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Spineless cactus varieties resistant to carmine cochineal (*Dactylopius* sp.) on the composition and sensory properties of goat milk

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ABSTRACT. The physical-chemical characteristics and sensory attributes of milk are variable. This study aimed to evaluate how spineless cactus varieties resistant to carmine cochineal (*Dactylopius* sp.) influences the composition and sensory characteristics of goat milk. Twelve lactating goats with body weights of 51.35 ± 3.75 kg were distributed in a 4 × 4 Latin square, with three simultaneous squares composed of four animals, four periods, and four experimental diets: Control - goats fed tifton grass hay and concentrate; SCOE - goats fed the Orelha-de-elefante spineless cactus, tifton hay, and concentrate; SCB – goats fed the Baiana spineless cactus, tifton hay, and concentrate; SCM – goats fed the Miúda spineless cactus, tifton hay, and concentrate. The levels of protein and non-greasy solids and the sensory attributes of the milk (odor, butter flavor, and global acceptance) did not differ between the treatments ($p > 0.05$). The lipid content of the milk was reduced in the SCOE treatment compared to the control ($p = 0.0014$). The milk obtained from animals fed the SCOE and SCM treatments had a stronger flavor ($p < 0.05$). These results suggest that varieties of spineless cactus resistant to carmine cochineal can be used as goat feed without affecting milk production or global acceptance.

Keywords: cactus; goats; *nopalea*; *opuntia*.

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Introduction

Goat milk is a healthy food and a source of protein with high biological value. It is a valuable commodity in many countries and has a greater composition and mineral bioavailability than cow milk. (Verruck, Dantas, & Prudencio, 2019; Montalbano, Segreto, Gerlando, Mastrangelo, & Sardina, 2016; Raynal-Ljutovac, Lagriffoul, Paccard, Guillet, & Chilliard, 2008). The composition, physicochemical characteristics, and sensory attributes of goat milk varies due to genetic, physiological, climatic, and dietary factors. Feeding is the most important factor underlying goat milk sensory attributes and quality (Gómez-Cortés et al., 2018; Pereira et al., 2010), as it directly influences the lipid profile.

In the semiarid region of northeastern Brazil, the lack of quality forage is a major problem for dairy goat producers. This region is characterized by low and irregular annual rainfall, which acts as a limiting factor of animal production (Aguiar et al., 2015; Pereira Filho, Silva, & Cézar, 2013; Lopes et al., 2012). Among the available plants in this region, the spineless cactus stands out as a low-cost feed option due to its adaptation to low water availability and its ability to provide animals nutrients and water. The chemical composition of different spineless cactus varieties is consistent, with an average of 10.83 % dry matter, 3.95 % crude protein, and a high non-fibrous carbohydrate content (53.04 %) (Bezerra, Araújo, Pereira, Laurentino, & Silva, 2014).

Some of the spineless cactus varieties in Northeast Brazil suffer from carmine cochineal (*Dactylopius sp.*) infestations, which have caused significant damage to several plantations (Almeida, 2012). Thus, varieties resistant to this pest are appealing (Lopes, Brito, Albuquerque, & Batista, 2010; Vasconcelos, Lira, Cavalcanti, Santos, & Willadino, 2009). Catunda et al. (2016) studied the effects of feeding goats the Miúda spineless cactus, Orelha-de-elefante Mexicana, and native plants (Mandacaru and Xique-xique) and observed significant differences in the levels of protein, lactose, and non-fat solids in the milk. Information on the use of carmine cochineal resistant spineless cactus varieties in ruminant diets and the consequential effects on milk composition and quality are scarce. To fill this knowledge gap in the literature, this study aimed to evaluate how the use of spineless cactus of varieties resistant to carmine cochineal influences the physicochemical and sensory characteristics of goat's milk.

Material and methods

Experimental protocol

The experiment was carried out at the Small Ruminant Research Unit of the Experimental Station of São João do Cariri (São João do Cariri- PB, Brazil). Twelve cross-bred goats (Saanen × Alpina Americana), with an average body weight of 51.35 ± 3.75 kg and approximately 30 days of lactation, were housed in individual stalls, equipped with feeders and drinking fountains.

The experimental design was a 4 × 4 Latin square, with three simultaneous squares of four animals, four periods, and four experimental diets. The experiment lasted 80 days, with 4 periods of 20 days each. The first 15 days of each period were used for diet adaptation and the final 5 days for data collection.

Four diet treatments were evaluated. The control group was fed tifton grass hay 85 (*Cynodon dactylon*) and concentrate, the SCOE group was fed the orelha-de-elefante spineless cactus (*Opuntia stricta* Haw), tifton hay 85, and concentrate, the SCB group was fed the baianaspineless cactus (*Nopalea cochenillifera* Salm Dyck), tifton hay 85, and concentrate, and the SCM group was fed miúda spineless cactus (*Nopalea cochenillifera* Salm Dyck), tifton hay 85, and concentrate. The diets were formulated according to the guidelines of the National Research Council [NRC] (2007) for lactating goats that produce 2 kg day^{-1} and 4 % fat milk.

The animals were fed immediately after milking, at 07:30 and 16:30, and individually supplied the mixed feed. The leftovers were weighed daily, and the amount of offered food was adjusted based on the previous day's consumption (allowing 10 % leftovers). The chemical analyses of the ingredients, leftovers, and feces were performed in the Food and Animal Nutrition Analysis Laboratory (LAANA) CCA/UFPB/PB/Brazil. The samples were analyzed according to the protocols from the Association of Official Analytical Chemists (AOAC, 1997) for dry matter (DM; method 930.15), crude protein (CP method 954.01), ether extract (EE, method 920.39), and ash (method 942.05). The analysis of the neutral detergent fiber (NDF) was performed on an ANKOM fiber analyzer (ANKOM200 Fiber Analyzer; ANKOM Technology Corporation, Fairport, NY, USA).

The total carbohydrate content (TC) was estimated with the equation of Sniffen et al. (1992): $TC = 100 - (\%\,CP + \%\,EE + \%\,ash)$. Non-fibrous carbohydrate (NFC) was estimated by the equation of Mertens (1997): $NFC = 100 - (\%\,CP + \%\,EE + \%\,ash + \%\,NDF)$. The total digestible nutrients (TDN) was estimated as in Weiss, Conrad, and St. Pierre (1992): $TDN = DCP + (DEE \times 2.25) + DNFC + DNDF$. The chemical composition of the individual ingredients is provided in Table 1, and the chemical composition of the experimental diets is provided in Table 2.

Table 1. Chemical composition of the individual ingredients of the experimental diets (based on dry matter; g kg^{-1}).

Composition (g kg^{-1})	Ingredients					
	SCOE [1]	SCB[2]	SCM[3]	Tifton Hay 85	Corn bran*	Soybean meal
DM[4]	202.2	196.2	256.7	885.1	885.8	872.9
MM[5]	62.1	75.7	68.9	59.6	34.9	61.4
OM[6]	937.9	924.3	931.1	940.4	965.1	938.6
CP[7]	32.7	30.1	19.6	89.1	92.0	487
EE[8]	10.3	13.2	9.3	26.5	117.6	22.7
NDF[9]	154	165	194	728	278	158
ADF[10]	99.0	114	114	329	102	104
TC[11]	894	881	902	824	755	428
NFC[12]	704	715	708	96.8	476	269
TDN[13]	731	704	733	555	877	790

[1]Spineless cactus Orelha-de-elefante; [2]Spineless cactus Baiana; [3]Spineless cactus Miúda; [4]dry matter; [5]mineral matter; [6]organic matter; [7]crude protein; [8]ethereal extract; [9]fiber in neutral detergent; [10]fiber in acid detergent; [11]total carbohydrates; [12]non-fibrous carbohydrates; [13]total digestible nutrients. *Industrial corn bran from São Braz.

Table 2. The composition of the experimental diets.

Ingredients	Diets (g kg^{-1})			
	Control	SCOE[1]	SCB[2]	SCB[3]
Tifton Hay 85	550.0	302.0	300.0	303.5
Spineless cactus orelha-de-elefante mexicana	-	464.0	-	-
Spineless cactus baiana	-	-	466.0	-
Spineless cactus miúda	-	-	-	468.0
Soybean meal	120.0	182.0	187.0	192.0
Corn bran	320.0	50.0	45.0	40.0
Mineral Supplement	10	3.0	3.2	3.0
Nutrients	DM contents[4] (g kg^{-1})			
Dry Matter	816.2	343.4	334.4	411.9
Ash	51	60	66	62
Organic Matter	936	938	932	940
Crude Protein	137	135	136	134
Ether Extract	55	23	24	21
Neutral Detergent Fiber	509	334	338	353
Acid Detergent Fiber	226	170	176	178
Total Carbohydrate	747	780	772	785
Non-Fibrous Carbohydrate	238	446	434	432
Total Digestible Nutrients*	681	695	699	699

[1]Spineless cactus orelha-de-elefante mexicana, tifton hay 85, and concentrate; [2]Spineless cactus baiana, tifton hay 85, and concentrate; [3]Spineless cactus miúda, tifton hay 85, and concentrate; [4]Dry Matter.

Milk composition

During the final five days of each experimental period, milk samples were collected twice a day. Sampling was individualized for each animal, and the collection bottles were cleaned with distilled water and dried in an oven at 105°C to avoid contamination. Three milk collections (200 mL) per animal were stored in new, clean, and properly sanitized plastic bottles. The milk collected in the morning was refrigerated at 4 °C until the afternoon collection, after which the samples were homogenized and frozen at -18°C. Composite samples of daily production were 200 mL per animal.

The protein content of the milk was determined via the Kjeldahl method (AOAC, 2005), the lipid content by the Gerber method (Instituto Adolfo Lutz [IAL], 2008), and the lactose content by the Fehling method (IAL, 2008). Measurement of total solids (TS) was obtained after the samples were kept in an oven at 105 ± 2°C for 24h, and the non-fat solids (NFS) was calculated as the total solids minus the percentage of fat. All analyses were performed in triplicate.

Milk sensory attributes

The goat milk samples were evaluated for their sensory attributes by the quantitative descriptive analysis technique (Stone & Sidel, 1993). A panel of 10 evaluators (aged 20 to 30 years) was trained to develop their descriptive terminology and to familiarize the evaluators with the reference materials. The milk was pasteurized and evaluated after one day of cold storage. The sensory evaluation occurred in individual booths, and the samples (~50 mL) were served in disposable cups labeled with random three-digit numbers. The perceived intensity of each milk attribute (Table 3) was scored from 1 (weak) to 5 (strong), and the global assessment of the milk ranged from 1 (dislike) to 5 (like).

Table 3. Sensory attributes of the goat milk.

Attribute	Definition
Odor	Perceived by the olfactory organ when volatile substances are aspirated
Rancid odor	Greasy odor, rancid
Odor of forage/bush	Odor of bush and leaf
Characteristic odor	Characteristic goat odor
Flavor	Complex; the olfactory, gustatory, and tactile sensations perceived during goat milk tasting
Butter/Rancid	Slightly bitter flavor with buttery perception
Characteristic flavor	Characteristic goat flavor
Fodder/bush flavor	Bush and leaf flavor
Aftertaste	Intensity: strong and striking presence of goat milk Persistence: perception of the time when palatable sensations characterize the flavor
Global Assessment	Overall perception of the goat milk

Statistical analysis

The data were analyzed in the Statistical Analysis System (SAS, 2009) program with an analysis of variance (PROC GLM), and the average milk compositions were compared with Tukey's test at a 5 % significance level. The following statistical model was used in the data analysis:

$$Y_{ijkl} = \mu + A(k)_i + P_j + Q_k + T_l + QT_{kl} + \xi i_{jkl}$$

where Y_{ijkl} is the observation of animal i (random effect), in period j (random effect), in square k (random effect), subject to treatment l (fixed effect); μ is the general effect of the mean; $A(k)_i$ is the effect of animal i on square k, with i = 1, 2, 3, or 4; P_j is the effect of period j; Q_k is the Latin square effect, with k = 1, 2, or 3; T_l is the effect of treatment l, with l = 1, 2, 3, or 4; QT_{kl} is the interaction of the effect for the Latin square × treatment l; and ξ_{ijkl} is the random error associated with each Y_{ijkl} observation.

The means of the sensory analyses were compared with the Ryan-Einnot-Gabriel-Welsch test at 5% significance, using the following statistical model:

$$Y_{ij} = \mu + T_i + \xi_{ij}$$

where Y_i is the observed value of the characteristic analyzed in treatment i; μ is the general effect of the mean; T_i is the effect of treatment i, where i = 1, 2, 3, or 4; and ξ_{ij} is the random error.

Correlations between the milk sensory attributes and composition were analyzed with PROC CORR at a 5% significance level. To better explain the (co) variation between these characteristics, analyses of the main components were conducted with PROC PRINCOMP.

Results and discussion

The varieties of forage palm used in this study are common to the semiarid region of Northeast Brazil and usually fed to dairy goats. The tifton hay and corn bran in the control diet were partially replaced by varieties of spineless cactus, which did not affect milk production ($p = 0.0705$) or the protein and NFS levels ($p > 0.05$; Table 4). The lactose content of the control treatment was lower than the SCOE and SCM groups ($p = 0.0001$).

Table 4. Production and composition of the milk from cross-bred Saanen × Alpina Americana goats fed carmine cochineal resistant spineless cacti

Yield (kg dia^{-1})	Diets				SEM	P
	Control	SCOE[1]	SCB[2]	SCM[3]		
Milk yield	2.22	2.69	2.57	2.69	0.241	0.0705
		Characteristics				
TS[4] (g 100 g^{-1})	11.19^a	10.43^b	10.72^{ab}	10.54^b	0.478	0.0011
NGS[5] (g 100 g^{-1})	7.50	7.52	7.59	7.65	0.330	0.7089
Protein (g 100 g^{-1})	3.84	3.82	3.76	3.82	0.298	0.8545
Lactose (g 100 g^{-1})	3.92^b	4.33^a	4.08^{ab}	4.17^a	0.227	< 0.0001
Fat (g 100 g^{-1})	3.46^a	2.93^b	3.17^{ab}	3.07^b	0.364	0.0021

[1]Spineless cactus orelha-de-elefante Mexicana, tifton hay 85, and concentrate; [2]Spineless cactus baiana, tifton hay 85, and concentrate; [3]Spineless cactus miúda, tifton hay 85, and concentrate; [4]Total solids; [5]Non-greasy solids; [ab]Means with a different letter in the same line are significantly different (Tukey's test; $p < 0.05$).

Lactose is the sugar of milk, synthesized from glucose in the liver by propionic acid in the rumen that transforms amino acids (Zychar & Oliveira, 2017; Pereira et al., 2012). Spineless cactus in the diet promotes increased production of propionate in the rumen, as it is rich in non-fibrous carbohydrates, which acts as a source of energy for ruminal fermentation (Lins et al., 2016; Batista et al., 2009). Increased propionate production in the rumen will be absorbed in greater quantities, increasing glucose synthesis in the liver. Propionate production was probably higher in the SCOE and SCM treatment groups and resulted in higher lactose contents.

The fat content of milk is greatly influenced by the diet (Rosa et al., 2017). Reduced lipid contents in the SCOE and SCM groups may have been related to decreases in the ether extract of the diet (55.0 and 21.0 g kg^{-1}, Table 2) - prior work has shown that the synthesis of lipids in breast cancer is affected by triglycerides in the diet (Chilliard, Ferlay, Rouel, & Lamberet, 2003). Approximately 44 % of milk fat comes from triglycerides consumed by the animal, while the rest comes from endogenous synthesis (González & Silva, 2003). Costa et al. (2010) reported a linear reduction in the milk fat of goats (decreasing from 3.84 to 2.97 %) when forage palm replaced increasing amounts of corn in the diet (0 %, 25 %, 50 %, 75 %, and 100 %). The authors attributed the reduction to the ethereal extract of the diet, which was reduced from 5.22 to 1.75 %.

The lower total solids (TS) content of the SCOE and SCM treatments (10.46 % and 10.54 %, respectively) can be attributed to the moderate milk fat content of the animals in these treatments. Lower TS contents may also be due to dilution effects, as the animals in the SCOE and SCM treatment groups produced less milk than the control animals. This characteristic is an important index required by the minimum standards for milk that influences the yield of dairy products.

There was no variation in the quantitative description of rancid odor, forage odor, and characteristic odor ($p > 0.05$; Figure 1), whose averages were 1.47, 1.33, and 1.65 %, respectively. There were also no differences in the butter and forage flavors, averaging 2.26 and 1.72 %, respectively. However, the characteristic flavors of the SCOE (2.56 %) and SCM (2.61 %) treatments were different from the control (2.11 %), representing a moderately weak perception of characteristic flavor. After the taste test, the intensity and persistence of the control group was lower (1.94 and 2.0 %, respectively) than the SCOE (2.42 and 2.44 %) and SCM treatments (2.50 and 2.61 %). Costa, Queiroga, and Pereira (2009) found that milk fat contributes to the goat flavor, primarily due to the lipid/lipolysis ratio. The intensity of these reactions is associated with the development of a sharp flavor, which results from the release of short-chain fatty acids such as hexanoic, octanoic, decanoic, and branched-chain acids, the latter of which is represented by 4-ethyl-octanoic, an important compound of goat flavor (Ha & Lindsay, 1993).

The most intense characteristic flavors of the SCOE and SCM treatments were not due to the fat content of the milk, as both groups had a lower fat content than the control (Table 4). Higher levels of short-chain fatty acids are more grounded since the intensity of the lipolytic reactions is associated with the development of accentuated flavor, which results from the release of short-chain fatty acids such as hexanoic, octanoic, decanoic, and branched-chain acids, the latter of which is represented by 4-ethyl-octanoic, an important compound of goat flavor (Há & Lindsay, 1993).

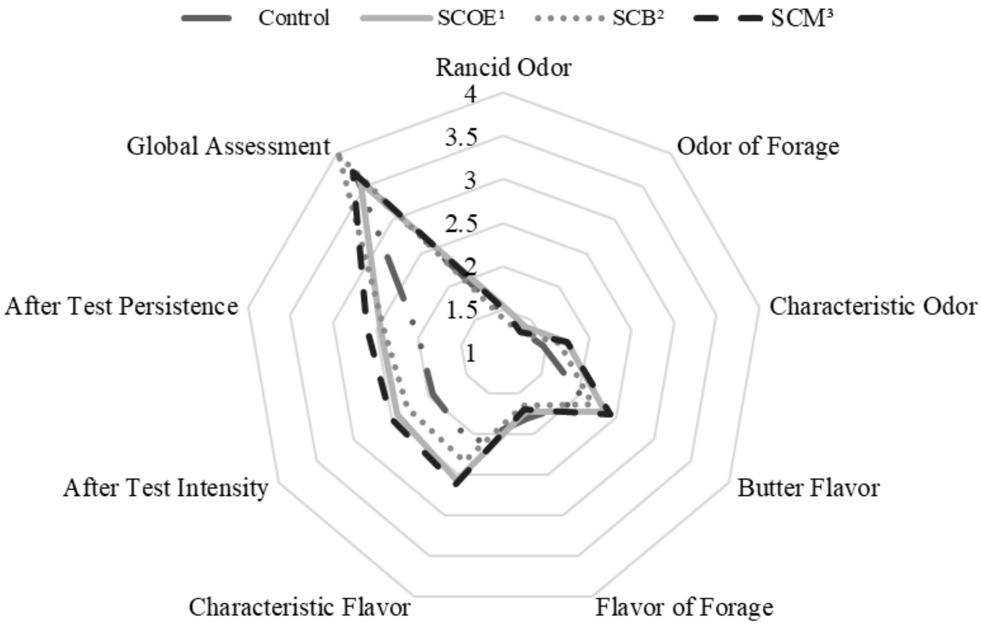

Figure. 1. Graphical representation of the sensory analysis of the milk from cross-bred Saanen × Alpina Americana goats fed carmine cochineal resistant spineless cacti. [1]Spineless cactus orelha-de-elefante Mexicana, tifton hay 85, and concentrate; [2]Spineless cactus baiana, tifton hay 85, and concentrate; [3]Spineless cactus miúda, tifton hay 85, and concentrate.

The results of the global acceptance test did not differ for the different varieties of spineless cactus ($p > 0.05$; Figure 1). The milk was generally well-accepted, with an average score of 3.4 (on a scale of 1 to 5).

We analyzed the principal components to identify the most relevant physicochemical and sensory variables to characterize the milk samples (Figures 2A and 2B). Figure 2A shows the distribution of eigenvectors and the contribution of each variable, while Figure 2B shows the distribution of the treatments within the components.

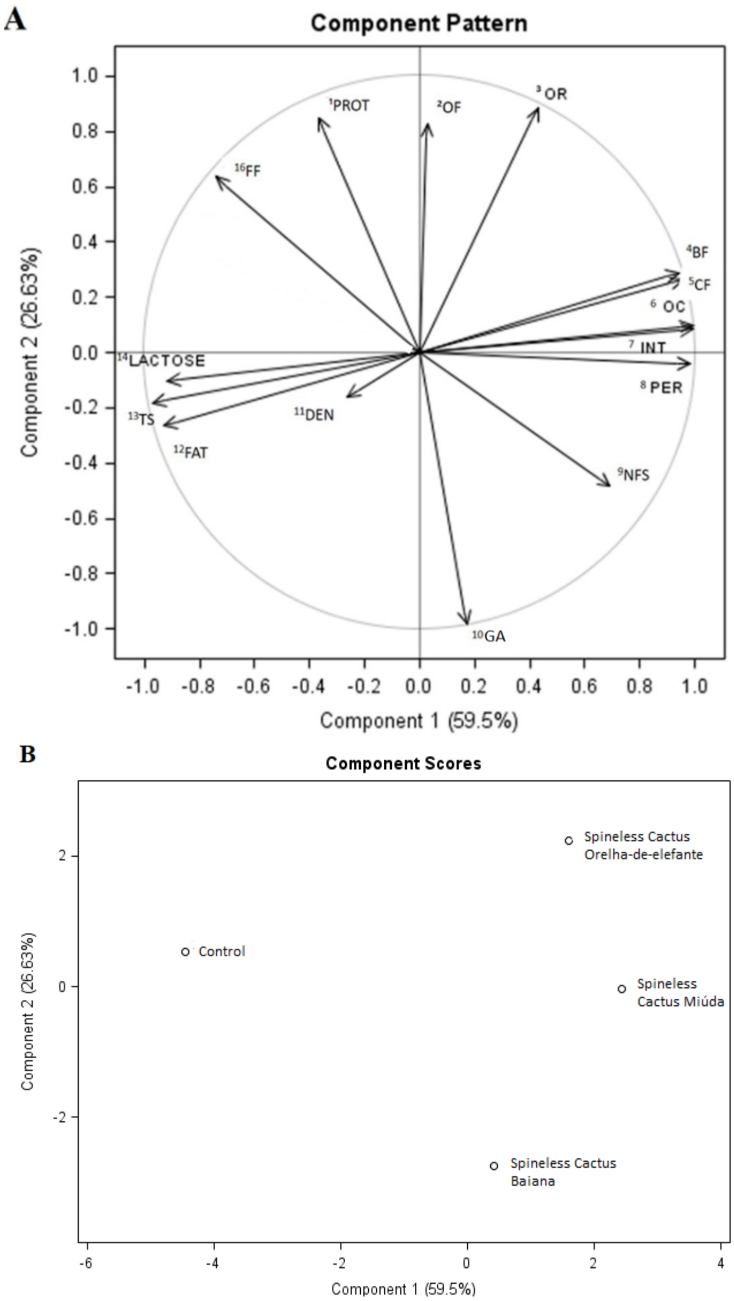

Figure 2. Distribution of the eigenvectors (A) and treatments (B) according to the main components of the milk from cross-bred Saanen × Alpina Americana goats fed carmine cochineal resistant spineless cacti. [1]protein; [2]forage odor; [3]rancid odor; [4]butter flavor; [5]characteristic flavor; [6]odor characteristic; [7]after test intensity; [8]after test persistence; [9]non-fat solid; [10]global assessment; [11]density; [12]fat; [13]total solid; [14]lactose; [15]acidity; [16]forage flavor.

This analysis identified two main components, representing 86.13 % of the total variance. Principal component 1 (PC1) accounted for 59.5 % of the total variance and represented a strong positive correlation between butter flavor, characteristic flavor, characteristic odor, and intensity (Figure 2A). As seen in Figure 2B, the different varieties of spineless cactus positively influenced the butter flavor, characteristic flavor, odor, intensity, persistence, and NFS. The control group was associated with the contents of lactose, TS, and fat.

As the composition of the variables decreased, the sensory characteristics of butter flavor, characteristic flavor, characteristic odor, and intensity increased (Figure 2A). This may be due to higher amounts of short-chain fatty acids, which were nearly three times higher than in cow's milk. When broken, the short-chain fatty acids activate enzymes, releasing volatile fatty acids from unpleasant odors. The length of the carbon chain (short or long), degree of saturation (saturated or polyunsaturated), and geometric isomerism (*cis* or *trans*) of the fatty acids influences the technological properties of the fat (i.e., texture and flavor) (Costa et al., 2009; Morand-Fehr, Fedele, Decandia, & Le Frileux, 2007).

PC2 accounted for 26.63 % of the total variance (Figure 2A). There was a correlation between the protein content and forage flavor that resulted in an antagonistic relationship between the variables for global assessment. The control and SCOE treatments influenced the forage flavor and odor attributes, protein content, and rancid odor, while the SCB treatment influenced global acceptance (Figure 2B). These characteristics are important; the sensorial quality of food and its favor maintenance directly affects consumer product loyalty and is an inherent part of an industry's quality control plan (Teixeira, 2009).

Conclusion

The varieties of spineless cactus resistant to carmine cochineal can be used as feed for dairy goats, as the produced milk is well-accepted by consumers. The orelha-de-elefante variety promotes the fat content and flavor of the milk but does not affect consumer acceptance.

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