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Fermentation Profile, Nutritional Quality and Microbial Populations of Melon Plant Biomass Silage Ensiled with Corn Bran

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Abstract: Currently, there is no use for melon plant biomass in agriculture and animal feeding. Using this biomass as silage provides a more sustainable production system. Thus, the objective of this study was to evaluate the silage produced with different mixtures of melon plant biomass and ground corn. The experimental design was completely randomized in a factorial scheme (5 × 2) with five replications. The treatments consisted of five mixtures of melon plant biomass between the plant (branch + leaf) and the fruit (melon scrapings) in amounts of 0% fruit, 5% fruit, 10% fruit, 20% fruit, and 100% fruit on an as-fed basis and ground corn in amounts of 0% and 5% AF of the ensiled biomass. The greatest dry matter contents were found in silages with corn and 0 and 5% fruit, which were 225.6 g/kg and 235.2 g/kg, respectively. The highest concentrations of acetic acid were found in the silages with 0% fruit without corn and 20% fruit with ground corn and were 10.96 and 10.00 g/kg DM, respectively. The use of melon fruit biomass with 0%, 5%, and 100% fruit is the most suitable for silage making, and adding ground corn improves silage quality parameters.

Keywords: additive; *Cucumis melo* L.; fermentation; agroindustry waste

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1. Introduction

Fruit farming is one of world's most important and advancing sectors of agriculture. In response to this advancement, the number of agroindustry companies has increased, generating greater availability of biomass not usable for human consumption but with potential uses as alternative sources in animal feeding [1]. The melon plant (*Cucumis melo* L.) is an annual herbaceous plant that develops well in dry, warm, and sunny environments, standing out in fruit production in both rainfed and irrigated agricultural systems [2]. Considered one of the 10 most popular cultivated fruits in the world, its production has become extremely popular in China [3]. According to Li et al. [4], melon cultivation is causing significant changes in soil physical properties, as large amounts of agricultural inputs are required, including fungicides, fertilizers, and plastic films. The accumulation of these inputs can lower soil pH and alter microbial community structure and can result in the leaching and runoff of fertilizers into nearby surface waters [5], which can result in an excess or imbalance of nutrients in the soil.

Crop residues are already used in agriculture for different purposes. Agricultural by-products improve the economic performance of production and can be used in the composition of ruminant diets, providing extra income to farmers [6,7]. According to Shaikhiev et al. [8], the by-products of melon fruit processing, such as the peel and seeds, are already being used. On the other hand, there are emerging multipurpose agro-industrial crops such as thistle (*Cynara cardunculus* L.), hemp (*Cannabis sativa* L.), and pomegranate (*Punica gra-natum* L.) [9] which can be used as protein feed for ruminants, allowing farmers

to exploit the waste from oil generation using these and reduce the ecological footprint of livestock production according Bragaglio et al. [10]. The use of biomass from agricultural crops also avoids waste accumulation and environmental contamination problems such as pests, nematodes, and fungi such as *Rhizoctoniosis solai Kuhn* [11]. Therefore, for these ingredients to be used in animal feeds, it is important to adopt conservation techniques that preserve the nutritional characteristics of the feed for animals, such as silage making. The main problems for ensiling the biomass of melon are factors intrinsic to the plant, such as its low dry matter content associated with a high proportion of soluble carbohydrates. According to Lima et al. [12], those characteristics interfere directly in the fermentation process, increasing nutrient losses. Losses in silage are related to the characteristics of forage plants both at harvest and during the production process. These situations can be modified by adopting techniques, such as the use of additives in the ensiled mass [13]. Among the additives, ground corn stands out, as it has an absorbing action of excess moisture of the ensiled material, and it is used in biomasses of high moisture content [14]. Since there is no information on the use of melon plant biomass for silage making with corn bran for animal feeding, the objective of the present study was to evaluate the quality of silage produced with different mixtures of melon plant biomass with ground corn added.

2. Materials and Methods

2.1. Statistical Design and Treatments

A completely randomized design in a factorial scheme (5 × 2) with five replications was adopted for this study. The treatments consisted of five mixtures of melon plant biomass between the plant (branch + leaf) and the fruit (melon scrapings) in amounts of 0% fruit, 5% fruit, 10% fruit, 20% fruit, and 100% fruit on an as-fed basis (AF) and ground corn in amounts of 0% and 5% of AF of the ensiled biomass.

2.2. Collection of Melon Plant Biomass and Silage Making

The melon plant biomass was collected after harvesting the commercial fruit in a rural melon-producing property located in the region of Vale do Gurgueia, South of Piauí State, in the town Canto do Buriti, Piauí, Brazil, with coordinates of latitude 8°6′4″ South and longitude 42°56′4″ West, at an altitude of 258 m. The region has climate classification A, with a drier winter season according to the Köppen's classification of 1936, and described by Alvares et al. [15] as having a minimum temperature of 21 °C, a maximum of 38 °C, and an average annual precipitation of 600 mm.

The material was removed from the field in September 2018 (the melon season in the region lasts from July to October), 85 days after planting, and after three harvests of the marketable melon. The material for study was characterized and comprised of the branch (stem + leaf) and fruit (melon scrapings) after three harvests of the commercial fruit. The melon biomass used in the production of silage was collected from the farm of the company Itaueira Agropecuária S.A. The melon variety 'Gold Mine' has strong yellow peel coloration and adapts better to hot and dry climates. It has a creeping habit with lateral branches [16]. The plants were drip irrigated and grown in soil covered with mulch (polyethylene of 25 microns and 1.20 m wide), with fertilization and phytosanitary control performed according to the needs and recommendations for the crop, according to Silva et al. [17].

Chemical composition analyses were performed after biomass collection, and the green forage mass (GFM) was measured through the frame method with a PVC pipe of 0.5 m × 0.5 m (0.25 m^2). Considered to be the best-known form of forage biomass assessment, the square technique uses a frame, usually in the form of a square or rectangle, to delimit the area to be cut [18]. The size of the frames will depend on the uniformity of the area. Typically, 0.5 m × 0.5 m (0.25 m^2) frames are used. In the experiment, spots were chosen randomly to collect the melon's biomass, which was cut at a height of 10 cm from the ground and packed in plastic bags for weighing to determine the total fresh weight.

After collection, the material was fractioned according to the treatments and taken to an oven to determine dry matter [19]. The calculation of the dry matter yield of silage

is determined by the dry matter recovery. Silage yield was calculated from the following equations: DMY = (BIO × DM)/100, where, DMY is dry matter production (t/ha), BIO is biomass (t), and DM is dry matter (kg); Silage yield = (DMY × DMR)/100, where silage yield is given in t/ha DM, dry matter yield in t/ha, and dry matter recovery in %.

After harvesting, the melon biomass was transported to the Professora Cinobelina Elvas campus (CPCE) of the Federal University of Piauí (UFPI), located in the city of Bom Jesus, Piauí, Brazil, for ensiling. Experimental silos (15 cm diameter × 40 cm height) made of polyvinyl chloride (PVC) with capacities of 4 kg were hermetically sealed. The material was packed to a density of 500 kg/m^3, and the silos had a Bunsen-type valve adapted to the lid to allow the escape of fermentation gases. The biomass was not pre-wilted before ensiling, because ground corn was used as a moisture sequestrant and was ensiled with the DM content of the plant and fruit (220.9 and 72.1 g/kg). A total of 5% ground corn was used, following the recommendations of Andrade [20], who obtained better-quality silage when it was produced with this amount of ground corn. The addition of ground corn was performed homogeneously in the biomass of the melon plant in proportions corresponding to the treatments. Silos were opened after 90 days

2.3. Silage Chemical Composition and Loss Quantification

"Samples were oven-dried at 55 °C for 72 h and ground in a Wiley-type mill (Wiley Mill, Arthur H. Thomas, PA, USA) for dry matter (DM) (method 934.010)" and Ash (method 942.05) determination (AOAC) [21]. Crude protein (CP) was calculated by determining the total nitrogen content using the micro-Kjeldhal technique (AOAC [21]; method 920.87) and fixed conversion factor (6.25). The concentrations of acid detergent fiber (ADF) and neutral detergent insoluble fiber (NDF) were determined by the methodology described by Van Soest et al. [22] with α-amylase".

Buffering capacity (BCAP) was determined according to the methodology of Playne and McDonald et al. [23] using 20 g of macerated silage with 250 mL of distilled water. The concentration of soluble carbohydrates (SC) was obtained through the concentrated sulfuric acid method described by Johnson et al. [24].

The pH determination in distilled water was performed in duplicate by collecting 25 g of the ensiled material of each treatment and adding 100 mL of water. After 1 h, reading was performed, according to the methodology described by Bolsen et al. [25], with a potentiometer. To determine the ammonia nitrogen (NH_3-N) content of the samples, the methodology of Bolsen et al. [25] was used.

The experimental silos were weighed at closure and opening in order to determine dry matter (DM) losses in the form of gases and effluents and dry matter recovery (DMR) according to the methodology described by Magalhães [26].

2.4. Microbial Populations, Organic Acids, and Aerobic Stability of the Silages

Microbial populations were evaluated according to the methodology described by González [27] by collecting 25 g of fresh silage sample extracted according to the pre-defined opening period. Microbial populations were quantified after incubation for 3–7 days at room temperature using selective growth medium for each microbial group listed as follows: Rogosa Agar (Difco™, MERCK, Darmstadt, Alemanha), for counting LAB; Brilliant Green Agar (Difco™, MERCK, Darmstadt, Alemanha), for counting ENT; and Potato Dextrose Agar (MERCK, Darmstadt, Alemanha), for counting MY.

For the analysis of lactic acid (LA), acetic acid (AA), propionic acid (PA), and butyric acid (BA), $10\times g$ of each silage was centrifuged, and 1.0 mL of metaphosphoric acid and two drops of 50% sulfuric acid were added. The analyses were performed on a high-performance liquid chromatograph (HPLC; SHIMADZU, SPD-10A VP) [28]. The HPLC apparatus was equipped with an UltraViolet Detector using an Aminex HPX-87H column (BIO-RAD, Santa Clara, CA, USA).

The aerobic stability test was carried out on the samples after 90 days of ensilage and lasted for 96 h. The silos were opened, and 1.5 kg of silage was placed in plastic buckets

and transported to a temperature-controlled room. Temperatures were checked every four hours using digital skewer thermometers positioned in the center of the silage mass. The breakdown of aerobic stability was calculated as the time in hours it took for the silage temperature to rise by 2 °C above the ambient temperature [29]. To evaluate pH over the silage aerobic stability, 100 g of silage was collected from each silo every 24 h to air [25].

2.5. Statistical Analysis

The data were subjected to analysis of variance with significance of $p < 0.05$. Means were analyzed through the Tukey's test, and compared with significance of $p < 0.05$. The data were analyzed in the SISVAR software version 5.0 [30].

The statistical model adopted was:

$$Yijk = \mu + \tau i + \gamma j + (\tau\gamma)ij + \varepsilon ijk$$

where Yijk = record referring to the different melon biomass mixtures i and additive use j; μ = general constant; τi = effect of the different melon biomass mixtures with additives i; i = 1, 2, 3, 4, and 5 (0% fruit, 5% fruit, 10% fruit, 20% fruit, and 100% fruit); γj = effect of additive use 1 and 2 (0% and 5% ground corn); (τγ) ij = effect of the interaction between the different melon biomass mixtures i and additive use j; εijk = random error associated with each mixture of melon biomass and additive use.

3. Results

3.1. Silage Yield, Chemical Composition, Loss Quantification, DM Recovery, pH, and Ammonia Nitrogen

The interaction effect between the different biomass mixtures and use of ground corn ($p < 0.05$) on silage yield, of dry matter content (DM), ether extract (EE), acid detergent insoluble fiber (ADF), crude protein (CP), and soluble carbohydrate was found (Table 1). Mineral matter (MM) content only had an effect of $p < 0.05$ of the different mixtures of melon plant biomass.

Table 1. Silage yield, chemical composition, loss quantification, DM recovery, pH, and ammonia nitrogen of silages with different mixtures of melon biomass and use of ground corn.

GC [1]	Quantity of Fruit (QF)					Mean	SEM [2]	*p*-Value		
	0%	5%	10%	20%	100%			GC	QF	GC × QF
Silage Yield (t/ha DM)										
0%	3.95Bb	6.71Ba	5.04Bb	5.12Ab	1.78Ac	4.53				
5%	6.14Ab	9.68Aa	7.10Ab	5.91Ab	1.68Ac	6.10	0.22	<0.01	<0.01	0.04
Mean	5.0	8.2	6.0	5.5	1.7					
Dry Matter (g/kg)										
0%	148.8Bb	158.4Bab	124.7Bbc	197.4Aa	88.5Ac	143.7				
5%	225.6Aab	235.2Aa	182.1Abc	175.4Ac	95.9Ac	182.8	0.4	<0.01	<0.01	<0.01
Mean	187.1	196.8	153.4	186.4	92.2					
Mineral Matter (g/kg DM)										
0%	57.3	51.7	55.7	66.3	71.9	60.6				
5%	63.6	69.1	60.0	61.2	78.3	66.4	0.2	0.06	<0.01	0.27
Mean	60.4b	60.4b	57.9b	63.7ab	75.1a					
Ether Extract (g/kg DM)										
0%	79.7Aa	89.4Aa	87.3Aa	55.0Aa	78.0Aa	83.5				
5%	56.3Aa	61.6Ba	66.9Aa	59.6Aa	69.7Aa	68.8	0.5	0.08	0.66	0.05
Mean	68.0	82.5	84.1	72.3	73.9					

Table 1. *Cont.*

GC [1]	Quantity of Fruit (QF)					Mean	SEM [2]	*p*-Value		
	0%	5%	10%	20%	100%			GC	QF	GC × QF
Neutral Detergent Insoluble Fiber (g/kg DM)										
0%	613.4	559.1	667.1	636.7	647.2	624.7				
5%	669.0	639.2	613.1	671.5	599.9	638.8	1.4	0.51	0.51	0.18
Mean	641.2	599.2	640.1	654.1	623.5					
Acid Detergent Insoluble Fiber (g/kg DM)										
0%	271.3Aab	229.8Ab	327.1Aab	228.2Ab	390.1Aa	289.3				
5%	278.3Aa	252.4Aa	319.3Aa	231.9Aa	232.4Ba	262.8	1.3	0.17	<0.01	0.04
Mean	274.8	241.1	323.2	230.0	311.2					
Crude Protein (g/kg DM)										
0%	54.3Ba	63.3Aa	58.6Aa	60.8Aa	58.6Aa	59.2				
5%	82.2Aa	56.4Ab	56.3Ab	53.4Ab	63.4Ab	62.3	0.2	0.15	0.02	<0.01
Mean	68.2	59.9	57.4	57.1	61.2					
Soluble carbohydrates (g/kg DM)										
0%	208.7Ab	159.0Ac	169.6Abc	208.8Abc	320.5Aa	211.6				
5%	162.4Bab	145.3Ab	137.1Ab	200.4Aa	199.7Ba	170.6	0.02	<0.01	<0.01	0.04
Mean	185.5	153.5	152.2	204.6	260.1					
Effluents (kg/t AF [3])										
0%	41.8	39.3	46.9	66.2	39.3	49.6				
5%	32.2	49.5	57.0	76.2	49.5	56.9	2.9	0.9	<0.01	0.38
Mean	37.1c	44.4bc	52abc	71.2a	61.7ab					
Gasses DM (%)										
0%	0.6	0.2	0.3	0.1	0.9	0.5				
5%	0.3	0.1	0.3	0.1	1.1	0.4	0.03	0.06	<0.01	0.17
Mean	0.5b	0.1c	0.3bc	0.1c	1.0a					
DM Recovery (%)										
0%	78.6	85.5	74.6	77.1	81.6	79.5b				
5%	97.0	96.2	81.7	80.4	77.9	86.6a	2.42	<0.01	0.03	0.36
Mean	87.8a	90.9a	78.1b	78.7b	79.8b					
pH										
0%	7.9Aa	7.7Aa	7.7Aa	7.4Aa	4.3Ab	7.0				
5%	6.2Bb	6.3Bb	5.8Bb	5.4Aa	4.0Ac	6.1	0.07	<0.01	<0.01	<0.01
Mean	7.1	7.0	6.7	6.2	4.2					
NH_3-N (% TN) [4]										
0%	0.6Aa	0.5Aa	0.4Aab	0.2Ab	0.3Aab	0.4				
5%	0.1Ba	0.2Ba	0.1Ba	0.0Ba	0.1Ba	0.1	0.02	<0.01	<0.01	0.04
Mean	0.3	0.4	0.2	0.1	0.2					

(GC) [1]: Ground corn; SEM [2]: corresponds to the standard error of the mean. AF [3]: as fed; NH_3-N (% TN) [4]: ammonia nitrogen in relation to the percentage of total nitrogen. Means followed by uppercase letters in the column and lowercase in the rows are statistically different according to Tukey's test $p < 0.05$.

Silage from melon plant biomass with 5% fruit showed the greatest yield, obtaining 9.68 t/ha DM of silage. The greatest DM contents were found in the silages with added ground corn with 0 and 5% fruit, which showed DM contents of 225.6 g/kg and 235.2 g/kg, respectively.

Silages with 100% fruit had the greatest MM content, presenting an average of 75.1 g/kg. Silages with 5% of fruit and with ground corn showed an EE content of 61.6 g/kg DM. The greatest ADF content was observed in the silage with 100% fruit without ground corn meal added, which was 390.1 g/kg DM. Silages with 0% fruit and 5% ground corn obtained the highest CP value of 82.2 g/kg DM. The greatest contents of soluble carbohydrates were

found in silages with greater amount of fruit, such as the silage without ground corn and with 100% fruit that showed 320.5 g/kg. An interaction effect was observed between the different mixtures of melon biomass and use of ground corn ($p > 0.05$) on pH and ammonia nitrogen (Table 1). There was the effect of the quantity of fruit ($p < 0.01$) on effluent and gas losses and the effect of the use of ground corn ($p > 0.05$) on dry matter recovery.

Effluent losses varied from 37.1 to 71.2 kg/t AF according to the amount of fruit in the silage, with the lowest loss recorded in silages produced with melon fruit biomass without fruit. Gas losses ranged from 0.1 to 1.0%, with the greatest loss recorded in silages with 100% fruit (1.0%). The highest DM recovery values were found in silages with 5% ground corn (86.6%) and in silages with biomass mixtures with 0 and 5% fruit (87.8 and 90.9%, respectively).

Regarding pH, the lowest values were seen in the silage with 100% fruit, without and with the addition of ground corn, which showed values of 4.3 and 4.0, respectively. Low concentrations of ammonia nitrogen (NH_3-N) were observed in silages of all amounts of fruit with the addition of ground corn, with values ranging from 0.0 and 0.2.

3.2. Microbial Populations, Organic Acids, and Aerobic Stability of the Silages

In the analysis of the microbial populations of the produced silages (Table 2), an interaction effect was observed between the different biomass mixtures and the addition of ground corn ($p < 0.05$) on the populations of lactic acid bacteria (LAB); on the contents of lactic, acetic, propionic, and butyric acids; on the time until a break occurred in aerobic stability; on pH; and on the internal temperature of the silages.

Table 2. Microbial populations, organic acids, and aerobic stability of silages with different mixtures of melon plant biomass with and without the addition of ground corn.

GC [1]	Quantity of Fruit (QF)					Mean	SEM [2]	*p*-Value		
	0%	5%	10%	20%	100%			GC	QF	GC × QF
Lactic Acid Bacteria (Log CFU g^{-1})										
0%	6.97Bb	6.97Ab	7.07Bb	6.97Ab	7.97Aa	7.19				
5%	7.98Aa	6.67Ac	7.98Aa	6.95Aab	7.53Abc	7.42	0.08	0.06	<0.01	<0.01
Mean	7.47	6.82	7.53	6.96	7.75					
Mold (Log CFU g^{-1})										
0%	5.01	5.84	5.21	5.54	5.21	5.42				
5%	5.88	5.55	5.33	5.33	5.00	5.36	0.4	0.81	0.58	0.48
Mean	5.44	5.69	5.27	5.43	5.11					
Enterobacteria (Log CFU g^{-1})										
0%	3.58	3.77	4.10	3.84	3.69	3.79				
5%	3.72	3.64	3.54	3.60	3.93	3.63	0.1	0.45	0.93	0.42
Mean	3.6	3.7	3.7	3.8	3.8					
Lactic acid (g kg^{-1} DM)										
0%	0.77Ba	0.23Bb	0.22Bb	0.22Bb	0.94Ba	0.46				
5%	1.51c	0.78Ad	1.61Ac	2.46Ab	2.99Aa	1.84	0.07	<0.01	<0.01	<0.01
Mean	1.59	0.50	0.91	0.83	1.96					
Acetic acid (g kg^{-1} DM)										
0%	6.87Bd	3.43Be	9.10Ab	10.0Aa	7.62Ac	4.96B				
5%	10.96Aa	6.78Ab	3.23Bc	2.13Bd	1.72Bd	7.40A	0.10	<0.01	<0.01	<0.01
Mean	8.91	5.10	6.17	6.07	4.67					
Propionic acid (g kg^{-1} DM)										
0%	3.01Ba	1.01Bb	3.01Aa	3.27Aa	2.06Ab	2.47				
5%	4.53Aa	2.77Ab	0.56Bc	0.35Bc	0.63Bc	1.77	0.19	<0.01	<0.01	<0.01
Mean	3.77	1.89	1.79	1.81	1.34					

Table 2. *Cont.*

GC [1]	Quantity of Fruit (QF)					Mean	SEM [2]	*p*-Value		
	0%	5%	10%	20%	100%			GC	QF	GC × QF
Butyric acid (g kg^{-1} DM)										
0%	1.67Ba	0.81Bb	1.66Ba	1.40Aa	1.05Ab	1.32				
5%	5.74Aa	3.28Ab	2.70Ac	0.23Bd	0.64Bd	2.52	0.07	<0.01	<0.01	<0.01
Mean	3.70	2.05	2.18	0.81	0.84					
Aerobic stability break (hours)										
0%	56.0Aa	56.0Ba	56.0Ba	56.0Aa	48.0Ab	54.4				
5%	72.0Bb	88.0Aa	88.0Aa	56.0Ac	56.0Ac	72.0	0.5	<0.01	0.07	0.02
Mean	64.0	72.0	72.0	56.0	52.0					
Internal temperature (°C)										
0%	33.5Aa	31.1Aa	27.8Ab	27.1Ab	33.5Aa	30.6				
5%	25.8Aa	27.8Aa	27.8Aa	26.8Aa	26.1Aa	26.9	0.5	<0.01	0.07	0.02
Mean	29.6	29.5	28.8	27.0	29.8					
pH in the aerobic stability break										
0%	7.6	7.5	6.8	6.3	4.3	6.5				
5%	6.4	6.1	6.3	5.1	4.1	5.6	0.1	<0.01	0.09	0.13
Mean	7.0a	6.8a	6.6a	5.7b	4.2c					

(GC) [1]: Ground corn; SEM [2]: corresponds to the standard error of the mean. Means followed by uppercase letters in the column and lowercase in the rows are statistically different according to Tukey's test $p < 0.05$.

Silages with 0% and 10% fruit with added ground corn and silages with 100% fruit without ground corn showed the largest LAB populations, showing averages of 7.98, 7.98, and 7.97 Log CFU g^{-1}, respectively. The average mold populations ranged from 5.36 to 5.42 Log CFU g^{-1}, and enterobacteria populations ranged from 3.54 to 4.10 Log CFU g^{-1} (Table 2), showing no significant effect.

Silages with 20% and 100% fruit with added ground corn showed the highest levels of lactic acid, averaging 2.46 and 2.99 g kg^{-1} DM, respectively. The acetic acid concentration was higher in silages with 0% fruit with ground corn, and 20% fruit without ground corn, averaging 10.96 and 10.00 g kg^{-1} DM, respectively. For propionic acid, higher values were observed in silages with 20% fruit without ground corn (3.27 g kg^{-1} DM) and 0% fruit with ground corn (4.53 g kg^{-1} DM). For butyric acid, the highest value was found in the silage with 0% fruit and added ground corn, which was 5.74 g kg^{-1} DM.

Breaks in aerobic stability occurred in silages with 100% fruit without the addition ground corn at 48 h, while in the other silages, aerobic stability broke down after 56 h. Higher values of internal temperature were recorded in silages with 0% and 100% fruit without ground corn, showing an average of 33.5 °C when the aerobic stability broke. The lowest pH was observed in the silage with 100% fruit, which was 4.2.

4. Discussion

4.1. Silage Yield, Chemical Composition, Loss Quantification, DM Recovery, pH, and Ammonia Nitrogen

The biomass with 5% fruit produced more silage. This result is related to the lower amount of fruit and greater amounts of leaf and shoot biomass available in the field. In melons, the number of fruits per plant and the average mass of fruits are determining characteristics in the productivity of the crop, which can change due to the partitioning of assimilates in the plant [31].

Adding ground corn in the silages increased the dry matter content. The lowest dry matter concentration was observed in silages with 100% fruit due to the low dry matter content of the fruits. According to Negrão et al. [32], the use of absorbent additives is efficient to reduce moisture because they contain high dry matter content, thereby diluting

the amount of water and favoring the preservation of the feed by inhibiting the development of undesirable microorganisms such as yeasts and enterobacteria.

Regarding the mineral matter content, the highest value was recorded in the silage with 100% fruit, which is related to the amount of organic salts present in the fruit. According to Fluck et al. [33], the higher the dry matter content of the forage, the higher the effluent production, and as a result, there will be higher losses of mineral matter, with relative increases in the percentages of organic matter.

The higher ether extract contents found in silages with 5 and 10% fruit are related to the melon's seeds, which have higher ether extract contents (80.3 g/kg DM) and fraction contents in silages. According to Borneroni et al. [34], in the process of silage fermentation, there is a concentration of the fractions content due to the consumption of soluble carbohydrates to produce organic acids and losses in the form of effluents and gases, which explains the higher concentration of ether extract in the produced silages. According to Kozloski [35], the maximum ether extract content in ruminant diets is 60 g kg^{-1} DM, and above this value, negative and inhibitory effects begin to appear on rumen fermentation, compromising nutrient digestibility due to the physical protection that lipids provide to fiber.

The higher acid detergent insoluble fiber content found in the silage with 100% fruit was probably due to the chemical composition of the fruit and seeds, so peels and seeds are considered lignocellulosic waste [36]. Regarding the greater CP content in the silage with 0% fruit and added ground corn, the addition of corn in the ensiled biomass probably caused less protein loss by favoring beneficial fermentations, which was also observed by Silva et al. [37]. The lower values observed in the other silages with ground corn can be explained by the dilution of crude protein present in the ground corn by the increasing amount of fruit in the silage, since melon fruit has a low crude protein content. A similar result was observed by Rêgo et al. [38], who added different amounts of corn meal in orange pomace silages and found a decrease in crude protein contents since the additive contained lower crude protein content than the orange pomace.

The higher contents of soluble carbohydrates observed in the silage with 100% fruit without ground corn is related to the chemical composition of the fruit, and in this silage, a pH of 4.3 was observed. An adequate concentration of soluble carbohydrates in the silage provides favorable conditions for the establishment and growth of homo-fermentative and hetero-fermentative bacteria. According to Carvalho et al. [39], these bacteria produce lactic acid in the fermentation process, which is desirable for providing rapid pH stabilization and preservation of the ensiled material.

The lowest effluent loss was observed in the silage produced with 0% fruit. Related to the moisture content of the fruit, the amount of effluent produced in a silo is mainly influenced by the ratio between the dry matter and moisture content. According to Melo et al. [40], moisture direct interferes in compaction, providing, therefore, greater loss through effluents. As for gas loss, the greater value found in the silage with 100% fruit may be related to the type of fermentation that occurred inside the silo, where the fruit favored fermentations that produce more gases (Table 1), probably because of the high moisture content and soluble carbohydrates present in the fruit. According to Jacovetti et al. [41], gas loss is influenced by the microbiology of the silage, where fermentation by yeasts propitiates dry matter losses, arising from the transformation of soluble carbohydrates into ethanol and the production of CO_2, which leads to reduced dry matter recovery.

The higher dry matter recovery rates observed in silages with 5% ground corn indicates lower losses during the fermentation process. The addition of corn bran reduced losses through effluent in the silage of melon biomass, which is a material that has high moisture, and the additive was responsible for increasing silage dry matter recovery. According to Pacheco et al. [42], higher dry matter recovery rates are related to lower gas losses, and the production of CO_2 by yeasts during fermentation is the main reason for the reduced dry matter recovery. Acting as a moisture-sequestering agent, ground corn improved the DMR of the melon silage, except for the silage with 100% fruit.

According to McDonald [43], pH is one of the indicators of silage quality and should be between 3.8 and 4.2. The silage with 100% fruit and added ground corn was the only one that fell within that range. The addition of ground corn associated with the low buffering power of the fruit (4.96 e.mg NaOH/100 g/DM) favored fermentation, explaining the lower pH values, in addition to the fact that the melon fruit has high amounts of soluble carbohydrates. Dórea et al. [44] evaluated jackfruit silage, and observed that the addition of 5% corn meal caused the lowest pH value, followed by the silage produced exclusively from jackfruit. The other silages showed pH levels higher than 6, which is explained by the fact that the melon plant biomass, especially the plant part, contains buffering substances, as it showed high buffering capacity (29.13 e.mg NaOH/100 g/DM), which hinders the reduction in pH and lowers the production of acids [45], thus impairing beneficial fermentation processes in the silage.

Ammonia nitrogen reflects the protein breakdown during the fermentation process, where values below 10% based on total nitrogen are acceptable to produce good-quality silage [25]. All values found in this study were below 1%, indicating that there was no excessive loss of crude protein during fermentation in the silages evaluated.

4.2. Microbial Populations, Organic Acids, and Aerobic Stability of the Silages

The bigger populations of lactic acid bacteria found in the silage with 100% fruit are related to the higher content of soluble carbohydrates suitable for the multiplication of these bacteria, the drop in pH, the lower buffering capacity, and to losses through effluent, thus producing more lactic acid. Larger LAB populations reduce the effect of undesirable microbials and retain a large amount of carbohydrates, which was observed in this experiment; however, the size of the LAB population was higher than the minimum limit of 5 log CFU/g recommended by Pahlow [46] and Muck [47]. According to Coelho et al. [48], it is desired that ensiled materials have a greater colonization of these bacteria because they are primarily responsible for the fermentation of sugars and the production of lactic acid.

The addition of ground corn increased dry matter content, thus favoring the development of hetero- and homo-fermentative lactic acid bacteria. According to Santana et al. [49], the higher protein contents of the silages may have served as a substrate for these microbials.

The mold population was within the expected average range, even though some melon plant biomass mixtures presented the optimal pH range (5–6), according to Muck [50], for their growth, which is considered undesirable. Enterobacteria populations were also within the expected average, as they do not develop at pH below 5, according to Muck [50].

The greater contents of lactic acid in silages with 20% and 100% fruit with ground corn show that the soluble carbohydrates content of the fruit provided higher concentration of this acid in these silages. According to Silva et al. [51], in well-fermented silages, lactic acid preserves the ensiled mass and is produced by LAB in an anaerobic environment, LAB being the main acidity-regulating agents of the ensiled mass.

Regarding the levels of acetic acid, the highest concentrations were found in silages with 0% and 20% fruit. The acetic acid content is related to higher final pH values in silages, corresponding mainly to the prolonged action of hetero-fermentative lactic bacteria and enterobacteria [52]. This increase in acetic acid was sufficient to reduce yeast populations, which explains the effect on the aerobic stability of the silages.

The propionic acid content in silages with 20% fruit and 0% fruit was beneficial to the preservation and stability of the silages, since this acid has been used for many years as a forage-preserving agent, in addition to its antifungal effect when there is a drop in silage pH, making it a desirable acid to improve the aerobic stability of silages at low pH [53] and given that its production is associated to the conversion of lactic acid to acetic acid. However, the concentrations were below the recommended range by Kung, Jr. et al. [54], who state that only concentrations above 5 g/kg DM can indicate high fermentation by clostridia because of Clostridium propionicum activity.

The concentration of butyric acid in the silages were considered low for all treatments. Butyric acid can be considered as one of the main negative quality indicators of the fermentation process, as it indicates the proliferation of saccharolytic clostridia in the ensiled mass, which decreases the conservation potential [55] due to the anaerobic degradation of lactate into butyric or acetic acid, with a consequent increase in pH.

Aerobic stability broke down faster in the silage with 100% fruit without ground corn, which is related to the high content of soluble carbohydrates in this silage. Silages with high concentrations of remaining sugars are more affected by aerobic deterioration [56]. Melon plant biomass silages with 0%, 5%, and 10% fruit with ground corn added showed delayed deterioration in aerobic stability, probably due to the lower amount of fruit. According to Santos et al. [57], smaller amounts of fermentable substrates inhibit or hinder the development of aerobic spoilage microorganisms.

Silages with 0% and 100% fruit without ground corn had higher internal temperatures due to the high moisture content and residual soluble carbohydrates that elevate the temperature and pH of the silage, propitiating greater aerobic deterioration. According to Coutinho et al. [58], the increase in temperature occurs by the action of opportunistic microorganisms that started their metabolic activities, producing heat and consuming residual soluble carbohydrates, which may lead to losses of dry matter and energy.

The higher pH values during aerobic stability in silages with 0%, 5%, and 10% fruit, may be related to the biomass of the melon plant, especially the plant biomass, which has high buffering power, reducing the concentration of lactic acid after exposure to air. According to Furtado et al. [59], the aerobic fermentation that occurs in silages after opening the silo is performed by microorganisms that use organic acids as main substrates, such as lactic acid, soluble sugars, and ethanol, since aerobic fermentation causes pH to increase due to microbial action.

5. Conclusions

Quality indicators obtained from the different melon biomass silages showed that silages with 0%, 5%, and 100% fruit have the potential to be used in ruminant diets.

Adding ground corn improves the quality parameters of silages produced from the remaining melon biomass after harvesting the commercial fruit.

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