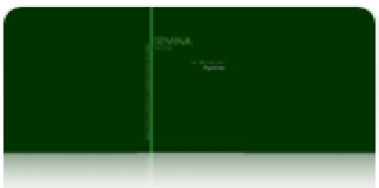

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Roughage sources for Holstein cows under experimental feeding conditions in Brazil - a meta-analysis[1]

Volumosos na alimentação de vacas da raça Holandês em condições experimentais no Brasil - Metanálise

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Abstract

The aim of this study was to evaluate the composition, voluntary intake, and digestibility of the diet of Holstein cows, as well as milk yield and milk composition as a function of different roughage sources used under experimental feeding conditions in Brazil, through meta-analysis. The database of this study consisted of 109 experiments with 424 treatments of 3,903 lactating Holstein cows. The data were obtained from studies published between January 2000 and December 2015, and were evaluated by variance analysis. Lactating dairy cow diets with a single source of roughage other than corn silage resulted in lower voluntary intake, milk yield, and differences in milk composition, compared to diets based on corn silage or the combination of two roughages, probably due to reduced nutrient digestibility. Diets based on corn silage are distinguished by feed efficiency, milk yield, and composition. Diets based on the combination of two roughage sources are similar with respect to milk yield and composition, compared to diets based on corn silage; whereas, diets with a single source of roughage (other than corn silage), even when containing a higher proportion of concentrate, led to reduced voluntary intake, milk yield, and food efficiency due to the lower utilization of the nutrients. Diets based on corn silage in general allow a higher proportion of roughage in the diet due to energy density.
Key words: Digestibility. Fiber. Intake. Milk. *Saccharum officinarum. Zea mays.*

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Resumo

Objetivou-se avaliar a composição, consumo e digestibilidade da dieta, bem como produção e composição do leite em função da fonte de volumoso utilizado nas dietas das vacas da raça Holandês confinadas em condições experimentais no Brasil, por meio de metanálise. Neste estudo, a base de dados ficou composta de 109 experimentos, com 424 tratamentos, envolvendo 3.903 vacas em lactação da raça Holandês, informações oriundas de publicações compreendidas entre janeiro de 2000 e dezembro de 2015. Os dados foram avaliados pela análise de variância, considerando a distribuição das variáveis resposta. Dietas com uma única fonte de volumoso que não a silagem de milho apresentaram consumo voluntário, produção e composição do leite inferior as dietas baseadas em silagem de milho e na combinação de dois volumosos em função da reduzida digestibilidade dos nutrientes. As dietas a base de silagem de milho destacam-se pela eficiência na produção e composição do leite. A utilização de dieta baseadas na combinação de dois volumosos assemelham-se em produção e composição do leite com as dietas a base de silagem de milho, enquanto que as dietas com uma única fonte de volumoso que não a silagem de milho, mesmo com maior proporção de concentrado, apresenta consumo, produção de leite e eficiência alimentar inferiores em função do menor aproveitamento dos nutrientes. Dietas a base de silagem de milho permitem maior proporção de volumoso na dieta em função da densidade energética.

Palavras-chave: Consumo. Digestibilidade. Fibra. Leite. *Saccharum officinarum*. *Zea mays.*

Introduction

Brazil produces a great diversity of roughage sources for the feeding of livestock. However, for dairy cow nutrition in confined systems, it is important that the selected roughage species are adapted to the edaphoclimate of the respective region in order to ensure sufficient quality and quantity. In this regard, storage and transport conditions are another important point to consider. According to Van Soest (1994), roughage is essential for feeding lactating cows as it is the main source of fibrous carbohydrates. These are mostly represented by neutral detergent fiber (NDF), which consists of cellulose, hemicelluloses, and other non-glycolic compounds. Reviewing literature from 1918 to 2017, Hall and Mertens (2017) emphasized that it is crucial to improve the understanding of the dynamics of carbohydrate fermentation in high-production dairy cows.

In cows, roughage is degraded by ruminal bacteria and as result of fermentation of fibrous carbohydrates (FC) and non-fibrous carbohydrates (NFC), microbial protein (MP) and volatile fatty acids (VFAs) are produced. These compounds are the main sources of protein and energy for the productive and reproductive performance of lactating dairy cows and of nutrients for the synthesis of milk components (LANZAS et al., 2007; WHITE et al., 2017a, 2017b).

Among the different roughage sources used in tropical regions, corn (*Zea mays*) whole plant silage is one of the main forages for dairy cows in confinement systems due to its ability to produce dry matter (DM), easy harvesting and fermentation in the silo, presence of digestible neutral detergent fiber (NDF), and high concentrations of liquid energy (ROBINSON et al., 2016; HENTZ et al., 2017; ZARDIN et al., 2017). In addition to corn silage, sugarcane (*Saccharum officinarum*) also stands out due to low production costs, high DM production per hectare, resistance to pests and diseases, and availability during the dry season (when there is typically a shortage of forage), but offers only a low protein content and shows low rumen degradation of the fibrous fraction (CASTRO et al., 2009; TEIXEIRA JÚNIOR et al., 2016; VALADARES FILHO et al., 2017). Another important source of roughage is the forage palms *Opuntia* spp. and *Nopalea* spp., which are adapted to the edaphoclimatic conditions of the semi-arid regions. This adaption and their low production costs make forage palms potential alternatives for cattle feeding during prolonged droughts (GALVÃO JÚNIOR et al., 2014; PEREIRA et al., 2017).

A substantial number of studies has been conducted to investigate the effect of different roughage sources on feeding of dairy cows. Employing scientific systematization techniques (meta-analyses), data of previous studies can be retrieved in order to critically re-examine the results and statistically analyze metadata to improve our understanding of the subject (SAUVANT et al., 2008; RABIEE et al., 2012). Compared to classical reviews, meta-analyses offer the considerable advantage of integrating data of previous research into collective analyses, and therefore provide quantitative conclusions (NORMAND, 1999; LOVATTO et al., 2007; MARÍN et al., 2015). In this study, we performed meta-analyses to evaluate the composition, voluntary intake, and digestibility of different diets, as well as milk yield and composition as a function of the source of roughage used in the diets of Holstein cows confined under experimental conditions in Brazil.

Material and Methods

A database was compiled by surveying scientific publications accessible on the sites of the Scientific Electronic Library Online (SciELO), the Brazilian Institute of Information in Science and Technology (IBICT), Google Scholar, and in the main periodicals of Agrarian Sciences. For database compilation, we considered studies published between January 2000 and December 2015, thus comprising the last sixteen years of research on feeding lactating cows under experimental conditions in confinement systems in Brazil, whose references can be consulted on thesis of (ALESSIO 2017).

The publications (papers, theses, and dissertations) were initially selected by reading the abstract. Subsequently, the selected studies were fully read, and the following information was extracted completely or in part for integration into the database: number of different roughages, cow breed, individual body weight (BW), days in milk (DIM), diet composition (roughage proportion; DCRP), DM, crude protein (CP), ether extract (EE), non-fibrous carbohydrates (CNF), neutral detergent fiber (NDF), acid detergent fiber (ADF), total digestible nutrients (TDN). Furthermore, we processed data on voluntary intake, apparent digestibility of nutrients, and milk yield and composition. The data were tabulated in a Microsoft Excel spreadsheet. The design of this study was based on the methods described by Normand (1999), Lovatto et al. (2007), and Sauvant et al. (2008).

The resulting database comprised 109 experiments with 424 treatments of 3,903 individual lactating Holstein cows. We only processed data of studies in which the only source of roughage was corn silage (DRCS), diets with a single source of roughage other than corn silage (DRNCS), or diets composed by the combination of two roughage (DTR). DRNCS, consisted of sugar cane *in natura* or as silage, elephant grass *in natura* or as silage, alfalfa pre-dried or as hay, grass hay, sorghum, and star grass silage. Diets containing a combination of two roughages were composed of the following combinations (followed by the average respective proportions): corn silage plus grass hay (38.5: 6.5), sunflower silage (66.0: 34.0; 34.0: 66.0), *in natura* sugar cane (29.8: 20.2), forage palm (32.6: 35.7), pre-dried ryegrass (30.3: 11.7), or cassava branch silage (30.0: 25.6); forage palm plus sorghum silage (38.3: 30.7), grass hay (49.8: 25.3), or sugarcane bagasse (47.2: 26.8); sugarcane silage plus grass hay (24.4: 14.5), and grass hay plus Napier grass silage (30.3: 27.5).

We analyzed BW, DIM, RP, DM, NFC, NDF, ADF, CP, EE, TDN, and net milk energy of lactation (NEL) of the diets. Voluntary intake is typically expressed as an absolute value (in kg/day), however, we calculated intake as a percentage of body weight

(% of BW) and transformed it to grams per kilograms of metabolic weight (g/kg of $BW^{0.75}$), which is expressed as DFM, NFC, NDF, ADF, CP, EE, and TDN. For the apparent digestibility, we evaluated DM, NCF, NDF, CP, and EE. The performance of lactating cows was expressed as milk yield (kg/day), milk yield corrected for energy and protein (ECM), feed efficiency (FE), and milk fat, protein, and lactose content. The NEL (Mcal/kg) = 0.0245 x TDN (%) - 0.15, the ECM = (0.327 * milk yield) + (12.95 * fat content * milk yield/100) + (7.65 * milk protein/milk yield (100) and FE = milk yield (kg/day)/DM intake (kg/day) were calculated according to NRC 2001 (NRC, 2001).

The data were analyzed statistically using the MEANS and UNIVARIATE procedures and variance analyses, using the GLIMMIX procedure of SAS® statistical software (SAS INSTITUTE, 2002). To perform a comparison of means of the formed groups, the assumptions of normality and homogeneity of variances were tested (Shapiro-Wilk test and Levene's test, respectively). This mostly revealed significant deviations from normal distribution and homogeneity of variances ($P < 0.0001$, each), as at least one of the assumptions was not met by any one variable. Therefore, we chose an analysis of variance using the GLIMMIX procedure, which considers the distribution of the response variable for the comparison of means, and uses the LSMEANS procedure. Means were compared using a Tukey-Kramer test with a probability threshold of 5%. For all analyzed variables, a normal distribution was applied, in which a connection between the mean of the observations and the systematic part is made by the identity function.

The variance analysis was based on the method of restricted maximum likelihood (REML) which considers independency of fixed effects and random effects of each observation. The probability density function of the observations is therefore reflected in the sum of the functions of each part. The random effects, related to the components of variance, eliminate the bias resulting from the loss of degrees of freedom in the estimation of the fixed effects of the model. The REML considers the loss of degrees of freedom as a function of the fixed effects, thereby providing non-biased estimators with minimum variance for balanced data. For unbalanced data (even when providing biased estimates), the REML is recommended, as is meta-analysis in which each variable can present a different number of observations. For the variance analyses of the present study, the type of roughage used in the diet (corn silage, only one roughage, or two roughages combined) was considered as a fixed effect, and the number of cows per treatment was used as a random effect. In general, the statistical model was based on the equation below:

$$Y_{ij} = \mu + t_i + \delta_j + \varepsilon_{ij}$$

where:

Y_{ij}= response variable,

μ = average,

t_i = roughage source (fixed effect),

δ_j = number of cows (random effect),

ε_{ij} = effect of random error

Results

In the diet of lactating Holstein cows under experimental conditions in Brazil, DRCS produced higher RP compared to DRNCS, whereas DRNCS led to higher levels of DM, NCF, TDN, and NEL compared to DRCS and TR (Table 1). The DRCS and DTR led to higher intakes of DM, NDF, ADF, CP, and EE in kg/day, percent of LW and g/kg of $BW^{0.75}$, in relation to DRNCS (Table 2), which did not seem to correlate with NFC and TDN intake. The DRNCS and DTR showed higher NFC digestibility, but with reduced digestibility of NDF, compared to the DRCS. The DTR showed the highest digestibility for CP, but lower digestibility for EE, compared to the other diets, whereas the DRCS stood out for higher NDF digestibility (Table 3).

Cows that received DRCS and DTR were more efficient in terms of milk production and ECM, with higher FE and lactose content, but lower fat and protein content compared to the DRNCS. Lactating cows fed DRNCS showed higher fat and protein content with lower milk yield, ECM, FE, and lactose content compared to DRCS and DTR diets (Table 4).

Table 1. Average ± standard error of the means of general information and diet composition as a function of roughage source used in the diet of Holstein cows under experimental conditions in Brazil.

Variable	Roughage source used in the diet						P
	N	DRCS[1]	N	DRNCS[2]	N	DTR[3]	
	General information						
Body weight (kg)	174	578,69±4,03 a	55	550,80±7,17 b	77	561,10±6,06 a	=0,0099
Days in milk	208	112,57±3,83 b	62	146,40±7,02 a	99	99,86±5,55 c	=0,0002
Roughage proportion (%)	221	53,93±0,75 a	69	50,10±1,35 b	108	51,75±1,08 ab	=0,0459
	Diet composition (% of DM)						
Dry Matter (DM) (%)	171	53,08±0,86 b	41	57,91±1,76 a	90	46,98±1,19 c	=0,0004
Non-fiber carbohydrate	144	38,73±0,46 b	30	45,52±1,01 a	77	37,16±0,63 b	<0,0001
Neutral detergent fiber	209	36,51±0,49	56	34,55±0,95	95	37,04±0,73	=0,1278
Acid detergent fiber	152	21,14±0,39	55	20,39±0,64	81	22,18±0,53	=0,1247
Crude protein	216	15,89±0,19	65	15,82±0,34	108	16,44±0,26	=0,2218
Ether extract	190	3,67±0,10 a	51	2,62±0,20 b	95	3,64±0,14 a	=0,0007
Total digestible nutrient	141	68,43±0,43 b	39	70,89±0,82 a	60	68,03±0,66 b	=0,0474
Net energy of lactation (Mcal/kg)	141	1,55±0,01 b	39	1,61±0,02 a	60	1,54±0,02 b	=0,0481

[1]DRCS = only source of roughage used in the diet was corn silage; [2]DRNCS = diets with one source of roughage but not corn silage (sugar cane *in natura* or silage, elephant grass *in natura* or silage, alfalfa pre-dried or as a hay, hay of grass, sorghum and star grass silage); [3]DTR = diets based on the combination of two roughages (corn silage plus hay of grass, sunflower silage, *in natura* sugar, forage palm, pre-dried ryegrass, or cassava branch silage; forage palm plus sorghum silage, grass hay, sugarcane bagasse; sugarcane silage plus grass hay, and grass hay plus Napier grass). Different letters after averages in the same line indicate significant differences (Tukey-Kramer test, P < 0.05).

Table 2. Average ± standard error of the means of intake as a function of the source of roughage used in the diet of Holstein cows under experimental conditions in Brazil.

Variable	Roughage source used in the diet						P
	N	DRCS[1]	N	DRNCS[2]	N	DTR[3]	
	Intake in kilograms per live weight (kg/day)						
Dry matter	229	18,76±0,19 a	69	16,39±0,35 b	103	18,45±0,29 a	<0,0001
Non-fiber carbohydrate	149	7,29±0,13	38	7,60±0,26	72	7,07±0,19	=0,2977
Neutral detergent fiber	203	6,65±0,09 a	63	5,87±0,17 b	85	6,93±0,15 a	=0,0007
Acid detergent fiber	146	3,95±0,08 a	62	3,41±0,12 b	71	3,93±0,11 a	=0,0068
Crude protein	221	3,06±0,05 a	68	2,41±0,08 b	100	3,02±0,07 a	<0,0001
Ether extract	187	0,70±0,02 a	58	0,41±0,04 b	90	0,68±0,03 a	<0,0001
Total digestible nutrient	137	13,11±0,21	69	11,96±0,39	61	12,71±0,31	=0,0771

continue

continuation

	Intake as a function of body weight (% of BW)						
Dry matter	174	3,26±0,04 a	59	2,91±0,06 b	87	3,26±0,05 a	=0,0011
Non-fiber carbohydrate	134	1,25±0,02	27	1,36±0,05	53	1,27±0,04	=0,2459
Neutral detergent fiber	158	1,20±0,02 a	50	0,98±0,03 b	79	1,19±0,03 a	=0,0006
Acid detergent fiber	93	0,72±0,02 a	43	0,57±0,03 b	55	0,69±0,02 a	=0,0076
Crude protein	165	0,53±0,01 a	49	0,41±0,02 b	77	0,53±0,01 a	=0,0001
Ether extract	145	0,12±0,004 a	43	0,07±0,01 b	69	0,11±0,01 a	=0,0010
Total digestible nutrient	130	2,27±0,04	33	2,21±0,07	46	2,30±0,06	=0,6778
	Intake in grams per kilogram of metabolic body weight (g/kg de $BW^{0,75}$)						
Dry matter	165	159,62±1,92 a	59	140,82±3,21 b	84	159,17±2,69 a	=0,0008
Non-fiber carbohydrate	134	61,57±1,15	27	65,85±2,56	53	61,90±1,83	=0,3631
Neutral detergent fiber	149	58,61±1,01 a	44	49,55±1,86 b	74	58,45±1,43 a	=0,0037
Acid detergent fiber	93	35,39±0,86 a	43	28,06±1,27 b	55	33,31±1,12 a	=0,0063
Crude protein	165	26,11±0,44 a	49	20,21±0,81 b	77	26,02±0,65 a	=0,0001
Ether extract	145	6,13±0,22 a	43	3,55±0,41 b	69	5,77±0,32 a	=0,0010
Total digestible nutrient	126	111,58±1,80	33	107,19±3,52	46	111,65±2,98	=0,5420

[1]DRCS = only source of roughage used in the diet was corn silage; [2]DRNCS = diets with one source of roughage but not corn silage (sugar cane *in natura* or silage, elephant grass *in natura* or silage, alfalfa pre-dried or as a hay, hay of grass, sorghum and star grass silage); [3]DTR = diets based on the combination of two roughages (corn silage plus hay of grass, sunflower silage, *in natura* sugar, forage palm, pre-dried ryegrass, or cassava branch silage; forage palm plus sorghum silage, grass hay, sugarcane bagasse; sugarcane silage plus grass hay, and grass hay plus Napier grass). Different letters after averages in the same line indicate significant differences (Tukey-Kramer test, P < 0.05).

Table 3. Average ± standard error of the means of nutrients digestibility as a function of the source of roughage used in the diet of Holstein cows under experimental conditions in Brazil.

Apparent digestibility (%)	Roughage source used in the diet						P
	N	DRCS[1]	N	DRNCS[2]	N	DTR[3]	
Dry matter	135	66,04±0,42	41	67,20±0,77	62	67,21±0,62	=0,2414
Non-fiber carbohydrate	90	78,52±0,91 b	25	84,41±1,74 a	30	85,45±1,59 a	=0,0198
Neutral detergent fiber	136	51,16±0,89 a	41	47,72±1,62 b	60	47,46±1,34 b	=0,0728
Crude protein	127	69,61±0,59 b	39	69,07±1,06 b	40	74,54±1,05 a	=0,0080
Ether extract	103	78,88±1,02 a	33	76,07±1,81 a	36	68,58±1,74 b	=0,0066

[1]DRCS = only source of roughage used in the diet was corn silage; [2]DRNCS = diets with one source of roughage but not corn silage (sugar cane *in natura* or silage, elephant grass *in natura* or silage, alfalfa pre-dried or as a hay, hay of grass, sorghum and star grass silage); [3]DTR = diets based on the combination of two roughages (corn silage plus hay of grass, sunflower silage, *in natura* sugar, forage palm, pre-dried ryegrass, or cassava branch silage; forage palm plus sorghum silage, grass hay, sugarcane bagasse; sugarcane silage plus grass hay, and grass hay plus Napier grass). Different letters after averages in the same line indicate significant differences (Tukey-Kramer test, P < 0.05).

Table 4. Average ± standard error of the means for milk yield and composition, feed efficiency as a function of the source of roughage used in the diet of Holstein cows under experimental conditions in Brazil.

Variable	Roughage source used in the diet						P
	N	DRCS[1]	N	DRNCS[2]	N	DTR[3]	
Milk yield (kg/day)	236	24,15±0,37 a	74	18,07±0,66 b	114	24,17±0,53 a	<0,0001
ECM[4]	222	24,25±0,34 a	73	19,00±0,60 b	85	25,05±0,56 a	<0,0001
Feed efficiency[5]	224	1,28±0,02 a	70	1,09±0,03 b	103	1,27±0,02 a	<0,0001
Fat (%)	232	3,47±0,03 b	74	3,63±0,05 a	114	3,49±0,04 b	=0,0365
Protein (%)	222	3,16±0,02 b	73	3,27±0,03 a	85	3,12±0,03 b	=0,0022
Lactose (%)	133	4,47±0,02 a	52	4,34±0,03 b	60	4,46±0,02 a	=0,0055

[1]DRCS = only source of roughage used in the diet was corn silage; [2]DRNCS = diets with one source of roughage but not corn silage (sugar cane *in natura* or silage, elephant grass *in natura* or silage, alfalfa pre-dried or as a hay, hay of grass, sorghum and star grass silage); [3]DTR = diets based on the combination of two roughages (corn silage plus hay of grass, sunflower silage, *in natura* sugar, forage palm, pre-dried ryegrass, or cassava branch silage; forage palm plus sorghum silage, grass hay, sugarcane bagasse; sugarcane silage plus grass hay, and grass hay plus Napier grass). [4]Milk yield corrected for energy and protein (ECM) ECM = (0.327 * milk yield) + (12.95 * fat content * milk yield/100) + (7.65 * milk protein *milk yield /100), and [5]Feed efficiency = milk yield (kg/day)/DM intake (kg/day) (NRC, 2001). Different letters after averages in the same line indicate significant differences (Tukey-Kramer test, $P < 0.05$).

Discussion

Diet composition analyses showed that the DRCS allowed for an increase in RP as a function of energy density in corn silage (Table 1) when using a corn plant harvest stage in which the grain has a hard, farinaceous consistency with DM content varying from 30 to 35% (RESENDE et al., 2005). In this condition, the amount of digestible DM is maximal and the relative NDF proportion is reduced by the progressive increase in starch content due to grain filling (NUSSIO et al., 2001). In consequence, the energy density increases due to the presence of digestible NDF and the high concentration of energy in liquid components, which allows the reduction of concentrated foods with little compromise in the physiology and performance of lactating cows (SILVA et al., 2015). Moreover, harvesting the corn plant at a height of 0.47 meters above the ground yields the optimal relationship between quantity and quality of silage. In addition, this harvesting practice may achieve greater potential of economic returns and can thus help to finance management and fertilization strategies to avoid degradation of foraging systems, which is mainly caused by the negative potassium balance in the system (HÜLSE et al., 2017). According to Velho et al. (2014), corn silages containing high concentrations of energy usually hold large amounts of starch so that this feed can be considered both a roughage and a concentrate.

The DRNCS are mostly represented by sugar cane *in natura* or as silage. These have a higher DM content (which may be related to the higher amount of concentrate in the diet), followed by DRCS and then DTR, in which the use of forage palm combined with one more other roughages is predominant. The low DM content of DTR is due to *in natura* forage palm, which contains water to approximately 90%. Thus, diets containing a high proportion of forage palm have a high moisture content, which contributes to alleviate water shortages in prolonged droughts. Forage palm is fed to lactating cows in combination with other roughages in order to provide balanced diets. However, it is crucial to keep the DM content above a certain threshold in order to prevent conditions such as diarrhea and weight loss, which may occur when forage palm is fed as the only roughage source or *ad libitum*

(GALVÃO JÚNIOR et al., 2014; PEREIRA et al., 2017).

When forage palm is used in a DTR, it is important to correct for CP contents, as this particular source of roughage has an average of 4.08% CP (VALADARES FILHO et al., 2017). Thus, the use of non-protein nitrogen sources such as urea can be helpful in order to synchronize the degradation rate of energy and protein in the rumen (NRC, 2001; FORBES, 2007), regarding the high NFC and low NDF content of the forage palm (VALADARES FILHO et al., 2017). In consequence, it is crucial for the formulation of effective diets to observe the NDF content. The respective recommendations are 19 to 21% of physically effective NDF (LEAN et al., 2014), or 75% of the total NDF (28 to 33%) in the diet should be derived from forage (NRC, 1989). Furthermore, it is recommended to increase two percent units of the total NDF content and to reduce two percentage units in the NFC content of the diet for each percentage unit of reduced NDF content from roughage (NRC, 2001). The physically effective NDF content for adequate ruminal functioning is quantified either based on particle size, considering only particles larger than 8 mm (ZEBELI et al., 2012), or based on the percentage of the total diet retained in a sieve of 4.0 mm mesh size, using a particle separator (KMICIKEWYCZ; HEINRICHS, 2015). The long fiber particles form a floating fiber blanket in the rumen, which is important for maintaining rumination and ruminal motility, saliva production, stability of ruminal pH and, in consequence, for milk fat content (MERTENS, 1997; ZEBELI et al., 2012).

The DRCS and DTR produced higher intakes of DM, NDF, ADF, CP, and EE, expressed in kg/day, % BW, and g/kg of $BW^{0.75}$, compared to DRNCS, however no difference was found in NDF content regarding function of roughage type, which may explain the intake differences, as NDF restricts the intake due to physical limitations of ruminal filling (MERTENS, 1994). However, the differences between DRCS and DRNCS and DTR can be explained by the lower digestibility of NDF for both, CP for DRNCS and EE for DTR. The reduction in nutrient digestibility, especially that of NDF, is associated with an increase of lignin (VAN SOEST, 1994; HALL, 2014), which is not degradable by ruminal bacteria and therefore increases the retention time of feed in the rumen and impairs nutrient utilization and intake of new meal (NRC, 2001; KRIZSAN; HUHTANEN, 2013; HUHTANEN et al., 2016). Thus, the rumen may contain residuals from previous feedings, which have lower degradation rates and are diluted by the newly ingested fast-fermenting feed, but the accumulated residuals continue to occupy space and thereby limit intake (VAN SOEST, 1994; TRAXLER et al., 1998).

In the diets fed to lactating dairy cows in subtropical and tropical systems, indigestible NDF must be included in the diet formulation, as NDF is one of the main factors determining food intake and also plays a significant role in rumen diet degradation and voluntary intake. This is particularly prominent in feed systems based on C_4 forages with pronounced lignification, which withstands microbial degradation (VAN SOEST, 1994; TRAXLER et al., 1998; HARPER; MCNEILL, 2015). Therefore, formulating diets based on NDF content without reference to indigestible NDF may affect voluntary intake, apparent digestibility, and metabolizable energy content of the diet (HARPER; MCNEILL, 2015). The formulation of DRNCS is predominantly characterized by including sugar cane, which has low levels of protein and shows low ruminal degradation of the fibrous fraction (CASTRO et al., 2009; TEIXEIRA JÚNIOR et al., 2016; VALADARES FILHO et al., 2017).

Lactating Holstein dairy cows fed with DTR showed similar milk yield and composition, ECM, and FE as cows fed with DRCS. In contrast, cows fed DRNCS, despite receiving a higher proportion of concentrate in the diet, lower roughage proportion, with higher NFC, TDN, and NEL content in the diet, exhibited inferior performance compared to the other diets, in regard of milk yield and composition, ECM, and FE, most likely because nutrient availability was compromised by the reduced digestibility of NDF and CP, which had a negative effect on nutrient intake.

The differences found in milk fat and protein contents confirm the well-known antagonism between milk yield and milk fat and protein content, which is referred to as a 'dilution effect' in milk production (MIGLIOR et al., 2007). Regarding milk production and lactose content, these differences are related to the digestibility of the nutrients that compromise the intake, with negative effects on the FE due to the high energy-dependency of lactose (RIGOUT et al., 2002; QIAO et al., 2005), which is the main determinant of milk production (ALLEN; PIANTONI, 2014).

Conclusion

Diets based on the combination of two roughages produce milk yield and composition comparable to diets based on corn silage, whereas diets with a single source of roughage other than corn silage (even with a higher proportion of concentrate) lead to inferior intake, milk yield, and feed efficiency due to lower nutrient utilization. Diets based on corn silage allow for a higher proportion of roughage in the diet due to the inherent energy density.

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