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Chemical and organoleptic evaluation of silages of *Sorghum bicolor* (L.) Moench and *Citrus* sp. pulp

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Abstract

Objective: To evaluate the chemical composition and organoleptic characteristics of silages of *Sorghum bicolor* (L.) Moench *Citrus* sp. pulp.

Materials and Methods: The work was done with chopped *S. bicolor* plant and fresh citrus fruit pulp. A complete randomized factorial design and five treatments were applied: T1) 100 % *S. bicolor*, T2) 75 % *S. bicolor* + 25 % citrus fruit pulp, T3) 50 % *S. bicolor* + 50 % citrus fruit pulp, T4) 25 % *S. bicolor* + 75 % citrus fruit pulp and T5) 100 % citrus fruit pulp. The silages were evaluated on days 14, 28, 42 and 56 to determine the bromatological and organoleptic characteristics at the moment of final opening (56 days). Variance analysis was carried out to determine the dynamics of chemical composition, for which a linear model was used in which the treatments, times and treatments x times interactions were taken as effects.

Results: Treatments T1 and T2 showed excellent organoleptic quality; while T3, T4 and T5 were evaluated as of good quality. The dry matter decreased as the percentage of citrus fruit pulp increased, in a range between 37,5 and 14,1 %. The content of neutral detergent fiber showed significant differences among all the treatments ($p < 0,0001$) and increased when the percentage of inclusion of citrus fruit pulp decreased in the silages, with values between 31,2 and 70,0 %. The content of the minerals calcium and magnesium showed adequate levels for the requirements of grazing ruminants, between 3,3-4,9 and 1,9-2,4 g/kg DM, respectively, in the silages of *S. bicolor* and citrus fruit pulp.

Conclusions: The organoleptic characteristics of silages confirmed that they had from good to excellent quality. The inclusion of citrus fruit pulp in the mixtures decreased the content of dry matter and neutral detergent fiber; while the crude protein behaved according to the utilized raw materials.

Keywords: fermentation, animal nutrition, nutritional value

Introduction

In animal husbandry systems, herd feeding is the main source of expense, especially when using concentrate feeds based on corn, *Zea mays* L., or soybean, *Glicine max* (L.), which have high prices, due to their demand for feeding humans or monogastric animals (Campos-Granados and Arce-Vega, 2016; Hernández-Montiel *et al.,* 2017). Under these conditions, it is essential to search for new technological alternatives for feeding ruminants, which are less costly and more widely available, and which allow adequate nutritional contribution, besides the increase in productive yields (Lazo-Salas *et al.,* 2018; Rojas-Cordero *et al.,* 2020).

Forages are an essential part of rations in the diets of ruminants for maintaining the rumen function and the development of rumen microorganisms (Xue, 2020). Knowing their value as feedstuff and their most appropriate form of conservation is highly important for production systems in the tropical region, where there is evident seasonality in forage production (Li *et al.,* 2019). This forage when well-preserved is necessary for animal production during the periods of feed shortage.

In spite of the above-explained facts, pasture and forage production varies throughout the year. The dry season (DS) is characterized by lower biomass availability; while in the rainy season (RS) forage biomass surplus is produced that is lost if it is not efficiently preserved (Paytan *et al.,* 2017). Thus, in animal husbandry systems it is essential to have quality forage during the DS, stage in which the pasturelands and tropical pastures practically do not grow and those which stand have low quality.

A way to decrease the feed deficit experienced by cattle during the DS is preserving or transferring

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a portion of the produced forage in the higher production period towards the moment in which the pasture is scarce. Thus, the feed offer can remain stable throughout the year. The forage can be preserved in silos (in humid form, fermented without O_2) or as hay (dry forage) and as grass meal, variants that allow to preserve the surplus that occurs during the RS, in order to supply it in the DS (Morales *et al.,* 2016; Mapato and Wanapat, 2018). Thus, the production of mixed silages allows to utilize the forage surplus that is produced in certain periods of the year, facilitate the inclusion of agroindustrial byproducts in cattle feeding, increase the stocking rate and improve the balance of the animal diet (Ermgassen, 2018).

Due to its nutritional characteristics, *S. bicolor* is an important energy resource in ruminant feeding, because it shows adequate levels of soluble carbohydrates, relatively low buffering capacity, protein content between 5 and 19,3 %, with an average of 10,7 %, depending on the cultivar, soil, climate and crop management. The DM content is higher than 20 % and the fiber content is low, which increases its digestibility (Cabral-Filho *et al*., 2013). Citrus pulp is a residue from the processing industry of these fruits, intended for human consumption. It is used as an energy-rich feedstuff in the diet of cattle, due to its nutritional value. The shell (fresh, ensiled or dried) is used to partially replace components of the conventional diet, such as cereals (Zema *et al*., 2018).

The objective of this research was to evaluate the chemical composition and organoleptic characteristics of *S. bicolor* (L.) Moench and *Citrus* sp. pulp silages.

Materials and Methods

Location. The tests were carried out in the Nutrition Laboratory of the Pastures and Forages Research Station Indio Hatuey (EEPFIH), located between 22º 48’ 7’’ NL and 81º 2’ WL, at 19,01 m.a.s.l., belonging to the University of Matanzas, Cuba and in the Department of Biophysiological Sciences of the Institute of Animal Science (ICA) of the Republic of Cuba, located between 22º 58’ NL and 82º 02 WL, at 80 m.as.l.

Plant material. The work was done with the plant of *Sorghum bicolor* cv. UGD-110 and fresh citrus *Citrus* sp. fruit pulp. *S. bicolor* was planted by drilling, in experimental areas of the EEPFIH, established on a Ferralitic red soil, with good surface and internal drainage and a uniform profile (Hernández-Jiménez *et al*., 2015), at a distance of 1,0 m between rows (dose of 20 kg ha^{-1}) and fertilized with organic matter. The *S. bicolor* forage was harvested in a serous status, approximately between 65 and 70 days after sowing. The citrus fruit pulp was obtained at the Jagüey Grande Citrus Fruit Enterprise, Matanzas province. The samples underwent a manual cleaning process to remove any type of dirt. In addition, damaged or altered parts were removed.

The nutritional composition of the materials used in the elaboration of the silages is shown in table 1.

Treatments and experimental design. A factorial design was used with random distribution and five treatments (table 2), for which 20 microsilos were constructed per treatment, with average weight of 500 g. At each time of the evaluation, three replicates per treatment were used. The microsilo was considered as the experimental unit. For this

Table 1. Chemical composition of *S. bicolor* and the fresh citrus fruit pulp, used in the elaboration of microsilos.

Nutrients	Fresh pulp	Fresh *S. bicolor*	Pre-dried *S. bicolor*
DM, %	15,9	26,8	41,7
Ash, %	5,4	6,5	5,25
CP, %	7,9	11,1	8,0
NDF, %	33,1	68,3	64,4
ADF, %	34,1	34,1	32,9
Ca, g/kg DM	4,6	4,5	4,1
Mg, g/kg DM	2,3	2,2	2,1
P, g/kg DM	0,51	0,47	0,34

DM: dry matter, CP: crude protein, NDF: neutral detergent fiber, ADF: acid detergent fiber, Ca: calcium, Mg: magnesium, P: phosphorus purpose, the laboratory silage scale, proposed by Ojeda *et al*. (1991), was used.

Experimental procedure. For elaborating the microsilos, the *S. bicolor* plant was pre-wilted under shade for 48 hours, until the moisture was reduced and a DM value higher than 30 % was reached. Then, it was chopped in a fodder mill until it reached a particle size of 4-5 mm. *S. bicolor* and the citrus fruit pulp were mixed homogeneously in three proportions. To pack the silage, polyethylene bags 17 cm high, 8 cm long, 7 cm wide and with a capacity of 1 L, were used. The material was manually compacted inside the bags, trying not to perforate them. After filling them, they were sealed with adhesive plastic tape to create anaerobic conditions and were placed on plastic trays. They were stored in the EEPFIH Nutrition Laboratory, protected from routine tasks that could affect the ensiling process.

Sampling and experimental variables. The silages were evaluated on days 14, 28, 42 and 56 after their elaboration until their opening (56 days), to determine the nutritional quality analyses of the materials to be preserved. DM, ash (Ash), crude protein (CP), and the minerals calcium (Ca), magnesium (Mg) and phosphorus (P) were studied according to the techniques suggested by AOAC (2016). The content of neutral detergent fiber (NDF) and acid detergent fiber (ADF) was determined following the procedure proposed by van Soest *et al.* (1991). In addition, the organoleptic characteristics, color, smell, texture and humidity at the time of opening (56 days) were evaluated, according to the indicators proposed by Sánchez *et al*. (2018).

Statistical analysis. The normality of the data distribution in all the variables was verified by the modified Shapiro-Wilk test, and the homogeneity of variance according to Levene. For analyzing the data of the chemical composition dynamics, a linear model was used. Treatments, times, and treatment x time interactions were taken as effects. When differences were found ($p < 0,05$), treatment means were compared through Duncan's multiple range test. The statistical package InfoStat (Di Rienzo *et al*., 2020) was used.

Results and Discussion

Organoleptic characteristics. Regarding color, during the evaluation period, treatments T1 and T2 showed an olive green coloring, unlike T3 and T4, whose color was yellowish green; while T5 showed a yellowish color (table 3). This difference in the colors of the evaluated silages could be due to the inclusion of citrus fruit pulp in the silages, so that as the proportion of pulp increased, the yellowish color became more accentuated. The material obtained in silages T1 and T2 was classified as having excellent quality; while that of T3, T4 and T5 as good, according to the indicators proposed by Sánchez *et al*. (2018).

In their study about the evaluation of the chemical composition and organoleptic characteristics of *Pennisetum* sp. with different proportions of *Manihot esculenta* Crantz, Maza *et al*. (2011) rated the quality of the experimental treatments as excellent (olive green color), better than that of the control treatment (yellowish green color).

Two smells were distinguished: light vinegar and ripe fruit. Only treatment T1 showed a slight smell; while the others had a ripe fruit smell (table 3), which became more pronounced as the level of inclusion of citrus fruit pulp in the silages increased. This result characterized silages T2, T3, T4 and T5 as having excellent quality; while T1 was classified as having good quality, according to the report by Sánchez *et al*. (2018). Well fermented silages should not have a strong smell, due to lactic acid, since the main organic acid of fermentation is almost odorless. However, most silages tend to have a slight vinegar (acetic acid) smell, because this acid occurs in the second highest concentration, after lactic acid, and is highly volatile (Kung *et al*., 2018).

Table 2. Proportion of the *S. bicolor* plant and fresh citrus fruit pulp for elaborating the microsilos (%.)

Treatments	*S. bicolor*	Citrus fruit pulp
T1	100	0
T2	75	25
T3	50	50
T4	25	75
T5	0	100

Table 3. Organoleptic characteristics of the silages of *S. bicolor* plant and fresh citrus fruit pulp.

Treatments	Color	Smell	Texture	Moisture	Final quality
T1	Olive green[1]	Slightly acetic[2]	Continuous contours[1]	It does not moisturize when compressed[1]	Excellent
T2	Olive green[1]	Ripe fruit[1]	Continuous contours[1]	It does not moisturize when compressed [1]	Excellent
T3	Yellowish green[2]	Ripe fruit[1]	Continous contours[1]	It moisturizes when compressed[3]	Good
T4	Yellowish green[2]	Ripe fruit[1]	Continuous contours[1]	It moisturizes when compressed [3]	Good
T5	Yellowish[2]	Ripe fruit[1]	Continuous contours[1]	It moisturizes when compressed [3]	Good

[1]Excellent, [2]good; [3]regular.
T1) 100 % *S. bicolor*, T2) 75 % *S. bicolor* + 25 % citrus fruit pulp, T3) 50 % *S. bicolor* + 50 % citrus fruit pulp, T4) 25 % *S. bicolor* + 75 % citrus fruit pulp, T5) 100 % citrus fruit pulp

These results differ from the ones obtained by Villalba *et al.* (2011). Those authors, when evaluating the bromatological and organoleptic quality of silages of organic waste from the coffee-Musaceae production system, found smells ranging from light and strong, like vinegar, to ripe fruit. Maza *et al.* (2011) classified *Pennisetum* sp. and *M. esculenta* silages as excellent and good, in terms of smell, which coincides with this study.

Regarding texture, the silages analyzed here had excellent quality, showing all their contours well defined, which guarantees firm texture throughout the evaluation period (table 3). This was shown in all the experimental treatments of this research; results that do not corroborate those reported by Villalba *et al.* (2011). These authors found that the texture of the evaluated silages was regular, when using fibrous materials that show a little more resistance to pressure by the fist. Nevertheless, Morales *et al.* (2016) and López-Herrera *et al.* (2019) observed changes in the consistency of the ensiled material due to the degradation of structural carbohydrates.

Due to the type of used microsilo (nylon bags), there were no losses through effluents, causing moisture retention during the fermentation process, which at the time of opening the bags and homogenizing, was combined with all the material present . Thus, the moisture content in the silages increased linearly and was directly proportional to the percentage of citrus fruit pulp inclusion.

Similar results are reported by Rojas-Cordero *et al.* (2020) when evaluating the effect of the inclusion of different levels of *Musa* sp. on the nutritional and fermentative quality of *Morus alba* Linn silages. For such reason, in this study, treatments T1 and T2, when compressed, did not show losses due to effluents or wetting of the hands (table 3); while the proportions T3, T4 and T5, when compressed, had a certain moisture content, which increased as the proportion of citrus fruit pulp increased in the silage. Treatments T1 and T2 showed excellent quality, according to the indicators reported by Sánchez *et al.* (2018); while T3, T4 and T5 had regular quality. However, this regular rating does not discard them as well-fermented silages. The other evaluated organoleptic variables have adequate performance, which includes these silages among those of good quality (table 3).

The increases in moisture can negatively influence the final quality of the ensiled material, because they promote undesirable fermentation processes, such as the one produced by clostridia, the formation of effluents and the reduction of lactate, with the subsequent increase in pH (Callejo-Ramos, 2018; Rojas-Cordero *et al.*, 2020).

In general, when opening the silages of *S. bicolor* and fresh citrus fruit pulp, it was found that the evaluated organoleptic characteristics had a quality from good to excellent (table 3), independently from the raw materials and the combinations between them, which confirmed that the silage process was carried out properly. In none of the treatments there was degradation of the ensiled material, which showed an adequate level of conservation during the fermentation dynamics. According to Bertoia (2007), the above-explained facts allow the treatments to be classified as well-fermented silages, which are greenish-yellow in color, with a pleasant, vinegary and spicy odor; in addition to having a firm texture and nutritional value similar to that of green forage.

Chemical composition. Table 4 shows the DM values of the evaluated silages. On all the days sampled, as the level of citrus fruit pulp increased, the DM content of the silage decreased, with values between 37,5 and 14,1 %. There were differences in all the evaluation days (p < 0,001).

To validate forage as an alternative feed source for ruminant animals, Mamédio *et al*. (2020) when including citrus fruit pulp and evaluating the chemical composition, DM losses and aerobic stability of the silage of the aerial part of arrowroot (*Maranta arundinacea* L.), reported that, with the increase, the pulp in the silages increased the DM, performance that differs from the one observed in this study.

Likewise, the results obtained here exceed those obtained by Padilla-Montes (2018) in the evaluation of forage *S. bicolor* silages, with inclusion levels of *Crescentia alata* Kunth. Only in the proportion T3, similarities were found with regards to the report by this author (27,2 %), if compared with the range recorded in this research, which was between 25,4 and 27,5 %. Granados-Niño *et al*. (2021) reported values of 29 % in the DM content, when identifying the optimum cutting height in the *S. bicolor* forage harvest, in order to improve the nutritional quality of the silage, without reducing the forage DM yield, results that are different from those found in this experiment.

An important factor that determines the fermentation type in the ensiling process is the DM value of the plant. Studies conducted by Pinho *et al.* (2015) and Martínez and Schieda (2017) refer that in the different varieties of *S. bicolor* the DM content varies with the cutting age and with the nature of the plant stem. In this sense, the pre-drying of the *S. bicolor* plant during 48 h contributed to the DM contents recorded in this study, because it is known that such process increases the value of that component. Pre-drying was necessary to reduce, as much as possible, moisture during fermentation, because it is known that high moisture levels in the forages to be ensiled can cause losses due to effluents and favor undesirable fermentations (Sánchez, 2018; Rojas-Cordero *et al.,* 2020). In addition, according to McDonald *et al.* (1992), these effluents contain most of the soluble components of forage, such as sugars, organic acids, proteins and other nitrogen compounds.

In order to obtain good-quality silages and decrease the losses because of effluents, the DM content should be as minimum 30 %. Ojeda *et al.* (2006) indicated that, if a silage shows between 25 and 30 % DM and its pH is lower than 4,3 it can be considered that the process was satisfactorily developed. Nevertheless, other authors state that good-quality silages should have between 30 and 35 % DM (Flores, 2015). Yet, Sánchez (2018) refer that an adequate fermentation process can be achieved with at least 25 %.

Based on the proposal made by these authors, treatments T1, T2 and T3 reached from 25 to 37 % DM (table 4), for which it is considered that the losses due to effluents in these silages should be minimal. They would be then considered good-quality silages. This performance would be different from that of the silages with higher content of citrus fruit pulp (T4 and T5), whose DM values oscillated between 21 and 14 %.

The ash content was not influenced by the inclusion level of citrus fruit pulp in the silages, so

Table 4. Dry matter content in silages of *S. bicolor* and fresh citrus fruit pulp (%).

Treatments	Moments, days			
	14	28	42	56
T1	35,7[a]	35,6[a]	37,5[a]	37,0[a]
T2	31,9[b]	32,8[b]	33,4[b]	33,0[b]
T3	27,0[c]	25,4[c]	27,5[c]	26,4[c]
T4	22,3[d]	22,4[d]	22,4[d]	21,1[d]
T5	15,5[e]	14,6[e]	15,4[e]	14,1[e]
SE ±	0,134	0,109	0,179	0,113
P - value	<0,0001	<0,0001	<0,0001	<0,0001

a, b, c, d and e: Different letters in the same column indicate differences (p < 0,05)T1) 100 % *S. bicolor*, T2) 75 % *S. bicolor* + 25 % citrus fruit pulp, T3) 50 % *S. bicolor* + 50 % citrus fruit pulp, T4) 25 % *S. bicolor* + 75 % citrus fruit pulp, T5) 100 % citrus fruit pulp that differences were found between treatment T1 and the other treatments at all the evaluation moments (table 5).

According to Hoffman (2005), the decrease of the mineral fraction is favorable, because it increases the quantity of rumen-fermentable organic matter. That is why the evaluated silages in this study show adequate values of such fraction, which can contribute to the energy content of the diets for ruminants. Granados-Niño *et al*. (2021) obtained ash values between 10,9 and 13,7 % DM, with marked trend to decrease this indicator, as the cutting height increased, results that are not in correspondence with the ones in this trial for T1, possibly because of evaluating different varieties, subject to different cultivation conditions.

The protein values recorded during the silage fermentation are shown in table 6. They were between 6,7 and 9,9 % and varied according to the CP contents of the raw materials before ensiling (table 1).

On day 14, treatments T1, T2 and T3 showed significant differences ($p < 0,05$) with regards to the other evaluated silages, with the lowest value of this variable throughout the evaluation process (6,7 %). Meanwhile, on day 28 no differences were recorded among proportions T2, T3, T4 and T5; while the differences were between T1 and the other treatments. On day 42, the differences appeared between treatments T2 and T3 compared with T1, T4 and T5 ($p < 0,0064$). At 56 days, treatment T2 showed differences with regards to T1, T3, T4 and the proportion T5 ($p < 0,0387$).

In general, the maturity stage of the ensiled material possibly had effect on protein. The storage days influenced the protein content of the silages, which was higher at 28 and 42 days, with values of 9,7 and 9,9 % in treatments T1 and T3, respectively. Meanwhile, on days 14 and 56, the silages with proportions T4 (6,7 %) and T2 (7,4 %) obtained the lowest values. Another factor that could have affected the protein levels in the evaluated treatments could be the mechanical treatment to which the raw materials were subject before ensiling, which can cause changes in the protein bonds and improve the water absorption capacity, by increasing protein solubility. Likewise, the dehydration to which *S. bicolor* was subject could have caused an increase in the concentration of the latter, which can produce aggregation and favors the interactions of proteins with other feed components.

When determining the productive and qualitative aptitude of two *S. bicolor* genotypes, preserved as silage, De León *et al*. (2019) found in comparison with *Z. mays*, protein values between 6,5 and 7,3 %, lower than those recorded in this study, where they varied between 8,7 and 9,7 % in treatment T1. This may be due to the use of different varieties from those used in this study. The environmental and management conditions of the plantations were also different. However, Padilla-Montes (2018) reported CP values higher than those obtained here, when using *S. bicolor* and integral *Crescentia alata* pulp as fresh material, with higher protein contents than those of *S. bicolor* and citrus fruit pulp (12,15 % and 16,50 % *vs*. 8,0 % and 7,9 %, respectively), for which their mixtures reached figures between 12,1 and 17,4 %, higher than those of this research (6,7 – 9,9%). Granados-Niño *et al*. (2021) referred between 6,1 and 7,2 % CP in *S. bicolor* silages, results similar to those of this trial.

Table 7 shows the changes in the NDF content of the treatments during the fermentation dynamics

Table 5. Ash content in silages of *S. bicolor* and fresh citrus fruit pulp (%).

Treatments	Moments, days			
	14	28	42	56
T1	$6,1^{a}$	$6,3^{a}$	$6,3^{a}$	$6,3^{a}$
T2	$5,3^{b}$	$5,7^{b}$	$5,3^{b}$	$5,3^{b}$
T3	$5,5^{b}$	$5,6^{b}$	$5,2^{b}$	$5,3^{b}$
T4	$5,5^{b}$	$5,6^{b}$	$5,5^{b}$	$5,3^{b}$
T5	$5,1^{b}$	$5,6^{b}$	$5,4^{b}$	$5,2^{b}$
SE ±	0,094	0,024	0,031	0,004
P - value	0,0175	0,0006	0,0002	<0,0001

a and b: Different letters in the same column indicate differences ($p < 0,05$).
T1) 100 % *S. bicolor*, T2) 75 % *S. bicolor* + 25 % citrus fruit pulp, T3) 50 % *S. bicolor* + 50 % citrus fruit pulp, T4) 25 % *S. bicolor* + 75 % citrus fruit pulp, T5) 100 % citrus fruit pulp

Table 6. Crude protein content in silages of *S. bicolor* plant and fresh citrus fruit pulp (%).

Treatments	Moments, days			
	14	28	42	56
T1	8,9[a]	9,7[a]	8,7[ab]	9,0[a]
T2	9,4[a]	9,1[ab]	9,6[a]	7,4[b]
T3	8,6[a]	8,2[b]	9,9[a]	8,6[a]
T4	6,7[b]	8,3[b]	7,9[b]	8,3[ab]
T5	6,7[b]	7,8[b]	7,5[b]	8,6[a]
SE ±	0,221	0,508	0,497	0,317
P - value	<0,0001	0,0503	<0,0064	<0,0387

a and b: Different letters in the same column indicate differences (p < 0,05)
T1) 100 % *S. bicolor*, T2) 75 % *S. bicolor* + 25 % citrus fruit pulp, T3) 50 % *S. bicolor* + 50 % citrus fruit pulp, T4) 25 % *S. bicolor* + 75 % citrus fruit pulp, T5) 100 % citrus fruit pulp

of the silages. At all evaluation times there was an increase in NDF content, as the percentage of pulp inclusion decreased, with significant differences among treatments (p < 0,0001). This performance could be due to the low amount of fiber shown by the citrus fruit pulp compared with *S. bicolor* (table 1). Similarly, an increase in the content of this component was recorded over time (table 7), except in T4. Rodriguez *et al*. (2016) state that this increase indicates the disappearance of part of the soluble material during fermentation, which increases the percentage of the proportion of fibrous material.

Similar results were reported by Nava-Berumen *et al*. (2017) when evaluating the yield and forage quality of three *S. bicolor* varieties. These authors found NDF levels in the range observed for the treatment with 100 % *S. bicolor*, which were between 63,4 and 70,1 %. Likewise, Granados-Niño *et al*. (2021) recorded similar values to those of this study.

The ADF content of the different studied combinations of silages is shown in table 8. Significant differences were observed among treatments only on days 14, 28 and 42 (p < 0,05).

At 14 days, higher values were obtained in treatments T1 and T4 (35,0 and 34,1%, respectively) compared with the others. At 42 days, the proportion T5 was lower than the rest (31,2 %). Meanwhile at the end of the conservation process (56 days), ADF contents that varied in the range of 34,6 to 35,6 % were recorded. Nava-Berumen *et al*. (2017) reported values of 41,1% ADF, which do not coincide with those obtained in this study. In this case, they varied between 34,6 and 38,2 % for treatment T1, which could be due to such factors as climate, cutting age and used *S. bicolor* variety.

From the point of view of nutrition physiology, fiber is the portion of the feedstuff that limits digestion. However, it is essential to keep proper functionality of the rumen, it stimulates feedstuff chewing and rumination, as well as to help main-

Table 7. Content of neutral detergent fiber in silages of *S. bicolor* and fresh citrus fruit pulp (%).

Treatments	Moments, days			
	14	28	42	56
T1	63,4[a]	68,6[a]	69,4[a]	70,1[a]
T2	56,9[b]	59,4[b]	62,9[b]	64,2[b]
T3	54,5[c]	54,9[c]	56,0[c]	57,3[c]
T4	47,0[d]	51,5[d]	49,1[d]	52,1[d]
T5	31,7[e]	31,2[e]	34,5[e]	36,3[e]
SE ±	0,432	0,577	0,648	0,947
P – value	<0,0001	<0,0001	<0,0001	<0,0001

a, b, c, d and e: Different letters in the same column indicate differences (p < 0,05)
T1) 100 % *S. bicolor*, T2) 75 % *S. bicolor* + 25 % citrus fruit pulp, T3) 50 % *S. bicolor* + 50 % citrus fruit pulp, T4) 25 % *S. bicolor* + 75 % citrus fruit pulp, T5) 100 % citrus fruit pulp

Table 8. Acid detergent fiber content in silages of *S. bicolor* and fresh citrus fruit pulp (%).

Treatments	Moments, days			
	14	28	42	56
T1	35,0^{a}	38,4^{a}	38,2^{a}	34,6
T2	31,4^{b}	36,4^{ab}	36,8^{a}	35,4
T3	31,1^{b}	35,1^{b}	34,0^{b}	34,6
T4	34,1^{a}	35,3^{b}	37,0^{a}	35,6
T5	31,2^{b}	31,2^{c}	32,3^{b}	33,6
SE ±	0,680	0,855	0,561	0,891
P - value	0,0012	0,0006	0,0001	0,795

a, b and c: Different letters in the same column indicate differences (p < 0,05).
T1) 100 % *S. bicolor*, T2) 75 % *S. bicolor* + 25 % citrus fruit pulp, T3) 50 % *S. bicolor* + 50 % citrus fruit pulp, T4) 25 % *S. bicolor* + 75 % citrus fruit pulp, T5) 100 % citrus fruit pulp

tain an appropriate pH for the development of the rumen microbiota. Thus, the NDF fraction offers an estimation of the fiber present in the feed, mainly cellulose, hemicellulose, lignin, and is closely related to DM intake. According to Sousa (2017), as the NDF value increases, animal intake decreases, for which providing diets with high NDF content limits the voluntary intake of forage and animal productivity, due to a feeling of fullness in the rumen.

In this study, the decrease in fiber in the mixtures of *S. bicolor* and citrus fruit pulp was favorable, so that all the silages were of good quality for ruminant feeding. In the diet, this component is directly linked to the feedstuff digestibility (Maruelli, 2017). The higher the amount of fiber is, the lower the feedstuff digestibility by the animal will be. However, the treatments in which the content of citrus fruit pulp increases (T4 and T5) should not be used as a forage basis but as a complement in a balanced diet, with an adequate supply of effective fiber.

Minerals are an essential part of the diet of ruminants. Table 9 shows the values reached for Ca, Mg and P in the silages of *S. bicolor* and fresh citrus fruit pulp. Its contents were 3,30-4,95; 1,89-2,43; 0,28-1,18 g/kg DM, respectively.

Regarding the non-ensiled materials, no changes were observed in terms of the analyzed minerals (table 1). Ca, Mg and P were in the range recorded in forages by Martínez-Sáez *et al*. (2018) and in the requirements for grazing ruminants, described by McDowell and Arthington (2005). Sales (2017) reports Ca, Mg and P values in the order of 3,4; 1,4 and 3,1 g/kg DM, respectively, for the diet of beef cattle. In this study, the evaluated silages satisfy the Ca and Mg requirements, for which when supplementing ruminants with them, the low P content present must be considered. However, the

Table 9. Ca, Mg and P content in silages of *S. bicolor* and citrus fruit pulp (g/kg DM).

Treatments	Moments, days											
	14			28			42			56		
	Ca	Mg	P	Ca	Mg	P	Ca	Mg	P	Ca	Mg	P
T1	3,57^{d}	2,10^{b}	0,44^{ab}	4,04^{a}	2,08^{ab}	0,43^{c}	3,74^{b}	2,04	0,40^{b}	3,78^{a}	2,10	0,37^{ab}
T2	4,13^{c}	2,29^{ab}	0,49^{a}	3,83^{ab}	2,11^{ab}	1,18^{a}	3,61^{b}	2,03	0,43^{b}	3,81^{a}	2,03	0,39^{ab}
T3	4,52^{b}	2,22^{ab}	0,47^{ab}	3,30^{c}	2,00^{bc}	0,84^{b}	3,91^{ab}	2,05	0,46^{ab}	3,64^{a}	2,01	0,43^{a}
T4	4,48^{bc}	2,32^{ab}	0,40^{b}	3,59^{ab}	2,18^{a}	0,81^{b}	3,72^{b}	2,10	0,56^{a}	3,37^{b}	1,94	0,32^{ab}
T5	4,95^{a}	2,43^{a}	0,46^{ab}	3,79^{ab}	1,89^{c}	0,49^{c}	4,14^{a}	2,08	0,37^{b}	3,61^{a}	2,07	0,28^{b}
SE ±	0,041	0,018	0,001	0,018	0,006	0,013	0,038	0,011	0,003	0,014	0,007	0,004
P - value	0,001	0,108	0,076	0,007	0,011	0,001	0,055	0,932	0,017	0,008	0,268	0,141

a, b and c: Different letters in the same column indicate differences (p < 0,05)
T1) 100 % *S. bicolor*, T2) 75 % *S. bicolor* + 25 % citrus fruit pulp, T3) 50 % *S. bicolor* + 50 % citrus fruit pulp, T4) 25 % *S. bicolor* + 75 % citrus fruit pulp, T5) 100 % citrus fruit pulp

treatments are considered suitable for ruminant supplementation.

Conclusions

The organoleptic characteristics of the studied silages showed a quality from good to excellent, which allows to state that the fermentation process was carried out adequately. The inclusion of citrus fruit pulp in the mixtures decreased the DM and NDF content; while the CP performed according to the raw materials used in the preparation of the silages. Therefore, *S. bicolor* and fresh citrus fruit pulp, due to their characteristics and chemical composition, constitute valuable resources for the elaboration of mixed silages for ruminant feeding, because they have adequate nutritional value.

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Conflict of interests

The authors declare that there is no conflict of interests among them.

Authors' contribution

- Dariel Morales-Querol. Did the setting up of the research experiments, as well as the data recording and processing. Participated in the search for bibliographic information. Executed the writing and corrections of the manuscript.
- Rafael Rodriguez-Hernandez. Did the design of the research experiments. Participated in the revision of the manuscript.
- Onel Lopez-Vigoa. Did the design and setting up of the research experiments. Participated in the revision of the manuscript.
- Felix Ojeda-Garcia. Designed the experiments and participated in the research advisory.
- Dianet Camejo Rodriguez. Participated in the writing of the manuscript and the search for bibliographic information.
- Flavia Garcia-Sanchez. Did the setting up of the research experiments, as well as the data recording. Participated in the search for bibliographic information.
- Leyanis Fundora-Fernández. Did the setting up of the research experiments, as well as the data recording. Participated in the search for bibliographic information.

Bibliographic references

AOAC. *Official methods of analysis*. Arlington, USA: Association of Official Analytical Chemists, 2016.

Bertoia, M. L. *Algunos conceptos sobre el cultivo de maíz para ensilaje*. Venezuela: Universidad Nacional de Lomas de Zamora. https://www.engormix.com/ganaderia-carne/articulos/algunos-conceptos-sobre-ensilaje-t27275.htm, 2007.

Cabral-Filho, S. L. S.; Abdalla, A. L.; Bueno, I. C. S.; Gobbo, S. P. & Oliveira, A. A. M. Effect of sorghum tannins in sheep fed with high-concentrate diets. *Arq. Bras. Med. Vet. Zootec.* 65 (6):1759-1766, 2013. DOI: https://doi.org/10.1590/S0102-09352013000600025.

Callejo-Ramos, A. Conservación de forrajes (V): Fundamentos del ensilado. *Frisona española*. 223:70-78. https://www.revistafrisona.com/Noticia/conservacion-de-forrajes-v-fundamentos-del-ensilado, 2018.

Campos-Granados, C. M. & Arce-Vega, J. Sustitutos de maíz utilizados en la alimentación animal en Costa Rica. *Nutr. Anim. Trop.* 10 (2):91-113, 2016. DOI: http://dx.doi.org/10.15517/nat.v10i2.27327.

De-León, M. & Giménez, R. A. *Ensilajes de sorgo y maíz: rendimiento, composición, valor nutritivo y respuesta animal*. https://www.engormix.com/ganaderia-carne/articulos/ensilajes-sorgo-maiz-rendimiento-t43931.htm?utm_source=campaign&utm_medium=email&utm_campaign=1-1-0&src_ga=2. 2019.

Di Rienzo, J. A.; Casanoves, F.; Balzarini, Mónica G.; Gonzalez, Laura A.; Tablada, M. & Robledo, C. *InfoStat. version 2019*. Córdoba, Argentina: Grupo InfoStat, FCA, Universidad Nacional de Córdoba. http://www.infostat.com.ar, 2020.

Ermgassen, E. K. H. J. zu. *Strategies for sustainable livestock production in Brazil and the European Union*. Dissertation is submitted for the degree of Doctor of Philosophy: Department of Zoology, University of Cambridge. https://core.ac.uk/download/pdf/153572174.pdf, 2018.

Flores, Jorgelina. *Claves de un buen silo de sorgo*. Argentina: Sitio Argentino de Producción Animal. https://www.produccion-animal.com.ar/produccion_y_manejo_reservas/reservas_silos/302-claves.pdf. 2015.

Granados-Niño, J. A.; Reta-Sánchez, D. G.; Santana, O. I.; Reyes-González, A.; Ochoa-Martinez, Esmeralda; Díaz, F. *et al.* Efecto de la altura de corte de sorgo a la cosecha sobre el rendimiento de forraje y el valor nutritivo del ensilaje. *Rev. mex. de cienc. pecuarias*. 12 (3):958-968, 2021. DOI: https://doi.org/10.22319/rmcp.v12i3.5724.

Hernández-Jiménez, A.; Pérez-Jiménez, J. M.; Bosch-Infante, D. & Castro-Speck, N. *Clasifi-*

cación de los suelos de Cuba 2015. Mayabeque, Cuba: Instituto Nacional de Ciencias Agrícolas, Instituto de Suelos, Ediciones INCA, 2015.

Hernández-Montiel, W.; Ramos-Juárez, J. A.; Aranda-lbáñez, E. M.; Hernández-Mendo, O.; Munguía-Flores, V. M. & Oliva-Hernández, J. Uso potencial y limitantes de la leguminosa en la salud y productividad de los ovinos. *Ecosistemas y recur. agropecuarios*. 4 (10):187-200, 2017. DOI: https://doi.org/10.19136/era.a4n10.672.

Hoffman, P. C. Ash content of forages. *Focus on forage*. 7 (1):1-2. https://fyi.extension.wisc.edu/forage/files/2014/01/ASH05-FOF.pdf, 2005.

Kung Jr., L.; Shaver, R. D.; Grant, R. J. & Schmidt, R. J. Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. *J. Dairy Sci*. 101 (5):4020-4033, 2018. DOI: https://doi.org/10.3168/jds.2017-13909.

Lazo-Salas, G. J.; Rojas-Bourrillon, A.; Campos-Granados, C. M.; Zumbado-Ramírez, C. & López-Herrera, M. Caracterización fermentativa y nutricional de mezclas ensiladas de corona de piña con guineo cuadrado Musa (ABB) I. Parámetros fermentativos, análisis bromatológico y digestibilidad *in vitro*. *Nutr. Anim. Trop*. 12 (1):59-79, 2018. DOI: https://doi.org/10.15517/nat.v12i1.33847.

Li, Dongxia; Ni, K.; Zhang, Y.; Lin, Y. & Yang, Fuyu. Fermentation characteristics, chemical composition and microbial community of tropical forage silage under different temperaturas. *Asian-Australas. J. Anim. Sci*. 32 (5):665-674, 2019. DOI: https://doi.org/10.5713/ajas.18.0085.

López-Herrera, M.; Rojas-Bourrillon, A. & Briceño-Arguedas, E. Sustitución del pasto *Megathyrsus maximus* por guineo cuadrado y urea en mezclas ensiladas. *Agron. Mesoam*. 30 (1):179-194, 2019. DOI: https://dx.doi.org/10.15517/am.v30i1.32478.

Mamédio, D.; Loures, Daniele R. S.; Barros, Jeskarlandia S. & Rocha, Grazielle F. Ensilaje de parte aérea de araruta (*Maranta arundinacea* L.) con inclusión de pulpa cítrica. *Res. Society Devel*. 9 (7):1-19, 2020. DOI: http://dx.doi.org/10.33448/rsd-v9i7.4290.

Mapato, C. & Wanapat, W. Comparison of silage and hay of dwarf Napier grass (*Pennisetum purpureum*) fed to Thai native beef bulls. *Trop. Anim. Health Prod*. 50 (7):1473-1477, 2018. DOI: https://doi.org/10.1007/s11250-018-1582-y.

Martinez, R. L. & Schieda, F. *Evaluación de la calidad de fibra y de la productividad de materia seca en diferentes híbridos de sorgo*. Trabajo final de graduación presentado para obtener el título de Ingeniero Agrónomo. Santa Rosa, Argentina: Facultad de Agronomía, Universidad Nacional de La Pampa. https://repo.unlpam.edu.ar/bitstream/handle/unlpam/1573/a_mareva354.pdf?sequence=1&isAllowed=y, 2017.

Martínez-Sáez, S. J.; Deribew, H. & Entele, T. Contenidos minerales de algunos macro y microelementos en forrajes producidos en Finca Modelo, de la región de Asela, Etiopía. *Rev. prod. anim*. 30 (2):74-76. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2224-79202018000200010, 2018.

Maruelli, Jesica N. *Valoración nutritiva de los alimentos: importancia de la fibra en la alimentación animal*. Tesis para optar por el grado de Licenciatura en Química. Argentina: Universidad Nacional de la Pampa. https://repo.unlpam.edu.ar/bitstream/handle/unlpam/2408/x_marval312.pdf?sequence=1&isAllowed=y, 2017.

Maza, L.; Vergara, O. & Paternina, Elisa Evaluación química y organoléptica del ensilaje de maralfalfa (*Pennisetum* sp.) más yuca fresca (*Manihot esculenta*). *Rev. MVZ Cordoba*. 16 (2):2528-2537. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0122-02682011000200011&lng=en&tlng=es, 2011.

McDonald, P.; Henderson, A. R. & Heron, S. *The biochemistry of silage*. Marlow, United Kingdom: Chalcombe Publications, 1992. DOI: https://doi.org/10.1017/S0014479700023115.

McDowell, L. & Arthington, R. *Minerales para rumiantes en pastoreo en regiones tropicales*. Gainesville, EUA: Centro de Agricultura Tropical, Universidad de Florida, 2005.

Morales, A.; Rodríguez, R.; Gutiérrez, D.; Elías, A.; Gómez, S. & Sarduy, L. Evaluación de la inclusión de VITAFERT en el valor nutritivo de ensilajes de *Tithonia diversifolia* y *Pennisetum purpureum*. *Cuban J. Agric. Sci*. 50 (4):619-930, http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2079-34802016000400011, 2016.

Nava-Berumen, Cynthia A.; Rosales-Serna, R.; Jiménez-Ocampo, R.; Carrete-Carreón, F. Ó.; Domínguez-Martínez, P. A. & Murillo-Ortiz, M. Rendimiento y valor nutricional de tres variedades de sorgo dulce cultivadas en cuatro ambientes de Durango. *Rev. mex. de cienc. pecuarias*. 8 (2):147-155, 2017. DOI: https://doi.org/10.22319/rmcp.v8i2.4426.

Ojeda, F.; Cáceres, O. & Esperance, M. *Conservación de forrajes*. Ciudad de La Habana: Editorial Pueblo y Educación, 1991.

Ojeda, F.; Montejo, I. L. & López, O. Estudio de la calidad fermentativa de la morera y la hierba de guinea ensiladas en diferentes proporciones. *Pastos y Forrajes*. 29 (2):195-202. https://payfo.ihatuey.cu/index.php?journal=pasto&page=article&op=view&path%5B%5D=713&path%5B%5D=215, 2006.

Padilla-Montes, M. A. *Patrones de fermentación y estabilidad aeróbica de ensilaje de sorgo forrajero (Sorghum bicolor M) con diferentes niveles de inclusión de pulpa integral de jícaro (Crescentia alata)*. Trabajo de graduación para optar al grado de Maestro en Ciencias en Producción Animal Sostenible. Managua: Facultad de Ciencia Animal, Universidad Nacional Agraria. https://repositorio.una.edu.ni/3857/1/tnq52p123.pdf, 2018.

Paytan, L. M.; Sáez, M.; Cordero, A. G.; Contreras, J. L.; Curasma, J.; Tunque, M. *et al.* Efecto de aditivos químicos en la composición del ensilado de avena (*Avena sativa* L). *Rev. complut. cienc. vet*. 11 (1):69-75, 2017. DOI: http://dx.doi.org/10.5209/RCCV.56117.

Pinho, R. M. A.; Bezerra, H. F. C.; Santos, E. M.; R., Rosângela C. da S.; Oliveira, Juliana S. de; Freitas, Poliane M. D. de *et al.* Sorghum cultivars of different purposes silage. *Ciênc. Rural*. 45 (2):298-303, 2015. DOI: http://dx.doi.org/10.1590/0103-8478cr20131532.

Rojas-Cordero, D.; Alpízar-Naranjo, A.; Castillo-Umaña, M. A. & López-Herrera, M. Efecto de la inclusión de *Musa* sp. en la conservación de *Morus alba* Linn. *Pastos y Forrajes*. 43 (3):202-211. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-03942020000300210, 2020.

Sales, F. *Importancia de los minerales para la alimentación de bovinos en Magallanes*. Punta Arenas, Chile: Ministerio de Agricultura, Instituto de Investigaciones Agropecuarias, INIA Kampenaike. Informativo No. 7. https://hdl.handle.net/20.500.14001/4877, 2017.

Sánchez, W. Potencial de los forrajes para producir ensilaje de calidad. *Alc. Tecnol*. 12 (1):49-58, 2018. DOI: https://doi.org/10.35486/at.v12i1.37.

Sánchez, H.; Ochoa, Gloria; Peña, P. & López, A. Evaluación productiva de *Capra hircus* alimentados con ensilado de cascarilla de arroz y *Opuntia ficus*. *Manglar*. 15 (1):3-18. https://erp.untumbes.edu.pe/revistas/index.php/manglar/article/view/86, 2018.

Sousa, D. O. de. *Alteration of fiber digestibility for ruminants. Effects on intake, performance, and ruminal ecosystem*. Tese apresentada ao Programa de Pós-Graduação em Nutrição e Produção Animal da Faculdade de Medicina Veterinária e Zootecnia da Universidade de São Paulo para obtenção do título de Doutor em Ciências: Nutrição e Produção Animal. https://www.teses.usp.br/teses/disponiveis/10/10135/tde-18102017-124955/publico/DANNYLO_OLIVEIRA_SOUSA_original.pdf, 2017.

Van Soest, P. J.; Robertson, J. B. & Lewis, B. A. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci*. 74 (10):3583-3597, 1991. DOI: https://doi.org/10.3168/jds.S0022-0302(91)78551-2.

Villalba, Diana K.; Holguin, Vilma A.; Acuña, J. A. & Piñeros-Varon, R. Calidad bromatológica y organoléptica de ensilajes de residuos orgánicos del sistema de producción café-musáceas. *RECIA*. 4 (1):47-52. http://revistas.ut.edu.co/index.php/ciencianimal/article/view/143, 2011.

Xue, Z.; Liu, N.; Wang, Y.; Yang, H.; Wei, Y.; Moriel, P. *et al.* Combining orchardgrass and alfalfa. Effects of forage ratios on *in vitro* rumen degradation and fermentation characteristics of silage compared with hay. *Animals (Basel)*. 10 (1):59, 2020. DOI: https://doi.org/10.3390/ani10010059.

Zema, D. A.; Calabrò, P. S.; Folino, A.; Tamburino, V.; Zappia, G. & Zimbone, S. M. Valorisation of citrus processing waste: A review. *Waste Manage*. 80:252-273, 2018. DOI: https://doi.org/10.1016/j.wasman.2018.09.024.