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Research Paper

Is the total mixed ration the best option for feeding crossbred dairy cows using diets based on cactus cladodes on family farms?

¿Es la ración totalmente mixta la mejor opción para la alimentación de vacas lecheras mestizas con dietas a base de cladodios de cactus?

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Abstract

The study aimed to evaluate the effects on the performance of lactating cows of different strategies for supplying diets based on cactus cladodes. Eight Girolando cows at 97 ± 7.6 days into lactation, producing 12.2 ± 0.26 kg milk/day, were assigned to 4 treatments in two 4 × 4 Latin squares. The feeding strategies were: total mixed ration (TMR) based on a mixture of concentrates, cactus cladodes [*Opuntia stricta* (Haw.) Haw.] and sugarcane (*Saccharum officinarum* L.) fed after milking; concentrate fed during milking with cactus cladodes and sugarcane offered later (Con/CC+SC); cactus cladodes combined with concentrate fed after milking with sugarcane offered later (CC+Con/SC); and sugarcane combined with concentrate fed after milking with cactus cladodes offered later (SC+Con/CC). Intakes of neutral detergent fiber (NDF; 4.54 ± 0.09 kg/d) and total digestible nutrients (TDN; 9.30 ± 0.50 kg/d) were similar (P>0.05) for all feeding strategies and there was no effect of feeding strategy on milk yield (12.2 ± 0.26 kg/d). The different feeding strategies did not change the ingestive behavior or performance of lactating Girolando cows. Since the shortage of labor prohibits the feeding of TMRs on family farms because of labor required for preparation, these rations would be appropriate only on large farms where the costs of machines to prepare diets efficiently might be available. Cows fed concentrate during milking spent longer to consume the concentrate than the time to milk, resulting in inefficient usage of scarce labor. Appropriate feeding strategies for family farms appear to be SC+Con/CC and CC+Con/SC, i.e. partial separation of dietary ingredients, and all feeding should be done after milking.

Keywords: Dairy feeding management, dryland farming, family farming, Girolando cattle, *Opuntia stricta*.

Resumen

El estudio tuvo como objetivo evaluar el efecto de diferentes estrategias de suministro de dieta a base de cladodios de cactus sobre el desempeño de vacas lactantes. Ocho vacas Girolando con 97 ± 7,6 días de lactancia y producción diaria de leche de 12.2 ± 0.26 kg fueron asignadas a dos cuadrados latinos simultáneos 4 × 4. Las estrategias de alimentación fueron: ración totalmente mixta (RTM) a base de una mezcla de concentrados, cladodios de cactus [*Opuntia stricta* (Haw) Haw] y caña de azúcar (*Saccharum officinarum* L.) suministrada después del ordeño; concentrado suministrado durante el ordeño y los cladodios de cactus y caña de azúcar ofrecida posteriormente (Con/CC+CA); mezcla de cladodios de cactus

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con concentrado suministrado después del ordeño y caña de azúcar ofrecida separadamente (CC+Con/CA); y mezcla de caña de azúcar con concentrado suministrado después del ordeño y cladodios de cactus ofrecidos separadamente (CA+Con/CC). El consumo de fibra detergente neutro (FDN; 4.54 ± 0.09 kg/d) y nutrientes digestibles totales (NDT; 9.30 ± 0.50 kg/d) fueron similares (p>0.05) en todas las estrategias de alimentación. No hubo efecto de las estrategias de alimentación sobre la producción de leche (12.2 ± 0.26 kg/d). Las diferentes estrategias de suministro de dieta no afectaron el comportamiento alimentario ni el desempeño de vacas lactantes Girolando. Dado que la escasez de mano de obra limita el uso de RTM en fincas de pequeños productores, el uso de esta estrategia se adecua más para los grandes productores, los cuales tendrían mayor factibilidad de adquirir la maquinaria necesaria para preparar las dietas de forma eficiente. En las vacas alimentadas con concentrado durante el ordeño, el tiempo de consumo del suplemento fue mayor al tiempo de ordeño, resultando en un uso ineficiente de la escasa mano de obra. Las estrategias de alimentación adecuadas para los pequeños productores parecen ser CA+Con/CC y CC+Con/CA, que separan parcialmente los ingredientes de la dieta, y toda la alimentación debe realizarse después del ordeño.

Palabras clave: Agricultura familiar, agricultura de secano, ganado Girolando, manejo alimenticio, *Opuntia stricta*.

Introduction

In semi-arid regions around the world, one of the few viable economic activities is dairy farming, usually family farming. However, the production of roughage represents a significant obstacle to this activity. Since cactus grows well and persists in these environments, feeding of cactus forage has been identified as a strategy for solving this problem (Catunda et al. 2016; Alhanafi et al. 2019; Moraes et al. 2019; Inácio et al. 2020) and cactus cladodes have become an essential component in the diets of many herds in semi-arid regions. A total mixed ration (TMR) is the usual approach to supplying cactus cladodes to regulate dietary composition and provide adequate nutrient intake (Ferreira et al. 2011). However, where suitable machinery is not available, handling cactus cladodes is labor intensive (Vilela et al. 2010a) for harvesting, processing and feeding out, which is an obstacle to its usage on small properties. According to Silva et al. (2019), labor on such properties is almost exclusively supplied by family members and can be in short supply.

Souza Filho et al. (2011) point out that adoption of chemical and mechanical technologies in agriculture can result in a substantial reduction in labor use. They indicate that, in many countries, the agricultural employment market structure has been altered in favor of a more intensive temporary workforce, with a concomitant reduction in use of family labor.

With the rising variety of feed sources for ruminants, there is a need to study the most appropriate way to supply them, potentially creating new animal handling methods. For example, rewarding dairy cows with concentrates during milking is a common feeding strategy to condition them to being handled in ways that are not usually integrated into their routines, such as mechanical milking (Scott et al. 2014). However, little is known about impacts of this conditioning strategy on labor requirements and performance of animals submitted to such a strategy. In this situation, a TMR containing all ingredients is often prepared and fed manually, increasing labor requirement, which represents a significant part of production costs in a dairy farming system. In this way, effective management within a milk production system based on family farming becomes increasingly important for achieving economic objectives.

Feeding cattle either TMR or diets with ingredients supplied separately could have different impacts on composition of the diet selected, ruminal fermentation, milk production and growth performance, which can be explained by changes in feeding behavior (Moya et al. 2011). Vilela et al. (2010b) observed that a TMR feeding strategy can provide an adequate balance of nutrients and reduce selection of ration ingredients by cows. Roughages are an essential part of TMRs for dairy cattle, particularly in providing physically effective fiber components, which are necessary to maintain the proper health and function of the rumen (Zebeli et al. 2010). The study of ingestive behavior can be a useful tool to allow evaluation of these effects on the production system, helping farmers to adjust their feeding management (Andrade et al. 2017).

Based on the experience of our research group with different milk production systems, in which diets are based on cactus cladodes and supplied in different ways, we hypothesized that ingestive behavior of lactating dairy cows would be influenced by the feeding strategy employed, which would impact on performance. Thus, this trial was conducted to evaluate the effects of different feeding strategies for diets based on cactus cladodes on intake and digestibility of nutrients, distribution of behavioral activities throughout the day and milk yield and composition of lactating Girolando cows in mid-lactation.

Materials and Methods

The study was conducted at Experimental Station of the Instituto Agronômico de Pernambuco (IPA), located at Arcoverde, Pernambuco, Brazil (08°25′10″ S, 37°03′54″ W). The local climate is classified as Bsh, defined as semi-arid. During the experimental period, temperature ranged from 18.2 to 29.8 ºC, and average annual precipitation is 410 mm. All procedures were performed in full accordance with guidelines of the Committee of Ethics in the Use of Animals for Research registered under license number 068/2016 of the Universidade Federal Rural de Pernambuco (UFRPE).

Eight multi-parous lactating cows (5/8 Holstein 3/8 Gir) producing 12.2 ± 0.26 kg milk/d, weighing 521 ± 4.7 kg (BW) and at 97 ± 7.6 days into lactation were assigned to 4 × 4 double simultaneous Latin squares, balanced for the residual effect, according to Sampaio (1998). The trial lasted for 84 days, with 4 consecutive 21-day periods divided into 14-day adaptation and 7-day sampling periods. The cows were housed in individual pens of approximately 24 m^2, with individual bunks and with unrestricted access to water.

Feed was supplied twice a day (Table 1). The experimental treatments were comprised of 4 different strategies for supplying dietary ingredients:

a. TMR - total mixed ration (sugarcane + cactus cladodes + concentrate, all mixed in a feeder and supplied only after milking);
b. Con/CC+SC – twice daily, concentrate was fed and consumed during milking, after which cactus cladodes [*Opuntia stricta* (Haw.) Haw.] and sugarcane (*Saccharum officinarum* L.) were mixed and offered in a separate feeder;
c. CC+Con/SC – twice daily after milking, cactus cladodes mixed with concentrate were supplied for 2 hours (8:00–10:00 h and 14:00–16:00 h), after which sugarcane was fed separately; and
d. SC+Con/CC – twice daily after milking, sugarcane mixed with concentrate was supplied for 2 hours (8:00–10:00 h and 14:00–16:00 h), after which cactus cladodes were fed separately.

Dietary components in Treatments b, c and d were provided in different compartments inside the feeder on each occasion making it impossible for the animals to mix them. Cows were milked twice a day (7:00 and 13:00 h) and milk yield (MY) was registered during Days 15–21 of each experimental period.

Regardless of the feeding strategy, proportions of ingredients offered on each occasion based on fresh matter were fixed, as follows: 350 g/kg sugarcane, 450 g/kg cactus cladodes, 42 g/kg wheat bran, 130 g/kg soybean meal, 13 g/kg urea + ammonium sulfate, 10 g/kg mineral mix and 5 g/kg salt. Each day after removal of orts, amount of feed consumed the previous day was determined and amount of feed provided was 10% above that consumed the previous day in an endeavor to obtain ad libitum intake. Orts collected during the study represented the following percentages of dry matter (DM) fed: 7.0, 8.2, 6.8 and 7.4% for TMR, Con/CC+SC, CC+Con/SC and SC+Con/CC, respectively.

The diet (Table 2) was formulated to meet the requirements of dairy cattle producing 13.0 kg milk/d (4.0% fat-corrected) (NRC 2001). Sugarcane (stem only) was chopped in a forage machine into sections with an approximate size of 4 mm and cactus cladodes were also processed in a forage machine into sections around 10 mm.

Voluntary intake was measured during Days 15–21 of each period, where samples of feed and refusals were collected and stored in plastic bags at -20 °C for further chemical analyses. Samples were evaluated for: DM (method INCT-CA G-003/1); organic matter (OM; method INCT-CA M-001/1); crude protein (CP; method INCT-CA N-001/1); ether extract (EE; method INCT-CA G-005/1); neutral detergent fiber corrected for ash and protein (NDFap; methods INCT-CA F-002/1, INCT-CA M-002/1 and INCT-CA N-004/1); according to Detmann et al. (2012); and estimation of non-fiber carbohydrates (NFC) was according to Detmann and Valadares Filho (2010).

Spot fecal samples were collected directly from the animals' rectums between Day 16 and Day 20 of each experimental period (Torres et al. 2009). Total fecal excretion was estimated using indigestible neutral detergent fiber (iNDF) as an internal marker, and concentrations of iNDF in feces, feed and refusals were obtained after 288 hours of ruminal incubation time (Valente et al. 2015; Reis et al. 2017). The diet's TDN concentration was estimated according to Weiss (1999).

Observations concerning ingestive behavior of animals were performed during Days 15–17 of each experimental period by using the instantaneous scanning method proposed by Martin and Bateson (2007). It was adapted for observations at 10-minute intervals during 48 consecutive hours, starting immediately after the morning feeding. Ingestive behavior was classified into 3 main activities: feeding, ruminating and idling. Ingestion time (feeding; min/d) included grasping and handling the feed, chewing and swallowing, while rumination time (min/d) included regurgitation, re-mastication and re-swallowing, and idling time (min/d) included periods during which the animals slept, lay down without ruminating, walked or stood idly. Feeding and ruminating efficiencies were represented by the times spent feeding and ruminating per unit of DM and NDF ingested, expressed in min/kg DM and min/kg NDF, respectively, as described by Bürger et al. (2000). Further, duration of the feeding period was calculated as total meals per day (number and min/d), where a meal was considered as a sequence of activities associated with feeding and its end was marked by the animal either idling or ruminating, according to Fischer et al. (2002).

Nitrogen balance was estimated by the difference between nitrogen ingested and nitrogen excreted in urine, feces and milk. For the determination of plasma urea nitrogen, blood was collected from animals, 4 h after the morning feeding on Day 18 of each experimental period, through jugular venipuncture with 21G x 25 mm needles (BD Vacutainer®, USA), using Vacutainer® tubes with anticoagulant (heparin). The samples were centrifuged (3,000 rpm for 15 min).

At the same time as blood sampling, spot urine samples were collected from each cow (Chizzotti et al. 2008). Urine was filtered through gauze and an aliquot of 10 mL was diluted immediately in 40 mL of H_2SO_3 (0.036 N). Samples were stored at 20 °C for further nitrogen, urea, allantoin (AL), uric acid (UA) and creatinine analyses. Daily total urinary volume was estimated through the relation of daily urinary excretion of creatinine, using observed values of creatinine concentration in urine as described by Valadares et al. (1999). Daily urinary excretion of creatinine was based on 24.05 mg creatinine/kg of body weight (Chizzotti et al. 2008). Evaluation of urinary nitrogen was performed by the Kjeldahl distillation method according to the INCT-CA method N-001/1 (Detmann et al. 2012).

Plasma urea and urinary urea were measured via commercial kits (LABTEST Diagnostics SA®), using a colorimetric system in a semi-automatic biochemical analyzer D250Doles®. Total excretion of purine derivatives was obtained through the sum of the urinary excretions of allantoin, xanthine, hypoxanthine and uric acid. Furthermore, absorption of microbial purines was calculated from the excretion of purine derivatives (Chen et al. 1990). Intestinal flow of microbial nitrogen compounds was calculated according to the quantity of absorbed purines (Chen et al. 1992). Efficiency of microbial protein synthesis was obtained by dividing production of microbial protein (g/d) by daily intake of TDN.

During Days 15–21 of each experimental period a milk aliquot of 50 mL was conditioned in plastic bottles with Bronopol®, maintained between 2 and 6 °C and sent to the PROGENE Laboratory for evaluation of protein, casein, fat, lactose and total solids. The 4.0% fat-corrected milk yield (FCMY) was estimated using the equation: FCMY (4.0%) = (0.4*MY + 15*milk fat yield) (NRC 2001).

Data were submitted to analysis of variance and regression using the MIXED procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC, USA), adopting 5% as significance level for the Type I error, according to the following model:

Yijk = μ + Ti + Qj + Pk + (A/Q)lj + T*Qij + εijk,

where:

Yijk = observation ijk;

μ = overall mean;

Ti = fixed effect of treatment i;

Qj = fixed effect of square j;

Pk = random effect of period k;

(A/Q)lj = random effect of animal l into square j;

T*Qij = random effect of treatment i and square j interaction; and

εijk = random residual error.

Each of the behavioral activities distributed in 4 shifts was analyzed as the effect of repeated measures over time. When necessary, direct treatment/time effects were compared using the SNK test. For all statistical procedures adopted, a significant effect was declared at $P<0.05$.

Table 1. Feeding strategies (FS) and feed supply schedule of experimental diet.

FS[1]	Morning			Afternoon		
	07:00 h	08:00 h	10:00 h	13:00 h	14:00 h	16:00 h
TMR1	-	TMR	-	-	-	TMR
Con/CC+SC	Con	CC+SC	-	Con	CC+SC	-
CC+Con/SC	-	CC+Con	SC	-	CC+Con	SC
SC+Con/CC	-	SC+Con	CC	-	SC+Con	CC

[1]TMR = total mixed ration fed after milking; Con/CC+SC = concentrate fed during milking and cactus cladodes plus sugarcane fed after milking; CC+Con/SC = cactus cladodes mixed with concentrate were supplied first after milking, then sugarcane was supplied after 2 hours; SC+Con/CC = sugarcane mixed with concentrate was supplied first after milking, then cactus cladodes were supplied after 2 hours.

Table 2. Chemical composition (g/kg DM) of the ingredients and the experimental diet.

Item	Sugarcane	Cactus cladode	Soybean meal	Wheat bran	Salt	Mineral mix	Urea + AS[1]	Diet composition
DM[2]	262	111	880	890	970	970	980	178
OM	981	923	934	933	50.3	50.0	18.0	920
MM	19.0	77.1	65.8	66.7	949	950	978	79.4
CP	23.6	51.0	423	196	-	-	265	129
EE	14.4	15.8	32.0	13.4	-	-	-	15.2
NDFap	530	274	145	389	-	-	-	344
iNDF	189	59.8	100	93.3	-	-	-	105
NFC	414	582	334	335	-	-	-	464
TC	944	856	479	722	-	-	-	829

[1]AS = ammonium sulfate; [2]DM = dry matter; OM = organic matter; MM = mineral matter; CP = crude protein; EE = ether extract; NDFap = neutral detergent fiber corrected for ash and protein; iNDF = indigestible neutral detergent fiber; NFC = non-fibrous carbohydrates; TC = total carbohydrates.

Results

Regardless of feeding strategy used, intakes of DM (13.3 ± 0.28 kg/d), NDF (4.48 ± 0.10 kg/d) and TDN (9.29 ± 0.50 kg/d) did not differ (P>0.05) (Table 3). Average apparent digestibilities of DM and CP were 677 ± 30.6 g/kg and 699 ± 49.3 g/kg, respectively (Table 3).

Milk yield (12.2 ± 0.26 kg/d), FCMY (13.5 ± 0.34 kg/d) and milk composition were similar (P>0.05) for all feeding strategies (Table 4). Averages for milk composition were 38.9 ± 0.05 g protein/kg; 47.1 ± 0.11 g fat/kg; 42.7 ± 0.03 g lactose/kg; and 10.8 ± 1.33 mg urea/dL (Table 4). There was no effect (P>0.05) of feeding strategies on urinary volume (24.25 ± 0.85 L) (Table 5). Nitrogen balance (76.8 g/day) and microbial protein efficiency (113.2 g protein/kg TDN) were not affected by feeding strategy (P>0.05) (Table 5).

There was no effect (P>0.05) of feeding strategy on time spent feeding (274 ± 18.3 min/d), ruminating (435 ± 22.5 min/d) and idling (731 ± 15.8 min/d) by cows (Table 6). Daily number of meals (9.87 ± 0.83) and mean duration of meals (27.7 ± 2.45 min) also did not differ (P>0.05) among feeding strategies. Percentages of time spent feeding, ruminating and idling were 19.0, 30.2 and 50.8%, respectively. The efficiencies of eating (49.1 ± 11.1 g DM/min) and ruminating (30.9 ± 1.65 g DM/min) did not differ (P>0.05) among the feeding strategies. In addition, the efficiencies of consuming NDF (16.6 ± 0.25 g NDF/min) and ruminating NDF (10.4 ± 0.78 g NDF/min) did not differ (P>0.05) among the feeding strategies.

Table 3. Nutrient intake and digestibility by dairy cows under different feeding strategies.

Item		Feeding strategy[1]				s.e.	P-value
		TMR	Con/CC+SC	CC+Con/SC	SC+Con/CC		
Dry matter	Intake (kg/day)	13.6	13.5	12.8	13.3	0.28	0.194
	Intake (% BW)	2.59	2.54	2.50	2.57	0.06	0.717
	Digestibility (g/kg)	714	658	685	649	30.6	0.187
Organic matter	Intake (kg/day)	12.6	12.4	11.7	12.3	0.26	0.188
	Digestibility (g/kg)	734	684	696	669	28.4	0.172
Crude protein	Intake (kg/day)	2.01	2.02	1.94	1.96	0.05	0.721
	Digestibility (g/kg)	723	684	685	706	49.3	0.474
Neutral detergent fiber	Intake (kg/day)	4.36	4.56	4.34	4.67	0.13	0.516
	Intake (% BW)	0.87	0.88	0.88	0.86	0.02	0.950
	Digestibility (g/kg)	525	551	605	449	58.3	0.229
TDN	Intake (kg/day)	9.28	9.09	9.55	9.27	0.50	0.339

[1]TMR = total mixed ration; Con/CC+SC = concentrate fed during milking followed by cactus cladodes and sugarcane after milking; CC+Con/SC = cactus cladodes mixed with concentrate fed after milking, followed by sugarcane after 2 hours; SC+Con/CC = sugarcane mixed with concentrate fed after milking, followed by cactus cladodes after 2 hours; BW = body weight; TDN = total digestible nutrients.

Table 4. Milk yield and composition of dairy cows under different feeding strategies.

Item		Feeding strategy[1]				s.e.	P-value
		TMR	Con/CC+SC	CC+Con/SC	SC+Con/CC		
Yield (kg/day)	Milk	12.2	12.4	11.9	12.2	0.26	0.659
	FCMY	13.4	13.6	13.3	13.7	0.34	0.852
Milk composition (g/kg)	Fat	46.3	46.5	47.7	48.0	0.11	0.618
	Protein	39.5	38.7	38.7	39.0	0.05	0.633
	Lactose	42.4	43.4	42.9	42.1	0.03	0.285
	Casein	30.3	30.4	30.3	30.3	0.04	0.995
	Solids not-fat	91.0	91.5	90.3	90.6	0.05	0.297
	Total solids	137	138	138	139	0.15	0.705

[1]TMR = total mixed ration; Con/CC+SC = concentrate fed during milking followed by cactus cladodes and sugarcane after milking; CC+Con/SC = cactus cladodes mixed with concentrate fed after milking, followed by sugarcane after 2 hours; SC+Con/CC = sugarcane mixed with concentrate fed after milking, followed by cactus cladodes after 2 hours; FCMY = 4.0% fat-corrected milk yield.

Table 5. Nitrogen balance and microbial protein synthesis in dairy cows under different feeding strategies.

Item		Feeding strategy[1]				s.e.	P-value
		TMR	Con/CC+SC	CC+Con/SC	SC+Con/CC		
Nitrogen balance (g/day)	Intake	321	323	311	313	10.4	0.743
	Feces	51.4	58.7	55.7	66.3	6.85	0.378
	Urine	102	113	112	104	12.5	0.456
	Milk	75.5	75.2	72.2	74.6	3.56	0.955
	N balance	92.1	76.1	71.1	68.1	13.4	0.602
Urea nitrogen concentration (mg/dL)	Plasma	12.4	11.6	13.3	10.8	2.11	0.792
	Urine	48.3	57.3	46.6	49.7	8.06	0.715
	Milk	11.5	10.3	11.4	10.3	1.78	0.914
Microbial protein synthesis	Pmic (g Pmic/day)	1,158	1,088	1,135	903	183	0.667
	Emic (g Pmic/kg TDN)	124.8	119.7	118.8	97.4	23.9	0.878

[1]TMR = total mixed ration; Con/CC+SC = concentrate fed during milking, followed by cactus cladodes and sugarcane after milking; CC+Con/SC = cactus cladodes mixed with concentrate fed after milking, followed by sugarcane after 2 hours; SC+Con/CC = sugarcane mixed with concentrate fed after milking, followed by cactus cladodes after 2 hours; Pmic = microbial protein synthesis; Emic = microbial protein efficiency; TDN = total digestible nutrients.

Table 6. Behavioral activities of dairy cows under different feeding strategies.

Item[2]		Feeding strategy[1]				s.e.	P-value
		TMR	Con/CC+ SC	CC + Con/SC	SC + Con/CC		
Behavior	Idle (min/d)	714	695	785	757	31.5	0.153
	Ruminating (min/d)	459	465	395	406	22.9	0.124
	Feeding (min/d)	267	280	260	276	19.5	0.836
	Number of meals	10.5	11.0	9.8	9.6	0.83	0.513
	Meal duration (min/meal)	25.5	25.4	26.6	28.7	2.45	0.790
Feeding efficiency (g/min)	DM	50.9	48.2	49.2	48.2	5.35	0.786
	NDF	16.3	16.3	16.7	16.9	0.70	0.457
Rumination efficiency (g/min)	DM	29.6	29.0	32.4	32.8	1.48	0.543
	NDF	9.5	9.8	10.9	11.5	0.53	0.378

[1]TMR = total mixed ration; Con/CC+SC = concentrate fed during milking, followed by cactus cladodes and sugarcane after milking; CC+Con/SC = cactus cladodes mixed with concentrate fed after milking, followed by sugarcane after 2 hours; SC+Con/CC = sugarcane mixed with concentrate fed after milking, followed by cactus cladodes after 2 hours. [2]DM = dry matter; NDF = neutral detergent fiber.

Discussion

Although the physical separation of ingredients, in time and space, allowed animals to preferentially select various dietary portions, which might not have been easily achieved with TMR, there was obviously not enough selection to alter intake, apparent digestibility or performance of the animals (Tables 3 and 4). The desired proportions of the various dietary components were consumed by the cows regardless of whether a TMR was fed or components fed separately. This result would be partially a response to the fact that only limited quantities of ration ingredients were offered in each treatment in fixed proportions. According to NRC (2001), the daily requirement of DM for cows producing 12.2 kg milk as used in this trial would be 15.0 kg DM, 8.16 kg TDN and 1.88 kg CP. However, our results showed DM intake was 11.3% lower than those standards, while TDN intake was 14.0% higher and CP 5.3% higher (Table 3). During the 84 days of the study cows actually gained weight.

One of the main concerns that led researchers to develop TMRs as a feeding strategy was to ensure that cows did not consume large quantities of concentrates without adequate roughage, which can result in acidosis (Van Soest 1994). By limiting the animal's ability to select concentrate out of feed offered, TMRs avoid very high intake of concentrate at a single meal. In contrast, where feeds are offered individually, the animal has the option of selecting concentrate because of its high acceptability/palatability. However, in this study absolute amounts of concentrate offered at any single feeding time were limited, drastically reducing the chance of acidosis occurring. CP and NDF concentrations in the diets effectively ingested were 147, 149, 152 and 147 g of CP/kg DM and 321, 338, 339 and 351 g NDF/kg DM, respectively, for TMR, Con/CC+SC, CC+Con/SC and SC+Con/CC.

Evaluation of urea excretion is necessary to assess the efficiency of the diet's energy and protein use. When protein breakdown rate in the rumen exceeds that of carbohydrates, some nitrogen can be lost by excretion through urine (Vieira et al. 2017), resulting in financial losses to the farmer due to the high cost of protein sources. Plasma urea nitrogen values found in the present study indicated low protein losses, since they were well below those observed in the literature (51.0 and 31.4 mg/dL by Mendonça et al. 2004 and Vieira et al. 2017, respectively). This result can be related to the balance of ingested nutrients from diets and the cows' potential for milk production (Table 5).

Changes in behavioral parameters are common, especially regarding rumination time, when there is variation in the level of dietary fiber in rations (Beauchemin et al. 2003). In the present study, due to separation of the fibrous (sugarcane) and non-fibrous portions (concentrate + cactus cladodes) of the ration, potential preferential feed selection was expected when ingredients were offered separately. However, nutrient intake data (Table 3) demonstrate that, despite separating dietary ingredients, selective feeding by animals was minimal and the balance of dietary ingredients originally intended was maintained.

According to Sniffen and Robinson (1984), when ration components are fed separately, forage should be offered before concentrate, since rapidly fermentable carbohydrates in concentrates may cause acidic conditions in rumens of cows that have not been fed for more than 6 hours, resulting in reduced feed ingestion and fiber digestion. Results of the present study do not support this hypothesis (Table 3). With similar nutrient intakes for all feeding strategies, we assume that offering concentrate as the first meal in the morning, even when combined with other dietary ingredients rich in non-fibrous carbohydrates, such as cactus cladodes, did not change the ruminal environment sufficiently to have an impact on intake and digestion patterns (Table 6). Moreover, the NFC:NDF ratio was very close to the recommended range (minimum of 25.0% NDF to a maximum of 44.0% NFC) (NRC 2001) to maintain healthy ruminal conditions.

According to Ørskov (1999) and Silva et al. (2005) dairy cows with low production potential should be fed lower concentrate proportions in their diets than high-producing cows, which minimizes the risk of metabolic disturbances. Our results support this claim as the cows produced 13.5 kg FCMY/d and consumed a total of 13.3 kg DM with 20.0% concentrate, so the daily intake was 2.66 kg or 1.33 kg per meal (on a DM basis). Furthermore, fat concentrations in milk were similar for all feeding strategies, confirming that the quantities of nutrients ingested by all groups were similar during the experimental period, and ruminal acidosis apparently did not occur.

In the present study, when concentrate was supplied during milking (Con/CC+SC), milking staff had to wait for cows to consume the entire amount of concentrate offered at the beginning of milking. Time spent in the milking parlor increased to 20 minutes compared with only 12 minutes in a conventional mechanical milking system (no concentrate supply). Milking efficiency is the balance between amount of milk produced and time needed to obtain it. Supplying concentrate during milking increased the residence time of each cow by 8 minutes, which lowered milking efficiency.

To optimize milking and labor efficiency, supplying concentrate during milking is inadvisable due to the additional time spent in the milking process. According to Albright (1993), behavioral studies under controlled conditions, such as in individual stalls or metabolism cages, eliminate the variable of competition for feed from the study, which can generate different results from those observed in practical situations. In the present study, absence of competition for food possibly contributed to the longer time spent consuming the concentrate.

The goal of any strategy or feeding method is to have animals consume the amount of feed specified in a formulated diet. Considerations about choosing a better feeding system should include cost and availability of labor and equipment (NRC 2001) and be adapted to family farm conditions. Souza Filho et al. (2011) commented that most new technologies ignore the reality of smallholder systems, characterized by low availability of resources, low educational level, restricted access to markets and absence of technical assistance. An optimal system would involve low demand for external feed sources and financial resources and, consequently, lower production and financial risk for smallholders (Souza Filho 1997).

In that scenario, the use of cactus cladodes in a TMR, as recommended by Ferreira et al. (2011), did not seem viable for smallholder farms, where TMR was prepared manually and may demand more than a single employee to complete the task, causing the aforementioned low labor productivity. Even though there is a trend towards mechanization of agricultural activity and use of family labor exclusively (Oliveira et al. 2007), these producers do not possess the resources or workforce necessary to apply this technique. While the present study demonstrated that feeding lactating Girolando cows with TMR based on cactus cladodes did not affect intake, milk yield or milk fat concentration relative to providing various feeds separately, we consider that feeding TMRs containing cactus cladodes as recommended by Ferreira et al. (2011) is not appropriate for cows with low production potential. Farmers need to use available feed resources in the most efficient manner that suits the situation.

Evaluation of ingestive behavior was essential for gathering data and critical information to discern which of the proposed feeding strategies would be more advantageous in terms of labor efficiency in different scenarios of dairy cow production. Overall, feeding strategy did not alter intake, ingestive behavior, performance and efficiency of lactating Girolando cows producing 13.0 kg milk/day when fed a diet based on cactus cladodes. While cactus cladodes, due to their physiology, are frequently used in semi-arid regions, where cattle raising is one of the few viable activities, properties in these regions are usually predominantly small with only family labor available. We suggest that strategies SC+Con/CC and CC+Con/SC be implemented as alternatives to TMRs, as these strategies can potentially optimize labor usage and performance of smallholder systems, which depend almost exclusively on family labor. For more intensive production systems with contracted labor, large herds with higher production potential and availability of machinery, TMRs could be more appropriate. Time and motion studies to examine efficiency of labor usage on these farms would confirm or reject this hypothesis.

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