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Nutritional value of baled rice straw for ruminant feed

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ABSTRACT - The objectives of this study were to evaluate the effects of cultivation and hay making factors on chemical composition, protein fractionation, and digestibility in rice straw, as well as to identify the chemical fractions that contribute to the variation in its nutritional value for ruminants. Statistical procedures were performed in a model that included rice crop cycle, sowing season, baling season, soil classification, fertilizer application, and productivity (kg/ha) as fixed effects and the hay bale as random effect. Chemical composition, protein fractionation, and digestibility data were subjected to multivariate analyses including factor, cluster, and discriminant. Considering the cultivation and haymaking factors, development cycle, baling season, and grain production explained the most variation in the rice straw nutritional value. Straws derived from early maturing cultivars showed the lowest levels of neutral detergent fiber, acid detergent fiber, acid detergent insoluble nitrogen, and C nitrogen fraction in comparison with straw originating from mid cycle cultivars. Rice straw from more productive cultivars had lower levels of lignin and C fraction as well as higher levels of crude protein and B3 fraction compared with straws from less productive cultivars. However, the main variation in the nutritional value between the samples of rice straw was related to the baling season. The bailing seasons were grouped in two clusters. Straws with better nutritional value were those with lower levels of cell wall fractions, from more productive crops, with early development cycle and baled until March. Rice crop cycle, baling season, and grain production effects explain the variation in the nutritional value of rice straws. Straws with better nutritional value have lower levels of fractions related to secondary cell wall and lignification.

Key Words: digestibility, forage conservation, protein fractionation

Introduction

Rice is the second most cultivated cereal worldwide (FAO, 2013). In Brazil, the cultivated area is 2.4 million hectares, with a production of 11.75 million tons (FAO, 2013). In Rio Grande do Sul, the state with largest production in Brazil, the rice crop presented high productivity in the 2014/2015 harvest season, averaging 7780 kg/ha (IRGA, 2015). However, the utilization rate is only 50%, which results in a substantial amount of by-products, particularly straw.

Therefore, for each ton of rice grain harvested, one ton of straw remains in the field (Maiorella, 1985; Doyle et al., 1986). Despite the low nutritional value of rice straw due to its high silica content, low ruminal degradation of carbohydrates, and low nitrogen content, when stored in bales, it presents significant potential for strategic use in critical periods of food availability or in ruminant production systems with low nutrient requirements.

The conservation of straws in cylindrical rolls is a common practice adopted in Latin America (Wunsh et al., 2007). These rolls weigh 400-500 kg and the forage is compressed under great pressure, allowing its preservation and permanence in the environment without protection until it is used to feed the animals (Wunsh et al., 2007).

The nutritional value of rice straw is much lower than that of alfalfa hay, but there is substantial variability in the nutrient levels and feeding value among rice straws (Nader et al,. 2012) because the nutritional value of the straw is directly related to its chemical composition, combined with possible anti-nutritional factors, which are often involved in protecting the plant against predation and biodegradation (Van Soest, 1981), as well as genetic factors (Capper, 1988), climate (Sannasgala and Jayasuriya, 1986), morphological composition (Sannasgala and Jayasuriya, 1987; Nakashima and Orskov, 1990), and cultivation practices such as fertilizer application, water management, harvest maturing

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stage, and post-harvest storage (Ibrahim et al., 1988). However, there is little scientific evidence of the influence of factors such as baling season, soil classification, time between harvest and baling, and grain production on the nutritional value of the baled rice straw.

Thus, this study aimed to identify the cultivation and haymaking factors, as well as the chemical fractions that are important in the differentiation of nutritional value in stored rice straw bales in Rio Grande do Sul State, Brazil.

Material and Methods

Animal care procedures throughout the study followed protocols approved by the Ethics Committee for Animal Use (ECAU) of Universidade Federal do Rio Grande do Sul, under no. 18442/2010.

The experimental material consisted of 42 randomly collected composite samples of stored rice straw bales in the western region of Rio Grande do Sul State, Brazil. The temperature and humidity data were collected from an automatic weather station located at 29°84' S longitude and 57°08' W latitude (Table 1).

The bales were prepared on 14 farms (bailing location) that used baling as a routine practice after harvesting, aiming to use the straw for cattle supplementation. The bales were prepared in the range of up to six days after the grain harvest and thereafter maintained in the field until their use for feeding animals.

Three subsamples of each bale were removed, and after being homogenized, one composite sample was formed per bale. This procedure was repeated three times for each bailing location. The subsamples were collected in the exterior, in the middle (approximately 35 cm from the exterior), and in the central part of the bale (70 cm from the exterior surface). The subsamples of the intermediate and central portions were collected through the side of the bale, because the compression of the exterior surface does not allow reaching the deepest layers.

Samples were classified according to baling location (14 farms), rice crop development cycle (early: 110-120 days, and medium: 121-130 days), sowing and baling season (divided into fortnightly periods), soil classification (Neosol: slightly weathered soil, and Vertisol: soil with swelling clays), fertilizer application (N-P-K levels), and rice grain production (≤10000 and >10000 kg/ha) (Table 1).

Samples were ground in a stationary Wiley mill with 1 mm sieve and analyzed for dry matter (DM; Easly et al., 1965), organic matter (OM; AOAC, 1975), mineral matter (MM; AOAC, 1975), and crude protein (CP; AOAC, 1975). Neutral detergent fiber not assayed with heat-stable amylase and expressed exclusive of residual ash (NDFom) and acid detergent fiber expressed exclusive of residual ash (ADFom) were determined using the Ankon fiber analyzer with reagents described by Van Soest et al. (1991). Hemicellulose (HEM), cellulose (CEL), lignin determined by solubilization of cellulose with sulfuric acid (lignin-sa), and acid detergent insoluble silica (ADIS) were calculated according to Van Soest et al. (1991), but with a modification to determine silica in which the residue was burned in a muffle furnace at 550 °C overnight. Hemicellulose value was calculated as the difference between NDF and ADF performed in sequential analyses on the same sample.

Table 1 - Characterization of the rice straw composite samples collected according to bailing location, rice crop cycle, sowing season, baling season, soil classification, soil fertilization, and grain production

Composite sample	Baling location	Rice crop cycle[1]	Sowing season (fortnight)	Baling season (fortnight)	Soil classification[2]	Fertilization N-P-K[3] (kg/ha)	Grain production (kg/ha)	T (ºC)[4]	H (%)[5]
1, 2, 3	1	Early	October 1st	March 1st	Neosol	300 (5-20-30)	≤10000	24.27	59.98
4, 5,6	2	Early	October 1st	March 1st	Vertisol	250 (8-20-30)	>10000	24.27	59.98
7, 8, 9	3	Medium	September 2nd	March 2nd	Neosol	300 (5-20-20)	≤10000	22.36	70.20
10, 11, 12	4	Medium	September 2nd	April 1st	Neosol	300 (5-20-30)	≤10000	21.76	60.46
13, 14, 15	5	Medium	October 1st	April 1st	Vertisol	250 (8-20-30)	>10000	21.76	60.46
16, 17, 18	6	Medium	October 1st	March 2nd	Vertisol	250 (8-20-30)	>10000	22.36	70.20
19, 20, 21	7	Early	October 2nd	March 2nd	Neosol	300 (5-20-30)	≤10000	22.36	70.20
22, 23, 24	8	Early	October 2nd	March 2nd	Neosol	300 (5-20-30)	≤10000	22.36	70.20
25, 26, 27	9	Medium	September 2nd	February 2nd	Neosol	280 (5-20-30)	>10000	24.52	67.65
28, 29, 30	10	Medium	September 2nd	February 2nd	Neosol	280 (5-20-30)	>10000	24.52	67.65
31, 32, 33	11	Medium	September 2nd	March 1st	Neosol	250 (5-20-30)	≤10000	22.27	59.98
34, 35, 36	12	Medium	September 2nd	March 1st	Neosol	250 (5-20-30)	≤10000	22.27	59.98
37, 38, 39	13	Medium	October 1st	April 1st	Neosol	280 (5-20-30)	≤10000	21.76	60.46
40, 41, 42	14	Medium	October 1st	April 1st	Neosol	280 (5-20-30)	≤10000	21.76	60.46

[1] Early development cycle - 110-120 days; medium development cycle - 121-130 days.
[2] Neosols - slightly weathered soil; Vertisols - soil with swelling clays. Both are young and are characterized by high nutrient availability and silica (EMBRAPA, 2006).
[3] N-P-K - ratio between nitrogen, phosphorus, and potassium macronutrients in the fertilizer composition.
[4] Average temperature during the baling season.
[5] Average relative humidity during the baling season.

Nitrogen fractionation was performed according to Licitra et al. (1996). Fractions A and B1 were kept together due to the low content of non-protein nitrogen (fraction A) present in straws with low nutritional value, such as baled rice straw.

Nitrogen fractions (A+B1, B2, B3, and C) along with the theoretical degradation rates associated with each fraction (K_d) and the food passage rate through the stomach (K_p) were used to estimate the values of rumen degradable (RDP) and undegradable (RUP) protein (percent of CP), according to the model proposed by CNCPS (Sniffen et al., 1992), as follows:

$$\text{RDP (g kg}^{-1}\text{ CP)} = A+B_1[(k_dB_1)/(k_dB_1+K_p)]+B_2[(k_dB_2)/(k_dB_2+K_p)]+B_3[(k_dB_3)/(k_dB_3+K_p)];$$

$$\text{RUP (g kg}^{-1}\text{ CP)} = B_1[(k_p)/(k_dB_1+K_p)] + B_2[(k_p)/(k_dB_2+K_p)] + B_3[(k_p)/(k_dB_3+K_p)] + C.$$

Fractional theoretical rates of degradation (K_d) for B1, B2, and B3 fractions of 1.35, 0.10, and 0.0009/h, respectively, were considered for rice straw according to NRC (1996). A passage rate (K_p) of 0.02/h was used, considering that rice straw is a fibrous food of low consumption by animals.

In vitro digestibility was determined by the two-stage digestion technique proposed by Tilley and Terry (1963). Ruminal inoculum was obtained from two Texel sheep with an average weight of 60 kg. Two hours after the animals received the morning feed, rumen fluid and part of the rumen solid material was obtained in order to collect microorganisms adhered to the substrate. All collected material was homogenized in a blender at a ratio of 1:1 (solid: liquid portion) and filtered through four layers of gauze.

For descriptive statistics, the 42 samples data were analyzed using the MEANS procedure of SAS (Statistical Analysis System, version 9.3). Data were also analyzed using MEANS procedure of SAS in a model that included rice crop cycle, sowing season, baling season, soil classification, fertilizer application, and productivity (kg/ha) as fixed effects and the hay bale as random effects. Interactions were not tested due to the numbers of observations within most categories being unbalanced. Statistical differences were considered significant when P<0.05. Chemical composition, protein fractionations, and digestibility data were subjected to multivariate analyses including factor (FACTOR procedure), cluster (FASTCLUS and PROC TREE procedures), and discriminant (DISCRIM procedure).

Results

The rice straw samples evaluated varied widely in chemical composition (Table 2). The variation in the straw chemical composition was related to neutral detergent insoluble nitrogen (NDIN), B3 nitrogen fraction (B3), rumen undegradable protein (RUP), rumen degradable protein (RDP), A+B1 nitrogen fraction (A+B1), acid detergent insoluble silica (ADIS), neutral detergent fiber (NDFom), acid detergent fiber (ADFom), and cellulose (CEL) levels, explaining 86% of the total variation in the rice straw nutritional value (Figure 1). Straws with higher levels of RUP, B3, and NDIN showed lower levels of RDP, A+B1, and cell wall components, explaining 65.09% of the variation in the nutritional value (Eigenvector 1, Figure 1).

There is a subgroup of straws where the highest levels of RDP and A+B1 were observed when the levels of cell wall components, NDIN, RUP, and B3 were low, explaining 21.37% of the variation in the nutritional value (Eigenvector 2, Figure 1).

As there was no significant effect of sowing season, soil classification, and fertilizer application (P>0.05) on the nutritional value of rice straw, only the significant effects of rice crop cycle, baling season, and grain production (P<0.05) were shown (Tables 3, 4, and 5).

Dry matter was the only fraction of the chemical composition influenced by rice straw cycle, baling season, and grain production (Table 3). Dry matter contents were

Table 2 - Minimum, maximum, average, standard deviation of the mean (SEM) and coefficient of variation (CV) values of the chemical composition of the 42 samples of rice straw evaluated

Chemical composition	Minimum	Maximum	Average	SEM	CV (%)
DM (g kg^{-1} FM)	865	926	906	0.20	1.46
MM (g kg^{-1} DM)	108	249	181	3.04	9.47
IVDMD (g kg^{-1} DM)	336	533	441	0.77	11.36
IVOMD (g kg^{-1} DM)	353	563	481	0.71	9.68
NDFom (g kg^{-1} DM)	663	791	732	0.49	4.38
ADFom (g kg^{-1} DM)	376	505	449	0.43	6.32
HEM (g kg^{-1} DM)	260	333	300	0.23	4.97
CEL (g kg^{-1} DM)	355	470	417	0.42	6.58
Lignin-sa (g kg^{-1} DM)	16.8	46.5	31.5	0.10	22.04
ADIS (g kg^{-1} DM)	59.2	138	105	0.31	19.35
CP (g kg^{-1} DM)	36.3	48.4	42.2	0.04	6.99
NDIN (g kg^{-1} DM)	1.9	4.2	2.9	0.009	20.44
ADIN (g kg^{-1} DM)	0.9	1.7	1.1	0.002	16.22
A+B1(g kg^{-1} CP)	165	404	280	1.02	23.78
B2 (g kg^{-1} CP)	196	347	289	0.53	11.90
B3(g kg^{-1} CP)	111	398	253	1.32	33.84
C (g kg^{-1} CP)	128	231	176	0.48	17.90
RDP (g kg^{-1} DM)	463	692	558	0.93	10.86
RUP (g kg^{-1} DM)	307	536	441	0.93	13.74

DM - dry matter; FM - fresh matter; MM - mineral matter; IVDMD - *in vitro* dry matter digestibility; IVOMD - *in vitro* organic matter digestibility; NDFom - neutral detergent fiber not assayed with a heat-stable amylase and expressed exclusive of residual ash; ADFom - acid detergent fiber expressed exclusive of residual ash; HEM - hemicellulose; CEL - cellulose; lignin-sa - lignin determined by solubilization of cellulose with sulfuric acid; ADIS - acid detergent insoluble silica; CP - crude protein; NDIN - neutral detergent insoluble nitrogen; ADIN - acid detergent insoluble nitrogen; A+B1, B2, B3, and C - nitrogen fractions; RDP - rumen degradable protein; RUP - rumen undegradable protein.

lower in straw from early maturing cultivars compared with straws from medium maturing cultivars (899 and 909 g kg^{-1} of fresh material (FM), respectively). Straw baled in the 1st half of March had a lower dry matter content compared with the straws baled in the other seasons. Straws from more productive rice cultivars had lower dry matter content compared with straws from less productive cultivars (899 and 909 g kg^{-1} FM, respectively).

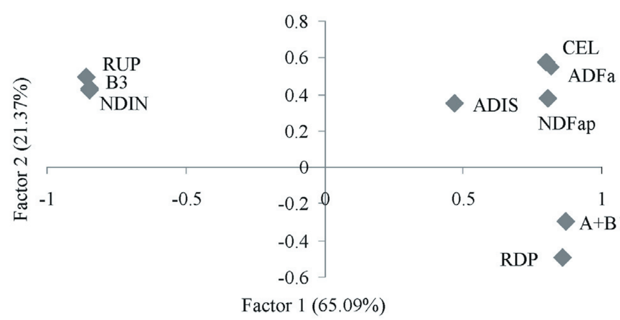
Table 3 - Effects of rice crop cycle, baling season, and grain production on dry matter (DM, g kg^{-1} of fresh matter), mineral matter (MM, g kg^{-1} of DM), *in vitro* dry matter digestibility (IVDMD, g kg^{-1} of DM), and *in vitro* organic matter (IVOMD, g $^{-1}$ of DM) of rice straw

Variable	DM	MM	IVDMD	IVOMD
Rice crop cycle				
Early	899b	192	420	464
Medium	909a	178	452	491
SEM	0.25	0.78	1.08	1.13
Baling season (fortnight)				
February 2nd	913a	192	457ab	477ab
March 1st	892b	163	473a	510a
March 2nd	905a	185	429b	478ab
April 1st	906a	201	384c	443b
SEM	0.39	1.06	1.47	1.54
Grain production (kg/ha)				
≤10000	909a	183	439	470
>10000	899b	187	433	485
SEM	0.34	0.78	1.09	1.14
Significance (P)				
Rice crop cycle	0.0108	0.2537	0.0640	0.1224
Baling season	0.0008	0.0506	0.0002	0.0132
Grain production	0.0066	0.6897	0.6556	0.3749

Different letters in the column differ statistically (P<0.05) by Tukey's test.
SEM - standard error of the mean.

Straws from early cycle cultivars showed lower levels of NDFom (706 and 733 g kg^{-1} DM), ADFom (429 and 449 g kg^{-1} DM), ADIN (1.0 and 1.2 g kg^{-1} DM), and C nitrogen fraction (158 and 179 g kg^{-1} CP) compared with straws from mid-cycle cultivars, respectively (Tables 4 and 5).

Straws from more productive crops (>10000 kg/ha of grain production) showed lower levels of lignin-sa (27.7 and 33.1 g kg^{-1} DM) and C nitrogen fraction (155 and 182 g kg^{-1} CP) and higher levels of crude protein (43.5 and 40.7 g kg^{-1} DM) and B3 nitrogen fraction (302 and 245 g kg^{-1} CP) compared with straws from less productive crops (≤10000 kg/ha of grain production), respectively (Tables 4 and 5).



RUP - rumen undegradable protein; B3 - nitrogen fraction; NDIN - neutral detergent insoluble nitrogen; CEL - cellulose; ADFom - acid detergent fiber; NDFom - neutral detergent fiber; A+B1 - nitrogen fraction; RDP - rumen degradable protein.

Figure 1 - Graphic representation of the first two principal components of the chemical composition of the rice straw.

Table 4 - Effects of rice crop cycle, baling season, and grain production on neutral detergent fiber (NDFom), acid detergent fiber (ADFom), hemicellulose (HEM), cellulose (CEL), lignin (Lignin-sa), and acid detergent insoluble silica (ADIS) of rice straw, expressed in g kg^{-1} of dry matter

Variable	NDFom	ADFom	HEM	CEL	Lignin-sa	ADIS
Rice crop cycle						
Early	706b	429b	295	398	29.7	109
Medium	733a	449a	300	418	31.1	102
SEM	0.66	0.56	0.37	0.53	0.16	0.39
Baling season (fortnight)						
February 2nd	683b	405c	295b	375c	30.4	89.4b
March 1st	725a	436b	309a	403b	32.5	91.1b
March 2nd	742a	463a	296b	430a	32.8	115a
April 1st	721a	451ab	290b	425a	25.9	127a
SEM	0.89	0.77	0.50	0.72	0.23	0.53
Grain production (kg/ha)						
≤10000	726	442	300	408	33.1a	101
>10000	712	436	295	408	27.7b	110
SEM	0.66	0.57	0.37	0.53	0.17	0.39
Significance (P)						
Rice crop cycle	0.0120	0.0238	0.4106	0.0203	0.5962	0.2574
Baling season	0.0044	0.0003	0.0315	<0.0001	0.0873	<0.0001
Grain production	0.1418	0.5495	0.3484	0.9526	0.0296	0.1116

Different letters in the column differ statistically (P<0.05) by Tukey's test.
SEM - standard error of the mean.

The highest variation in the nutritional value of the rice straw samples was related to the baling season. Higher digestibility was observed for baled straw in the first three fortnights evaluated (477, 510, and 478 g kg^{-1} DM) compared with the 1st fortnight of April (443 g kg^{-1} DM), respectively (P<0.05; Table 3). However, lower levels of neutral detergent fiber (683 and 725; 742; and 721 g kg^{-1} DM), acid detergent fiber (405 and 436; 463; and 451 g kg^{-1} DM), and cellulose (375 and 403; 430; and 425 g kg^{-1} DM) were observed for the straw baled in the 2nd fortnight of February compared with the other baling seasons (P<0.05; Tables 3, 4, and 5), respectively.

The straw baled on the 1st and 2nd fortnights of March were classified in the same cluster (Figure 2) and differed in the levels of A+B1 and B2, hemicellulose, and ADIS (Table 6). Another cluster was formed by the straw baled in the 1st fortnight of April and 2nd fortnight of February (Figure 2), which differed only in the contents of CEL (Table 6).

Discussion

Given the average nutritional composition of the samples evaluated, it is possible to assert that their use for feeding beef cattle, as the only food source, is not sufficient to meet the maintenance requirements of the animals (NRC, 1996; Sarnklong et al., 2010). However, this feed presents relevant potential for strategic use as part of the diet of animal categories with lower nutrient requirements in times of food shortage, as well as to preserve the body condition of the animals, intensify the production system, and still allow a better quality of postpartum nutrition (Barcellos et al., 1999).

The variation in the nutritional value of rice straws evaluated in this study was explained by the effects of rice crop cycle, baling season, and grain production. Previous research has also identified variations in the nutritional value of rice straw due to the rice crop development cycle (Santos, 2010) and grain production (Shahjahan et al., 1993; Vadiveloo, 2003).

Table 5 - Effects of rice crop cycle, baling season, and grain production on crude protein (CP), neutral (NDIN) and acid (ADIN) detergent insoluble nitrogen, rumen degradable protein (RDP), and rumen undegradable protein (RUP), expressed in g kg^{-1} of dry matter, and nitrogen fractions (A+B1, B2, B3, and C), expressed in g kg^{-1} of crude protein

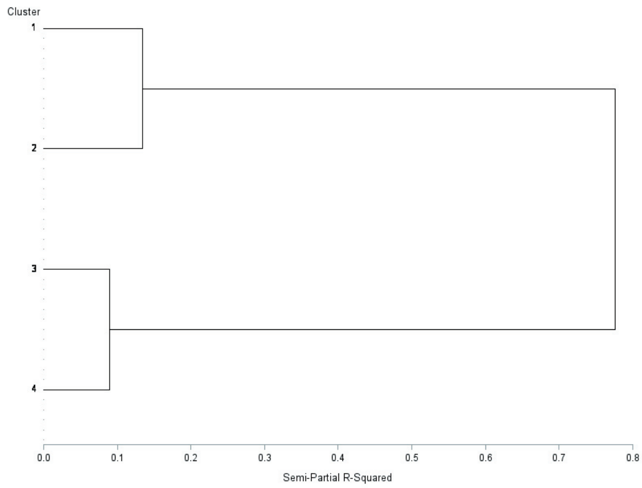
Variable	CP	NDIN	ADIN	A+B1	B2	B3	C	RDP	RUP
Rice crop cycle									
Early	41.8	3.0	1.0b	245	301	295	158b	537	462
Medium	42.5	2.9	1.2a	277	290	253	179a	557	443
SEM	0.06	0.009	0.004	0.76	0.89	1.85	0.67	1.39	1.39
Baling season (fortnight)									
February 2nd	40.1b	2.9ab	1.1	211b	321	293a	175	521b	479a
March 1st	44.4a	3.3a	1.1	235b	286	322a	155	522b	478a
March 2nd	43.3a	2.6b	1.1	343a	275	219b	162	603a	397b
April 1st	40.7b	2.9ab	1.1	255b	301	259ab	184	545b	455a
SEM	0.087	0.018	0.007	1.28	1.21	2.61	0.92	1.89	1.89
Grain production (kg/ha)									
≤10000	40.7b	2.8	1.1	277	295	245b	182a	557	443
>10000	43.5a	3.1	1.0	245	297	302a	155b	537	463
SEM	0.068	0.013	0.004	1.13	0.98	0.92	0.67	1.40	1.40
Significance (P)									
Rice crop cycle	0.5021	0.5852	0.0107	0.0721	0.4651	0.1420	0.0410	0.3624	0.3624
Baling season	0.0104	0.0140	0.9074	<0.0001	0.1420	0.0104	0.1122	0.0030	0.0030
Grain production	0.0069	0.0620	0.1754	0.0517	0.8404	0.0465	0.0097	0.3334	0.3334

Different letters in the column differ statistically (P<0.05) by Tukey's test.
SEM - standard error of the mean.

Table 6 - Significant variables in the discrimination between rice straw baling season through discriminant analysis

Baling season	1st fortnight of March	2nd fortnight of March	1st fortnight of April
2nd fortnight of February	B2 DM RDP	A+B1[1] CEL B3 MM	CEL[1]
1st fortnight of March		A+B1[1] B2 HEM ADIS	ADIS[1] DM
2nd fortnight of March			A+B1 CP

[1] Variables highly significant (P<0.0001) in discriminating between the baling rice straw seasons.
B2 - B2 nitrogen fraction; DM - dry matter; RDP - rumen degradable protein; A+B1 - A+B1 nitrogen fractions; CEL - cellulose; B3 - B3 nitrogen fraction; HEM - hemicellulose; ADIS - acid detergent insoluble silica; CP - crude protein.



Custer 1 - 1st fortnight of March; Cluster 2 - 2nd fortnight of March; Cluster 3 - 1st fortnight of April; Cluster 4 - 2nd fortnight of February.

Figure 2 - Dendrogram from cluster analysis of the baling rice straw seasons evaluated.

In this study, fractions related to secondary cell wall and lignification (acid detergent fiber, neutral detergent fiber, acid detergent insoluble nitrogen, and C nitrogen fraction) were higher in rice straw from cultivars with medium development cycle. According to Juliano (1985), for cultivars with medium and long development cycle, photosynthesis extends for a longer period, and consequently, the levels of the fractions linked to the cell wall are higher at the expense of starch and soluble sugars in the vegetative components.

Santos et al. (2010) also observed that the rice straw from a late development cycle cultivar (M401) showed higher concentrations of acid detergent fiber, lignin, total silica, and neutral detergent silica compared with straw from an early development cycle cultivar (M202), and attributed this difference to greater height of the late development cycle cultivar with longer stem and leaf sheath in relation to the early development cycle cultivar.

Rice straw samples from more productive crops had lower levels of lignin-sa and C nitrogen fraction, as well as higher crude protein and B3. Greater retention of crude protein in vegetative tissue due to increased enzyme activity may explain the higher crude protein content in straws from more productive crops, although the results of Shen et al. (1998) suggest that grain production had no impact on the rice straw crude protein content. Shahjahan et al. (1993) and Vadiveloo (2003) observed that rice cultivars with better agronomic traits (grain production, days to maturing, and stem weight) produced straws with higher digestibility levels.

The higher variation in the rice straw nutritional value observed in this study was found to be due to the straw baling season. Discriminant analysis showed that fractions related to protein (CP, RDP, A+B1, B2, and B3) and cell wall content (ADIS, HEM, and CEL) as well as DM and OM levels summarized the differences between the baling seasons evaluated. As the interval between the grain harvest and the straw baling occurred in a period up to six days, we may assume that the losses were normal and inherent to the process and maintained the straw palatability (smell, taste, and color), because, according to Drake et al. (2002), the nutritional value of forage starts to decrease from 6 to 10 days after harvest. Therefore, the differences in nutritional value between baling seasons can be related to the rice crop cycle, plant morphological characteristics, and maturing stage of the material collected and subsequently baled. The physiological maturing stage is considered the best time of rice harvest to optimize the production of grain and straw quality (Wang et al., 2006). From this stage, a decline in the nutritional value of rice straw occurs due to photosynthesis prolongation, resulting in a decrease in starch and sugars (Juliano, 1985) and an increase in dry matter and silica levels (Deren et al., 1994).

According to Van Soest (1981), the nutritional value of forage is directly related to its chemical composition, combined with possible anti-nutritional factors. In this study, NDIN, B3, RUP, RDP, A+B1, ADIS, NDFom, ADFom, and CEL levels explained 86% of the total variation in the nutritional value of the rice straw samples evaluated.

The high levels of cell wall were inversely related to the straw nutritional value, similar to that observed by Agbagla-Dohnani et al. (2001), in which the rice straw cell wall had higher levels of cellulose then hemicellulose and, as the degradation is positively correlated with hemicellulose content and the increase in the cellulose and lignin, it adversely affects the degradation rate.

According to Wioyastuti and Abe (1989), for each unit of silica present in the evaluated sample, a decrease of three units in the digestibility occurs. However, the possible mechanisms by which silica adversely affects the digestibility of the cell wall of rice straw may be related to its role as a physical barrier (Bae et al., 1997; Kim et al., 2002) or as an inhibitor of enzymatic hydrolysis in the rumen (Agbagla-Dohnani et al., 2003), which reduced the accessibility of wall carbohydrates to digestive microorganism attack.

According to Wang et al. (2006) and Santos et al. (2010), the morphological location of silica in the plant causes differences in the *in vitro* gas production of rice straw. Another possibility may be related to the low palatability of the food for the animal, due to the presence of highly silicified cells projected on the leaf edge, making the material rough to the touch (Jones and Handreck, 1967), although the participation of leaves is low in the total constitution of the bale.

Although the protein content was not a significant factor in the analysis, it was below the critical range of 60-80 g kg^{-1} DM, affecting the efficiency of microbial growth and the ability of fiber degradation in the rumen (Van Soest, 1994). Furthermore, almost half of the protein is in the form of B3 and C fractions. The B3 fraction has a very slow degradation rate, which is associated with the cell wall of the plant, while the C fraction is the unavailable protein consisting of proteins associated with lignin, tannin-protein complex, and Maillard products, which are highly resistant to attack of enzymes of microbial and host origin (Sniffen et al., 1992; Van Soest, 1994). The B3 fraction was one of the important chemical fractions in the differentiation between the rice straw baling seasons and was also included in the factor analysis to explain the total variation in the nutritional value of the rice straw samples evaluated.

Conclusions

Given the average nutritional composition of the samples evaluated, rice straw cannot be the only feed source for ruminants.

Rice crop cycle, baling season, and grain production effects explain the variation in the nutritional value of rice straws.

Straws that have better nutritional value are those with lower levels of fractions related to secondary cell wall and lignification.

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