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Characterization of Melon, (*Cucumis melo* L.) Silage with Different Biomass Mixtures and Dry Matter Contents

Romilda Rodrigues do Nascimento [1], Ricardo Loiola Edvan [1,*], Keuven dos Santos Nascimento [2], Dhiéssica Morgana Alves Barros [1], Lucas de Souza Barros [3], Luan Felipe Reis Camboim [3], Tairon Pannunzio Dias e Silva [1], Rafael de Souza Miranda [1], Marcos Jácome de Araújo [1], Anisio Ferreira Lima Neto [4], Leilson Rocha Bezerra [3], Francisco Naysson de Sousa Santos [5], Edson Mauro Santos [6] and Stelio Bezerra Pinheiro de Lima [1]

[1] Department of Animal Science, Federal University of Piaui, Teresina 64000-900, PI, Brazil; romildarn01@ufpi.edu.br (R.R.d.N.); morganabarros1@ufpi.edu.br (D.M.A.B.); pannunzio@ufpi.edu.br (T.P.D.e.S.); rsmiranda@ufpi.edu.br (R.d.S.M.); jacome@ufpi.edu.br (M.J.d.A.); steliolima@ufpi.edu.br (S.B.P.d.L.)
[2] Department of Animal Science, State São Paulo University, Jaboticabal 14884-900, SP, Brazil; keuven.s.nascimento@unesp.br
[3] Department of Animal Science, Federal University of Campina Grande, Patos 58708-110, PB, Brazil; lucas.barros1@estudante.ufcg.edu.br (L.d.S.B.); luanzootec@ufpi.edu.br (L.F.R.C.); leilson@ufpi.edu.br (L.R.B.)
[4] Brazilian Agricultural Research Company (EMBRAPA), Teresina 64006-220, PI, Brazil; anisio.lima@embrapa.br
[5] Department of Animal Science, Federal University of Maranhão, São Luís 65500-000, MA, Brazil; nayssonzootecnista@gmail.com
[6] Department of Animal Science, Federal University of Paraíba, CCA, Areia 58397-000, PB, Brazil; edson@cca.ufpb.br
* Correspondence: edvan@ufpi.edu.br

Abstract: The objective of this study was to obtain different dry matter contents and proportions of melon plant biomass for silage making. A completely randomized design with factorial arrangement (3 × 2) and four replications was adopted. The first factor consisted of three melon biomass mixtures based on as-fed composition of plant (branches + leaves) and harvested melon (fruits)—100% plant (0% fruit), 90% plant + 10% fruit, and 100% fruit. The second factor corresponded to the ensiled material, which was either fresh or dehydrated in the field after harvest (40% dry matter). Silages produced from dehydrated biomass after fruit harvest, containing 0% and 10% fruit, showed the highest dry matter contents: 297 g/kg and 293 g/kg, respectively. Silages produced from fresh biomass containing 0% and 10% fruit showed high concentrations of acetic acid, reaching 14.9 g/kg and 14.1 g/kg, respectively. Silages produced from dehydrated biomass containing 10% and 100% fruit showed better results in terms of the indicators associated with high-quality silage. Dehydration improves the fermentative profile and overall quality of melon silage.

Keywords: dehydration; fermentative indicators; nutrients; melon; silage

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1. Introduction

The fruit processing industry generates large amounts of biomass annually, which consists of several components, including shells, seeds, and leaves. The primary reason for the disposal of these residues is their low nutritional value or unsatisfactory sensory characteristics [1]. The implementation of strategies aiming to balance economic development with environmental protection and resource preservation is a crucial and highly relevant topic for the advancement of the agri-food sector. One strategic approach involves exploring the feasibility of utilizing residual cakes obtained from the seed oil extraction process of plants such as thistle and hemp. These cakes have the potential to serve as

valuable sources of protein-rich feed for ruminant animals, making it a recommended practice to be adopted [2,3].

The utilization of this agro-industrial fruit biomass offers favorable nutritional characteristics for animal feeding, making it a viable alternative, particularly in the form of silage [4]. Melon biomass is a suitable option for silage making. Following the harvest of commercial melons, a substantial amount of biomass of plant (branches + leaves) and fruit (melon scraps) becomes available in the field, presenting an opportunity to utilize them as components in the diet of ruminant animals, especially when used as silage. The preservation of this material through ensiling offers an attractive solution for animal feeding in melon-producing regions. This approach avoids waste while creating a new feed source for animals [5].

The ensiling process presents problems related to intrinsic factors of the plant. Low dry matter content, for example promotes the proliferation of undesirable microorganisms that interfere directly in the fermentation and nutritional aspects of the ensiled mass, leading to nutrient losses [6]. Dehydration is a technique used to mitigate losses in the ensiling process for biomasses with high moisture content. This method involves exposing the material to sunlight for a brief period before crushing it, which increases dry matter content of the material to be ensiled and thereby prevents undesirable fermentations [7].

To achieve high-quality silage with optimal fermentative and nutritional characteristics, it is essential to understand the factors that influence the dynamics of dry matter and nutrient losses. Similarly, having knowledge of fermentative indicators such as chemical composition, microbiology, stability, and organic acids is crucial to achieve productive efficiency in silage production [8].

Ensiling melon biomass poses significant challenges that stem from inherent qualities of the plant, requiring the use of additives to improve fermentation characteristics. The incorporation of corn bran as an additive has shown positive effects on the quality parameters of silages, while the addition of urea has contributed to reducing the yeast population, which is crucial for enhancing the aerobic stability of melon fruits. It was observed that specific fruit quantities (0%, 10%, and 100% fruits) yielded superior quality given indicative parameters in the silages produced [9,10]. These measures present viable options for farmers living in melon-producing regions.

The objective of this study was to characterize melon silage with different biomasses, dry matter proportions, and their effect on losses (gases and effluents), dry matter recovery, silage yield, microbiological dynamics, chemical composition, organic acids, and aerobic stability.

2. Materials and Methods

2.1. Statistical Design and Treatments

The experiment adopted a completely randomized design using factorial arrangement (3×2) in four replications. The first factor consisted of three mixtures based on the as-fed (AF) composition of plant material (branches + leaves) and harvested melon (fruits): 100% plant (0% fruit), 90% plant + 10% fruit, and 100% fruit. The second factor corresponded to the ensiled material categorized as either fresh with natural dry matter (DM) content or dehydrated after harvest, containing 40% dry matter content. The quantities of fruits used were determined based on prior research, which utilized varying percentages (0%, 5%, 10%, 20%, and 100%) as described by Nascimento et al. [10].

2.2. Collection of Melon Plant Biomass and Silage Making

The melon biomass was harvested from a melon farm situated in the Vale do Gurguéia region, located in the southern part of Piauí state. The melon season in this area typically lasts from July to October. The biomass collection took place in September, specifically 85 days after planting (DAP), following three rounds of commercial melon harvesting.

The melon biomass utilized for silage production originated from a farm owned by Itaueira Agropecuária S.A. The specific melon variety used was 'Gold Mine', which is

characterized by its vibrant yellow peel and adaptability to hot and arid climates. This variety exhibits a trailing growth habit with lateral branches. The cultivation process on the farm involves drip irrigation, with soil covered by a 1.20 m wide layer of mulch made from 25-micron polyethylene. Fertilization and phytosanitary measures were implemented in accordance with the crop's specific requirements and recommendations, as outlined by Silva et al. [11].

Following the biomass collection, chemical composition analyses were conducted. The determination of green forage mass (GFM) was performed using the square method, which involves using a PVC pipe structure measuring 0.5 m by 0.5 m (0.25 m^2). This technique is widely recognized as an approach for evaluating forage biomass. It entails cutting and evaluating the area delimited by the frame [12]. In this specific experiment, the collection points for melon biomass were selected randomly. The biomass was harvested by cutting it 10 cm from the ground, then it was chopped and packed into plastic bags for subsequent measurement of the total fresh weight.

After collection, the material was partitioned into fractions, with each portion being weighed before and after treatment allocation (100% plant, 90% plant + 10% fruit, and 100% fruit). Samples were then transported to a greenhouse for dry matter analysis [13]. Silage dry yield was determined through dry matter recovery (DMR). Silage DM yield (DMY) was determined using the following equations:

DMY = (BIO × DM)/100, where DMY is the dry matter yield (t/ha DM), BIO is the biomass (t), and DM is the dry matter content (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 %.

The fresh plant material was mechanically processed in a stationary forage chopping machine (model 30648-2 Garthen®, Santa Catarina, Brazil) equipped with a 2 cm sieve. After chopping, a portion of the material was promptly ensiled, while another portion was subjected to dehydration by exposing it to sunlight. During this period, the material was periodically turned over to ensure consistent dehydration. Once the forage reached a DM content of 40%, it was collected and ensiled. The determination of DM content was carried out using the microwave method, following protocol described by Souza et al. [14].

For this study, experimental silos made from polyvinyl chloride (PVC) with a capacity of 3 kg were utilized. These silos had a diameter of 10 cm and a length of 30 cm. To ensure adequate compaction, the material was compacted using wooden sticks until a density of 500 kg/m^3 was achieved. The silos were equipped with a Bunsen-type valve adapted to the lid, allowing for the release of fermentation gases. After 90 days, the silos were opened for subsequent analysis. All analyzes were conducted at the Animal Nutrition Laboratory (LANA) at CPCE/UFPI.

2.3. Silage Chemical Composition and Loss Quantification

Analyses were conducted to determine the content of dry matter (DM), ash, ether extract (EE), and crude protein (CP) following AOAC [15], specifically 934.01, 942.05, 920.39 and 968.06, respectively. The contents of neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using the methodology described by Mertens [16].

The determination of soluble carbohydrate concentration followed the method described by Nelson [17]. Buffer capacity was assessed using the methodology described by Mizubuti et al. [18]. The experimental silos were weighed both after closing and after opening to measure dry matter (DM) losses through gases and effluents and to calculate dry matter recovery (DMR) using the equations described by Jobim et al. [19]. The chemical composition of the material prior to ensiling is presented in Table 1.

Table 1. Chemical composition of melon plant prior to ensiling.

Analyses	100% Plant	90% Plant + 10% Fruit	100% Fruit
Dry matter (g/kg)	150.2	145.3	98.8
Ash (g/kg DM)	79.1	73.5	80.6
Crude protein (g/kg DM)	46.5	50.6	57.4
NDF [1] (g/kg DM)	652.0	457.2	472.9
ADF [2] (g/kg DM)	428.8	319.2	276.7
pH	7.29	5.57	6.53
N-NH_3 [3] (%)	0.68	0.70	0.95
CHO [4] (g/kg)	92.7	120.0	174.0
Buffer Cap. [5]	22.62	10.29	6.74

[1] Neutral detergent fiber; [2] Acid detergent fiber; [3] Ammonia nitrogen based on total N; [4] Soluble carbohydrates; [5] Buffer capacity (e.mg NaOH/100 g/DM).

2.4. Silage Fermentation Indicators, Microbiological Analysis and Organic Acids Determination

The values of pH and ammonia nitrogen (N-NH_3) were obtained through the methodology described by Detmann [20] using a digital potentiometer (Tecnal, Piracicaba, Brazil) for immediate measurement. The microbial populations were quantified using specific culture media for each microbial group—MRS Agar (Kasvi, São José dos Pinhais, Brazil) with nystatin (control of undesirable microorganisms—CUM) after sterilization and incubation for 72 h at 37 °C, Violet Red Bile Lactose (Kasvi, São José dos Pinhais, Brazil) with nystatin (CUM) and incubation for 24 h at 37 °C, and Potato Dextrose Agar (Kasvi, São José dos Pinhais, Brazil) with tartaric acid (CUM) after two days of incubation at 26 °C in B.O.D [21]. Values were considered countable between 30 and 300 CFU per plate.

The quantification of organic acids was performed through high-performance liquid chromatography (HPLC, SHIMADZU, SPD-10A VP, São Paulo, Brazil), as described by Erwin et al. [22]. The HPLC system used an Aminex HPX-87H column manufactured by BIO-RAD, Santa Clara, CA, USA.

2.5. Aerobic Stability

The experimental silos used to store the silage samples were left without lids and were not subjected to any compaction process. These silos were placed in a closed environment with a controlled temperature of 25 °C. To monitor the internal temperature of the silages, digital immersion thermometers were inserted into the center of the silage mass and readings were taken every four hours. The onset of deterioration was determined when the internal temperature of the silages exceeded the room's temperature by 2 °C, following the definition provided by Kung Jr et al. [23]. Samples were collected from the silos for pH measurements and microbiological analyses.

2.6. Statistical Analysis

The data were subjected to analysis of variance (ANOVA) for statistical analysis. Means were calculated using Tukey's test and statistical significance was determined at a p-value of $p < 0.05$. The analysis was performed using SISVAR software version 5.0 [24], following the equation below:

$$Y_{ijk} = \mu + \tau_i + \gamma_j + (\tau\gamma)_{ij} + \varepsilon_{ijk} \quad (1)$$

where: Y_{ijk} = is the record referring to the different mixtures of the melon biomass i and dehydration j; μ = general constant; τ_i = effect of the different mixtures of melon biomass and dehydration i; i = 1, 2, 3; (100% plant, 90% plant + 10% fruit, 100% fruit); γ_j = is the effect of dehydration (fresh or dehydrated); $(\tau y)_{ij}$ = is the effect of interaction between the different mixtures of melon plant biomass i and dehydration j; ε_{ijk} = is the effect of random error associated with each mixture of melon biomass and dehydration.

3. Results

3.1. Silage Yield and Chemical Composition

Table 2 shows the significant effect of interaction ($p < 0.05$) of the different biomass mixtures (varying levels of fruit inclusion in the silage, 0%, 10%, and 100% AF) with fresh or dehydrated material on silage yield, DM, and EE. However, no significant effects were observed on CP, ADF, and Ash contents of silages containing different dehydrated melon plant biomasses.

Table 2. Chemical composition of silages produced from different mixtures of fresh or dehydrated melon plant biomass.

Deh. [1]	Percentage of Fruit (PF)			*p*-Value		
	0%	10%	100%	Deh. [1]	PF	Deh. [1] × PF
Silage yield						
Fresh	3.96 Bb	4.91 Ba	1.75 Bc	0.001	0.001	0.001
Dehydrated	6.50 Ab	6.13 Aa	3.28 Ac			
Dry matter (g/kg)						
Fresh	215 aB	205 aB	135 bB	0.001	0.001	0.001
Dehydrated	297 aA	293 aA	249 bA			
Crude Protein (g/kg DM)						
Fresh	60.8	56.5	61.5	0.173	0.619	0.566
Dehydrated	60.9	60.4	55.4			
Acid Detergent Fiber (g/kg DM)						
Fresh	387	439	424	0.265	0.411	0.867
Dehydrated	372	391	402			
Ether Extract (g/kg DM)						
Fresh	35.0 cA	50.8 bA	88.8 aA	0.021	0.001	0.001
Dehydrated	31.1 cA	45.8 bB	84.1 aA			
Ash (g/kg DM)						
Fresh	73.0	77.5	82.4	0.124	0.238	0.085
Dehydrated	82.2	94.8	76.0			

[1] Deh—dehydration. Means followed by uppercase letters in the column and lowercase in the rows differ according to Tukey's test $p < 0.05$.

The silage containing 0% and 10% fruit produced from dehydrated material presented the highest yields, reaching 6.5 and 6.1 t/ha DM. Among the silages subjected to dehydration after melon harvest, those with 0% and 10% fruit had the highest DM contents, reaching 297 and 293 g/kg DM, respectively. On the other hand, the silage with 100% fruit showed the highest EE content, both dehydrated or not, reaching 84.1 and 88.8 g/kg DM, respectively.

Table 3 displays a significant difference ($p < 0.05$) in the contents of neutral detergent fiber (NDF) and soluble carbohydrates, with DM recovery and pH as the only effect of the percentage of fruits.

The silage containing 0% fruit showed the highest mean NDF content (661.5 g/kg DM) and the lowest mean for 10 and 100% fruit (632.5, 629.5 g/kg DM). Regarding soluble carbohydrates, the highest content was found in the silage with 100% of fruits, reaching 151 g/kg DM, and the lowest content for 0% and 10% of fruits (65.9, 78.1 g/kg MS).

Table 3. Chemical composition, DM recovery, and pH of silages produced from different mixtures of fresh or dehydrated melon plant biomass.

Deh. [1]	Percentage of Fruit (PF)			*p*-Value		
	0%	10%	100%	Deh. [1]	PF	Deh. [1] × PF
Neutral Detergent Fiber (g/kg DM)						
Fresh	653	604	651	0.231	0.050	0.576
Dehydrated	670	661	608			
Soluble Carbohydrates (g/kg DM)						
Fresh	62.5	79.9	152	0.895	0.001	0.334
Dehydrated	69.8	76.3	150			
DM Recovery (%)						
Fresh	79.2	79.2	62.5	0.643	0.001	0.274
Dehydrated	78.1	69.7	67.6			
pH						
Fresh	7.9	7.8	4.7	0.654	0.001	0.531
Dehydrated	7.4	7.3	4.1			

[1] Deh—dehydration.

The silages containing 0% fruit had the highest mean DM recovery (78.6%) and the lowest for 10% and 100% fruit (66.1, 65.8%). Silages with 0% and 10% fruit had the highest mean pH, reaching (7.6, 7.5), respectively, and the lowest for 100% fruit (4.4).

3.2. Losses and Fermentation Indicators

Table 4 shows a significant effect of interaction ($p < 0.05$) between different biomass mixtures (0%, 10% and 100% fruit AF) and dehydration (fresh or dehydrated biomass) on gases and ammonia nitrogen content in the evaluated silages.

Table 4. Fermentation losses of silages produced from different mixtures of fresh or dehydrated melon plant biomass.

Deh. [1]	Percentage of Fruit (PF)			*p*-Value		
	0%	10%	100%	Deh. [1]	PF	Deh. [1] × PF
Effluent (kg/t AF)						
Fresh	49.9	51.2	53.1	0.743	0.398	0.754
Dehydrated	50.3	49.3	57.0			
Gases (% DM)						
Fresh	2.0 Ab	2.0 Ab	4.5 Aa	0.001	0.001	0.001
Dehydrated	2.0 Ac	1.4 Bb	3.5 Ba			
$N\text{-}NH_3$ (% TN) [2]						
Fresh	0.9 Aa	0.4 Bb	0.9 Aa	0.434	0.023	0.001
Dehydrated	0.5 Bb	0.7 Aa	0.8 Aa			

[1] Deh—dehydration. [2] $N\text{-}NH_3$ (% TN)—ammonia nitrogen in relation to the percentage of total nitrogen. Means followed by uppercase letters in the column and lowercase in the rows differ according to Tukey's test $p < 0.05$.

Silages produced from fresh biomass containing 10% and 100% fruit showed the highest gases percentages, measuring 2.0% and 4.5%, respectively. The silages produced from fresh plant material containing 0% and 100% fruit had the highest ammonia nitrogen ($N\text{-}NH_3$) contents, reaching 0.9% and 0.9% TN, respectively.

3.3. Microbiology Analysis and Organic Acids of Silages

Table 5 shows the significant only effect of the different mixtures ($p < 0.05$) on the population count of lactic acid bacteria, yeasts and enterobacteria, butyric acid, and pH on aerobic stability.

Table 5. Microbial counts, butyric acid and pH on aerobic stability in silages produced from different mixtures of fresh or dehydrated melon plant biomass.

Deh [1]	Percentage of Fruit (PF)			*p*-Value		
	0%	10%	100%	Deh. [1]	PF	Deh. [1] × PF
Lactic acid bacteria (CFU/g) [2]						
Fresh	4.1	4.8	5.7			
Dehydrated	5.3	5.2	7.7	0.083	0.001	0.964
Yeasts (CFU/g)						
Fresh	0.0	0.0	4.95			
Dehydrated	0.0	0.0	4.59	0.756	0.001	0.904
Enterobacteria (CFU/g)						
Fresh	3.4	3.5	0.0			
Dehydrated	2.7	2.4	0.0	0.137	0.001	0.131
Butyric acid (g/kg DM)						
Fresh	4.1	3.5	1.5			
Dehydrated	6.3	4.4	1.1	0.084	0.001	0.145
pH						
Fresh	8.1	7.1	3.9			
Dehydrated	8.1	4.4	4.2	0.667	0.001	0.274

[1] Deh—dehydration. [2] CFU—colony forming units.

The highest mean population of lactic acid bacteria in the silage containing 100% fruit was 6.7 log CFU/g and the lowest for 0% and 10% fruit was 4.7, 5.07 logs CFU/g. The greatest yeast populations were found in silages containing 100% fruit (4.77 log CFU/g) and the lowest were found in 0% and 10% fruit (0.0, 0.0 logs CFU/g).

Regarding enterobacteria, the lowest mean was found in silages containing 100% fruit, reaching 0 log CFU/g, and the highest for 0% and 10% fruit was 3.0, 2.9 logs CFU/g. The highest average of butyric acid was found in silages with 0% reaching 5.2 g/kg DM and the lowest for 10% and 100% fruit was 3.9, 1.3 g/kg DM. The silage containing 0% fruit showed the highest mean pH (8.1) when exposed to air compared to 10% and 100% fruit (5.8, 4.0).

Table 6 presents the significant effect of interaction ($p < 0.05$) between different biomass mixtures (increased inclusion of fruit in the silages, 0, 10, and 100% AF) and dehydration (fresh or dehydrated material) on the populations of molds as well as on the contents of lactic, acetic, and propionic acids.

Silages containing 10% fruit produced from dehydrated material had the highest mold population value at 4.0 CFU/g. Silages containing 10% and 100% fruit produced from dehydrated biomass showed the highest contents of lactic acid, reaching 6.5 and 12.7 g/kg DM, respectively.

The concentration of acetic acid was higher in silages containing 0% and 10% fruit produced from fresh biomass, reaching 14.9 and 14.1 g/kg DM, respectively. Regarding the propionic acid, the highest value was found in silages produced from fresh material with 0% and 10% fruit, reaching 5.7 and 4.4 g/kg DM, respectively.

Table 6. Mold population count and contents of organic acids in silages produced from different mixtures of fresh or dehydrated melon plant biomass.

Deh. [1]	Percentage of Fruit (PF)			*p*-Value		
	0%	10%	100%	Deh. [1]	PF	Deh. [1] × PF
			Molds (CFU/g)			
Fresh	2.5 Aa	0.0 Bb	3.6 Aa	0.001	0.001	0.001
Dehydrated	2.8 Aa	4.0 Aa	3.1 Aa			
			Lactic acid (g/kg DM)			
Fresh	0.7 Bb	2.2 Bb	11.2 Aa	0.001	0.001	0.001
Dehydrated	4.4 Ac	6.5 Ab	12.7 Aa			
			Acetic acid (g/kg DM)			
Fresh	14.9 Aa	14.1 Aa	3.8 Ab	0.001	0.001	0.001
Dehydrated	9.2 Ba	5.5 Bb	4.5 Ab			
			Propionic acid (g/kg DM)			
Fresh	5.7 Aa	4.4 Ab	1.1 Bb	0.001	0.001	0.001
Dehydrated	3.6 Ba	2.1 Bb	2.3 Ab			

[1] Deh—dehydration. Mean followed by uppercase letters in the column and lowercase in the rows differ according to Tukey's test $p < 0.05$.

3.4. Aerobic Stability and Microbiology Analysis

Table 7 presents the significant effect of interaction ($p < 0.05$) between different biomass mixtures (0%, 10%, and 100% fruit) and dehydration (fresh or dehydrated material) on aerobic stability. Silages produced from dehydrated biomass with 100% fruit showed aerobic stability break at 48 h.

Table 7. Aerobic stability of silages produced from different mixtures of fresh or dehydrated melon plant biomass.

Deh [1]	Percentage of Fruit (PF)			*p*-Value		
	0%	10%	100%	Deh. [1]	PF	Deh. [1] × PF
			Hours			
Fresh	28.0 Bc	88.0 Aa	64.0 Ab	0.001	0.001	0.001
Dehydrated	36.0 A	36.0 B	48.0 B			
			Internal temperature (°C)			
Fresh	28.7	27.5	27.8	0.556	0.158	0.887
Dehydrated	28.2	27.5	27.6			

[1] Deh—dehydration. Means followed by uppercase letters in the column and lowercase in the rows differ according to Tukey's test $p < 0.05$. Hours internal temperature (°C).

Table 8 presents the significant effect of interaction ($p < 0.05$) between different biomass mixtures (increased inclusion of fruit in the silage, 0%, 10%, and 100% AF) and the dehydration on stability for enterobacteria and mold populations.

No yeasts were found in the silages containing 0% fruit. Regarding the mold population in terms of aerobic stability, higher values were observed in silages with 0% and 100% fruit, reaching 3.5 and 3.4 Log/CFU/g[1], respectively. Enterobacteria were not detected in silages with 100% fruit produced from fresh or dehydrated material.

Table 8. Microbial counts on aerobic stability of silages produced from different mixtures of fresh or dehydrated melon plant biomass.

Deh [1]	Percentage of Fruit (PF)			*p*-Value		
	0%	10%	100%	Deh. [1]	PF	Deh. [1] × PF
			Lactic acid bacteria (CFU/g)			
Fresh	5.2	4.2	5.3	0.951	0.308	0.729
Dehydrated	5.0	4.7	5.0			
			Molds (CFU/g)			
Fresh	2.5 Bb	5.2 Aa	0.0 Bc	0.968	0.001	0.001
Dehydrated	3.5 Aa	1.9 Bb	3.4 Aa			
			Enterobacteria (CFU/g)			
Fresh	2.9 Aa	3.0 Aa	0.0 Ab	0.001	0.001	0.001
Dehydrated	0.0 B	0.0 B	0.0 A			

[1] Deh—dehydration. Means followed by uppercase letters in the column and lowercase in the rows differ according to Tukey's test $p < 0.05$.

4. Discussion

4.1. Silage Yield and Chemical Composition

Silages produced from dehydrated material containing 0% and 10% fruit had higher silage yield, which can be attributed to effective crop management and the positive impact of dehydration. In addition to higher yield, the fruit is expected to possess superior quality, which is influenced by the crop management practices throughout its growth cycle affecting the soluble solids content [25].

Silages produced from dehydrated biomass after melon harvest and containing 0% and 10% fruit showed higher DM content. According to McDonald and Solow [26], a minimum DM content of 30 g/kg is recommended for adequate fermentation during ensiling. The values observed in this study were close to this threshold. Dehydration or withering techniques, as highlighted by Itavo et al. [27], can enhance certain characteristics of the ensiled material, such as the DM content, N-NH_3 concentrations, microbiology, in addition to reducing fermentation losses, resulting in improved fermentation in the stored silage.

Higher EE contents were observed in silages with 100% fruit, both from dehydrated and fresh material. These results can be attributed to the higher fat content present in melon seeds. According to Possenti et al. [28], melon stores its energy in the form of oil in its seeds. Palmquist [29] suggests that EE values should not exceed a maximum level of 50 g/kg DM in ruminant diets, which is lower than the values obtained in this study. Therefore, it is not recommended to rely on melon silage as the only source of roughage for ruminants.

The NDF content had a higher mean in silages with 0% fruit, indicating that the addition of dehydrated fruit caused the reduction of NDF values. Van Soest [30] suggests that the recommended NDF mean typically ranges from 550–600 g/kg DM. The values obtained in our study were within this range. Figueiredo et al. [31] stated that a high NDF mean can be detrimental as it hinders degradation by microorganisms in the animal's digestive tract, thus reducing nutritional quality. However, the inclusion of fruit and biomass dehydration led to a reduction in the NDF values.

The silage with 100% fruit had the highest mean soluble carbohydrate content, which can be attributed to the higher concentration of soluble carbohydrates naturally present in the melon fruit, making it suitable for silage production. The dehydration did not influence the total soluble carbohydrate content. According to Zamarchi et al. [32], adequate levels of soluble carbohydrates are necessary for silage to undergo proper fermentation. Plants with high carbohydrate content provide a favorable environment for the growth of desirable microorganisms. However, excessive soluble carbohydrates can predispose the medium to undesirable fermentations, resulting in losses that may impact the forage's DM content [33] and its nutritional value.

Silages with 0% fruit showed the highest mean dry matter recovery, which is strongly influenced by losses from effluent and gas production. Silages with higher DM content increased DMR as losses through gases and effluents were reduced. Machado et al. [34] noted that DMR below 80% can result in significant losses due to heat production and the generation of CO_2 and organic acids such as butyric acid, which fail to preserve the ensiled material.

Silages containing 0% and 10% fruit showed higher pH values, which can be attributed to the substantial buffer capacity of the plant branch (leaf + branch), measuring 22.62 e.mg NaOH/100 g/DM. Several factors, including the constituents present in the melon plant biomass, may have hindered a decrease in pH below the desirable range of 3.8–4.2 for ensiled material [35]. Additionally, the dehydration process of the silage influenced the results by reducing the amount of water in the forage, leading to increased dry matter. This facilitated a favorable fermentation process and promoted the proliferation of lactic acid bacteria which are responsible for lowering the pH [32].

4.2. Losses, DM Recovery and Fermentation Indicators

Higher gases losses were observed in silages with 10% and 100% fruit. These losses occur due to secondary fermentations within the silo. However, in this study, low losses of effluent and gases were recorded, indicating that secondary fermentations were insignificant. França et al. [36] explained that gas formation in silages is a result of secondary fermentations caused by enterobacteria, clostridia bacteria, and aerobic microorganisms, which typically thrive in higher pH environments.

Silages produced from fresh biomass with 0% and 100% fruit had the highest ammonia nitrogen (N-NH_3) levels, indicating a lower degree of proteolysis during the fermentation process. These values were lower than the recommended levels, suggesting that excessive protein breakdown did not occur [37]. The N-NH_3 reflects the degradation of protein during fermentation, and silages can be classified based on the content of ammonia nitrogen relative to total nitrogen. When values are lower than 10%, silages are considered excellent, indicating minimal protein breakdown.

4.3. Microbiology Analysis and Organic Acids of Silages

The populations of lactic acid bacteria increased in silages due to the contribution of dehydration in providing substrates for their multiplication. The proliferation ensures the stability and preservation of the ensiled mass by producing lactic acid and reducing the pH [38].

The highest yeast population mean was observed in the silage containing 100% fruit. The presence of this microorganism in silages raises concerns due to their potential for rapid multiplication after the silo is opened. When oxygen penetrates the silage, yeasts utilize lactic acid for energy production and multiplication, leading to an increase in pH when exposed to air [39]. This can result in heating and accelerate the break of aerobic stability.

Silages containing 100% fruit showed the lowest mean of enterobacteria. This can be attributed to the higher values of lactic acid and lower pH observed in these silages. Enterobacteria tend to thrive in higher pH ranges. The growth of enterobacteria is considered undesirable due to their ability to ferment carbohydrates into acetic acid and degrade amino acids, as mentioned by Napasirth et al. [40].

Higher means of butyric acid were observed in silages with 0% fruit. In addition, the dehydration promoted a reduction in butyric acid concentration, which can be attributed to the increased DM content. The presence of this acid is not desired since it is considered a product of undesirable fermentation by bacteria of the *Clostridium* genus, as mentioned by Kung Jr et al. [35].

The silage produced from fresh plant with 0% fruit had the highest pH mean, which can be attributed to the high buffer capacity of the plant branch (leaf + branch) of 22.62 e.mg NaOH/100 g/DM, even after exposure to oxygen. According to Rezende et al. [41],

pH variation during air exposure indicates potential spoilage due to contact with air, even with dehydration.

Silages from dehydrated biomass with 10% fruit had the highest mean mold population counts. The presence of molds throughout the fermentation period indicates that the produced organic acids were not sufficient to inhibit their growth. Molds are primarily responsible for aerobic deterioration of silages after the silo is opened, as suggested by Weinberg et al. [42].

Silages produced from dehydrated biomass with 10 and 100% fruit had higher levels of lactic acid. Dehydration promotes increased activity of lactic acid bacteria resulting in decreased pH values and a better balance between lactic and acetic acids. Lactic acid, with its higher dissociation constant compared to other acids, plays a crucial role in reducing the pH of the silage [43].

Silages containing 0% and 10% fruit produced from dehydrated material showed higher concentrations of acetic acid. The high acetic acid content in non-dehydration silages may be attributed to a slower pH decline, indicating lower efficiency of LAB in dominating the fermentation process and favoring other microorganisms that produce acetic acid.

In terms of propionic acid, higher values were observed in silages produced from fresh biomass with 0% and 10% fruit. The lower concentration of propionic acid in withered silages can be explained by better control of secondary fermentations, which are responsible for the formation of other organic acids. The propionic acid values of 5.4 and 3.2 g/kg DM for silages from fresh and dehydrated plant, respectively, at the end of the fermentation period, fall within the acceptable range of 1–10 g/kg DM for good-quality silage production [44].

4.4. Aerobic Stability and Microbiology Analysis

The aerobic stability break was observed in silages with 100% fruit, which can be attributed to the presence of fermentable substrates such as decreased soluble carbohydrates and lactic acid, increased pH, higher yeast, and filamentous fungi population values [40], as well as high temperature [45].

Silages with 0% fruit showed no presence of yeasts, indicating higher resistance to deterioration due to low lactic acid content. The presence of yeast plays a significant role in silage deterioration and may have been a result of limited residual sugars, as they degrade lactic acid into carbon dioxide and water, generating excessive heat and nutrient loss [46].

No count of enterobacteria was recorded in silages with 100% fruit from fresh and dehydrated plant material. Enterobacteria compete with lactic acid bacteria for the consumption of soluble carbohydrates, and the reduction in medium pH can inhibit or decrease the development of enterobacteria and *Clostridium*, which is influenced by the dehydration process [21].

Higher mold population values were observed in silages with 0% and 100% fruit during aerobic stability. This may be attributed to the duration of aerobic exposure and the lower aerobic stability, as reported by Tangni et al. [47], who noted that the presence of oxygen triggers microbial reproduction in silage, promoting proliferation.

5. Conclusions

Silages produced from dehydrated plant material with 10% and 100% fruit showed superior quality indicators, primarily due to the increased DM content. This improvement in dry matter content positively influenced the fermentation process, making these combinations of biomass the most recommended for silage production.

Furthermore, the process of dehydration improved the fermentative profile and overall quality of the melon silage.

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