Poultry waste supplementation increased nitrogen content, improving the nutritional value of the silage without negatively affecting the fermentation process. Principal component analysis confirmed that lactic acid, moisture, and reducing sugars were the main factors associated with fermentation quality. These findings demonstrate that mango agro-industrial residues can be successfully transformed into a sustainable, low-cost feed resource for ruminants, contributing to waste valorization and circular livestock production.

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ETHICS STATEMENT: All experimental procedures were conducted using agro-industrial residues under laboratory conditions; therefore, approval by an Institutional Ethics Committee was not required.

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