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Chemical Composition, Physical Characteristics, Rumen Degradability of NDF and NDF Fractionation in Rice Straw as an Effective Fibre in Ruminants

Research Article

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ABSTRACT

In order to determine of physical characteristics of rice straw as an effective source of fiber in ruminants, alfalfa hay, four varieties of rice straw (Taroum Neda, Taroum Neamat, Taroum Sangi, and Asgari), and four rations that contained four varieties of rice straws were investigated. The chemical (dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), nonfiber carbohydrates (NFC) and crude protein (CP)), and physical characteristics (bulk density, water holding capacity (WHC), and soluble and insoluble DM and ash of samples, kinetics of hydration and change in functional specific gravity (FSG) and feed particle size, physically effective factor (pef)) of forages and total mixed ration (TMR) were determined. Except on ether extract and ash content, the DM, OM, NDF, NFC, and CP content of four rice straw and rations were similar but there was different among alfalfa and rice straws. The rice straws had a bulk density lesser than alfalfa. However, TMR had a similar bulk density, WHC, hydration rate, insoluble DM and ash and greater than alfalfa hay. Alfalfa had lesser WHC than rice straws and there were not different in straws. The soluble DM and FSG of rice straws were similar and lesser than those of alfalfa hay. The TMR had similar physical characteristics. Alfalfa hay had greater FSG than rice straw at all incubation times. Four rice straws and four rations were similar in indegradable NDF (iNDF) and total tract NDF digestibility (TTNDFD). Results showed that regardless the system, rice straws were similar in physically effectiveness and physically more effective than alfalfa because of having greater NDF and iNDF content, geometric mean and pef than alfalfa.

KEY WORDS effective fibre, in degradable NDF, physical characteristic, rice straw.

INTRODUCTION

Rice is the world's second largest cereal crop after wheat, with an annual production of about 750 million metric tons (FAO, 2013). It is the staple food of more than half of the world's population. About 91% of it is grown and consumed in Asia. For every 4 tons of rice grain, about 6 tons of straw are produced, therefore this amounts to about 550 million tons of straw and 110 million tons of husks each year. Rice straw has low nutritive values because of low DM digestibility and low protein content (Van Soest, 2006). Rice straw is lesser in lignin and great in silica compared with the other straws. Until today, a lot of investigations have conducted using a variety of chemical and biological treatments to improve rice straw in ruminant nutrition. These treatments involve sodium hydroxide, ammonia, urea, pressure and heat in combinations with steam, pressure and ammonia, urine, enzymes, acids and fungi. However, the main goal of these treatments was enhancement of digestibility dry and organic matter. Nowadays, some new concepts in ruminant nutrition, such as physically effective fibre (peNDF) are being introduced (Mertens, 1997;

Mertens, 2000) to relate the physical characteristics of fibre (primary particle size) to its effects on chewing activity and the biphasic nature of rumen contents. Although particle size measurement is central to all effective fibre systems, nonetheless, some the physical characteristics such as functional specific gravity (FSG), bulk density, water holding capacity (WHC), insoluble ash, etc. influence effectiveness of fire and rate of passage (Teimouri Yansari *et al.* 2004; Teimouri Yansari and Pirmohammadi, 2009). In addition, plant breeding has been devoted to maximizing grain yield with less interest in the straw. This has resulted in short varieties in which the proportions of straw and leaf blades are reduced (Capper, 1988; Bainton *et al.* 1991). However, for more forages the physical characteristics and effectiveness have not been investigated.

Rice straw is important forage for in Northern Iran that was produced 1450 million metric tons rice grain (FAO, 2013). Using rice straw for animal production can save grains and provide additional income to farmers and decrease environmental pollution due to the burning of straw after harvest. Development and application of chemical treatments for upgrading straw have stimulated intense interest, but there are still some blind spots on the mechanism with which the treatments improve the nutritive value of straw. It seems that rice straws are sources of indigestible NDF that may retain in the rumen, make a consistence ruminal mat, stimulate rumination, chewing activity and saliva secretion and ultimately buffer rumen pH and increase the concentration of ruminal acetate and milk fat. On the contrary, they had a great ruminal filling factor, therefore; it is often considered as low-quality forage. Four rice varieties including Taroum Neda and Taroum Neamaat as short varieties and Taroum Sangi and Asgari as tall varieties are abundant. However, until now the quality had not studied and their effectiveness was not compared. Thus, the aim of the current experiment was determination of chemical composition, physical characteristics, ruminally degradability parameters of NDF and NDF fractionation of feeds and TMR that contained four different varieties of rice straw.

MATERIALS AND METHODS

Alfalfa at 15% flessering, four different varieties of rice straw (Taroum Neda and Taroum Neamaat as short varieties and Taroum Sangi and Asgari as tall varieties) were harvested, dried and chopped on the same day, at maturity 14 cm above the ground in August 2014 from the agricultural research center of Agricultural and Natural Resource University (SANRU), Sari, Mazandaran, Iran. Individual small rectangular bales (average weight 10 kg) were chopped with a forage field harvester (Jaguar # 62, Class Company, Germany) for theoretical cut length 19 mm.

Feeds were weighed, sub-sampled, dried at 55 ˚C, ground through a Wiley mill (1 mm screen) and analyzed for DM, OM, Kjeldahl N, ether extract (AOAC, 2002), NDF (Van Soest *et al.* 1991; using amylase and inclusive of residual ash), ADF (Van Soest *et al.* 1991) and ash at 605 ˚C. Non-fibre carbohydrate in g/kg was calculated as: 1000 - [CP + NDF + Ash + EE].

Bulk density (g/mL), WHC (g/g insoluble DM), and soluble and insoluble DM and ash (g/kg) of alfalfa and rice straws were measured as described by Giger-Reverdin (2000). Kinetics of hydration and change in FSG of forages were measured with 100 mL pycnometer at 39.0 ± 0.5 ˚C (Wattiaux, 1990; Teimouri Yansari *et al.* 2004). The mixed rumen fluids from two sheep fed only alfalfa were collected before to feeding and rinsed with eight layers of cheese cloth, centrifuged at 3000 × *g*, for 10 min and the supernatant (with density 1.0068±0.0005 g/mL) were used as hydration solution. Sodium azide (0.50 g/L) and penicillin G (25000 units/L) were added to the hydration solution to prevent microbial growth. About 1.5 g of each sample, in 5 replicates were weighed in pycnometers. The pycnometers were half-filled to allow vigorous shaking after initial soaking of samples and for removal of gas bubbles. The first reading of the total weight of pycnometers was taken after 6 min (0.1 h) of initial soaking, which was the shortest interval necessary to eliminate all gas bubbles. After completely filling the pycnometers, they were again put on the stirring plate for gentle and continual stirring. Pycnometers were refilled and weights were recorded at 0.5, 1.0, 1.5, 2, 4, 6, 12, 24, 36, 48 and 72 h.

During measurements of hydration kinetics, very small gas bubbles accumulated near the junction between adapter and flask of pycnometers, connecting a vacuum pump to pycnometer for 2 min dislodged gas bubbles from the junction. Data were used to estimate the rate of hydration and water uptake or WHC using NLIN procedures of SAS® (SAS, 1998; Wattiaux, 1990). A biexponential model as was described by the function below was used to estimate hydration parameters:

$$Y_t = Ae^{-k_a t} + Be^{-k_b t}$$

Where:
Y_t: water uptake over time (g/g of insoluble DM).
A and B: represent pool sizes of hydration.
k_a and k_b: represent respective fractional rates of hydration (min^{-1}).

Total WHC (g/g of insoluble DM) was calculated as the sum of total solution uptake (sum of A+B) and initial moisture content of samples. A mean for hydration rate that was weighted for pool sizes from biexponential models was calculated: $[(A\times k_a) + (B\times k_b)] / (A+B)$. As mentioned above, in this study, the WHC were measured using filtration method (Giger-Reverdin, 2000; Table 1) and non-linear curve fitting method (Wattiaux, 1990).

Feed particle size and distribution were determined by dry sieving in four replicates, using the Penn State particle separator. The physical effective factor (pef) of TMR were determined as the sum of retained particle on two 19 and 8mm sieves ($pef_{>8}$; Lammers *et al.* 1996), and three 19, 8, and 1.18mm sieves ($pef_{>1.18}$; Kononoff, 2002). The NDF of all materials retained on each sieve were measured (Van Soest *et al.* 1991). The $peNDF_{>8}$ and $peNDF_{>1.18}$ were calculated by multiplying NDF content of each portion on each sieve on $pef_{>8}$ and $pef_{>1.18}$, respectively (Table 2). The geometric mean and its standard deviation were calculated (American Society of Agricultural Engineers, 2002).

Using two ruminally fistulated Zel ewes (BW=30.5±1.8 kg); 5 g sample in 4 replications was weighed in sealed nylon bags (7 cm×8 cm, polyamide, with 15±2 µ pore size) and incubated in the rumen for 240 h (Huhtanen *et al.* 1994). Sheep housed on front shed, fed a total mixed ration (TMR) containing 50% chopped alfalfa hay, 25% rice straw, 25% barely grain, and mineral/vitamin supplement according to their requirements. On removal, bags were washed using cold water, dried at 55 ˚C for 48 h, residues for the periods were homogenized and analyzed for Kjeldahl N, NDF, and acid detergent lignin (ADL; Van Soest *et al.* 1991; Table 1), and multiplied by a fixed factor of 2.4 calculated as ADL × 2.4 ($iNDF_{2.4}$). The pdNDF calculated using the following equation: pdNDF= NDF – iNDF (Cotanch *et al.* 2014; Raffrenato and Van Amburgh, 2010).

Experimental data were analyzed using the PROC MIXED of SAS (1998) as a completely randomized design with 5 replications by the following model:

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

Where:
Y_{ij}: dependant variable.
µ: overall mean.
T_i: random effect of treatment.
e_{ij}: experimental error.

The data of particle size was analyzed as a completely randomised design with model effects of forage and two methods of particle size measurement using the REML variance component and PROC MIXED of SAS (1998).

The data of particle size was analyzed as a completely randomized design with model effects of forage and two methods of particle size measurement using the REML variance component and PROC MIXED procedure of SAS (1998) (Table 1). Mean separation was determined using the PDIFF procedure, and significance was declared at (P<0.05).

RESULTS AND DISCUSSION

Dry matter, OM, NDF, NFC and CP content of the four rice straw varieties were similar, except EE and ash content, but there was significant difference among alfalfa and rice straws (Table 1).

Rice straw had greater NDF and ash and lesser NFC and CP than alfalfa. The TMR that contained four different varieties of rice straw were also similar on DM, OM, NDF, NFC and CP content, however, their EE and ash content was significantly different. Previous researches have evaluated rice varieties for their composition and nutritive value and found that there is considerable variation among varieties relative to straw quality (Singh and Singh, 1995; Vadivelloo, 1995; Vadivelloo, 2000; Vadivelloo and Phang, 1996). In addition, short and tall varieties are different in chemical composition and digestibility relative to leaf, sheath and stem proportions.

Leafiness is associated with height among varieties in contrast to other grasses (Vadivelloo, 1995). Leaves tend to be less digestible than stems (Vadivelloo, 1995; Vadivelloo, 2000; Vadivelloo and Phang, 1996). The total mixed rations that contained Taroum Neda had lesser EE and ash content than others (Table 1). However, the quality of rice straw varieties is highly dependent on soil type and any genetic study will require control of the soil type (Van Soest, 1994). In the current study, since all varieties cultivated at the similar condition, the similarity in chemical composition was expected. Bulk density or packing density is the ratio of the mass of a collection of discrete pieces of solid material to a sum of the volume of the solid in each piece, the voids within the pieces, and the voids among the pieces of the particular collection (D3766, D32, ASTM Committee EO2 On Terminology, 2000). The rice straws had a bulk density lesser than alfalfa. The values of bulk density for rice straws and alfalfa were lesser than 1 and confirmed that as other forages these materials easily bounced over ruminal particulate post feeding (Table 2). There is a negative correlation among NDF and bulk density. Singh and Narang (1991) and, Giger-Reverdin (2000) reported that feedstuffs with high NDF content had low bulk density, and might have more effect on rumen fill than feedstuffs with high bulk density. Hence, forages that occupy larger volumes per unit of DM weight should have a greater effect on fill than another feeds (Wattiaux, 1990). Wattiaux (1990); Van Soest, (1994) and Van Soest, (2006) reported that bulk density influences dry matter intake (DMI), passage rate, and ruminal mean retention time.

Table 1 Chemical composition (% of DM) of feeds and total mixed rations that contained four different varieties of rice straws

Item	DM	OM	NDF	NFC	CP	EE	Ash
Feeds							
Alfalfa hay	89.20^{a}	91.90^{a}	48.63^{b}	27.30^{a}	14.16^{a}	1.57^{b}	8.33^{c}
Taroum Neda	90.50^{b}	86.77^{b}	76.80^{a}	3.21^{b}	5.37^{b}	1.41^{a}	13.23^{ab}
Taroum Neamaat	90.53^{b}	87.23^{b}	77.13^{a}	2.33^{b}	5.50^{b}	1.53^{ab}	13.50^{a}
Taroum Sangi	90.43^{b}	87.50^{b}	77.20^{a}	3.02^{b}	5.10^{b}	1.63^{a}	12.63^{b}
Taroum Asgari	90.70^{b}	86.83^{b}	78.63^{a}	2.76^{b}	5.37^{b}	1.60^{a}	12.63^{b}
SEM	0.333	0.306	0.388	0.509	0.126	0.010	0.124
P-values	0.0208	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0058	< 0.0001
Total mixed rations that contained four different varieties of rice straw							
Taroum Neda	91.83	92.23	53.13	22.60	11.20	1.40^{b}	11.67^{c}
Taroum Neamaat	92.93	92.13	52.80	22.90	10.70	1.53^{ab}	12.07^{bc}
Taroum Sangi	92.67	92.87	52.93	21.57	11.10	1.63^{a}	12.50^{ab}
Taroum Asgari	92.70	92.67	53.20	21.47	10.90	1.60^{a}	12.83^{a}
SEM	1.580	0.688	0.637	0.947	0.111	0.009	0.127
P-values	0.4366	0.6738	0.9210	0.2518	0.3279	0.0301	0.0185

DM: dry matter; OM: organic matter; NDF: neutral detergent fiber; NFC: nonfiber carbohydrates; CP: crude protein and EE: ether extracts.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 2 Physical characteristics of feeds and total mixed rations that contained four different varieties of rice straws

Item	Bulk density (g/mL)	Water holding capacity (g/g insoluble DM)	Hydration rate (g/g insoluble DM /min)[1]	Hydration rate (g/g insoluble DM /min)[2]	Functional specific gravity	Soluble DM (g/g DM)	Insoluble DM (g/g DM)	Insoluble ash (% of ash)	Insoluble ash (g/g DM)
Feeds									
Alfalfa hay	0.838^{a}	3.09^{b}	0.058^{b}	0.068^{b}	1.143^{a}	0.288^{a}	0.712^{b}	91.30^{a}	8.70^{b}
Taroum Neda	0.645^{b}	6.52^{a}	0.069^{a}	0.075^{a}	1.005^{b}	0.128^{b}	0.872^{a}	88.87^{b}	11.13^{a}
Taroum Neamaat	0.655^{b}	6.62^{a}	0.066^{a}	0.076^{a}	1.004^{b}	0.130^{b}	0.870^{a}	89.50^{b}	10.50^{a}
Taroum Sangi	0.644^{b}	6.65^{a}	0.067^{a}	0.073^{a}	1.003^{b}	0.129^{b}	0.871^{a}	89.16^{b}	10.13^{a}
Taroum Asgari	0.670^{b}	6.66^{a}	0.069^{a}	0.075^{a}	1.006^{b}	0.137^{b}	0.866^{a}	88.87^{b}	10.84^{a}
SEM	0.032	0.055	0.004	0.003	0.015	0.002	0.002	0.002	0.002
P-values	< 0.0001	0.0455	< 0.0001	< 0.0001	0.0036	< 0.0001	< 0.0001	0.0041	0.0041
Total mixed rations that contained four different varieties of rice straw									
Taroum Neda	0.621	5.97	0.038^{b}	0.042^{b}	1.174	0.210	0.790	79.00	8.97^{b}
Taroum Neamaat	0.621	5.89	0.035^{a}	0.043^{a}	1.186	0.200	0.800	80.30	9.77^{ab}
Taroum Sangi	0.622	5.93	0.032^{a}	0.042^{a}	1.172	0.213	0.787	78.67	11.40^{a}
Taroum Asgari	0.618	6.10	0.034^{a}	0.041^{a}	1.175	0.214	0.786	78.77	10.17^{ab}
SEM	0.046	0.038	0.001	0.002	0.235	0.022	0.033	0.042	0.022
P-values	0.056	0.0654	< 0.0001	< 0.0001	0.0765	0.0632	0.0578	0.0672	0.0001

[1] Water holding capacity that measured using filtration methods (Giger-Reverdin, 2000).
[2] Water holding capacity that calculated using curve fitting methods (Wattiaux, 1990).
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

As presented in Table 1, since rice straws had a high NDF content than alfalfa and their bulk densities were lesser than alfalfa, Taroum Asgari had relatively greater bulk density compared to others because of greater ash content. However, TMR that contained four different varieties of rice straw had similar bulk density. The WHC, hydration rate, insoluble DM, and ash contents of rice straws significantly greater than alfalfa hay, however, there were no difference among straws. In the current experiment, hydration rate is measured using two methods.

The values obtained using filtration methods (Giger-Reverdin, 2000) were lesser than using curve fitting methods (Wattiaux, 1990).

Nonetheless, in both the methods, alfalfa had significantly lesser WHC than rice straws and there were no significant different amongst straws. It seems that greater values for WHC in straws varieties were the result of a high NDF content and lesser bulk density. On the contrary, soluble DM and FSG of rice straws were significantly lesser than alfalfa hay (Table 2).

In addition, except insoluble ash content in ration, TMR that contained four different varieties of rice straw were similar for others physical characteristics. The FSG of alfalfa and rice straws over incubation time in pycnometer is presented in Table 3. Alfalfa hay had significantly greater FSG than four varieties of rice straw at all incubation times. Using the original two sieves Penn State particle separator, the distribution of the particle for rice straws and TMR on different sieves was significantly different. In this system, the geometric means of the particle were significantly different (Table 4). Using three sieves of Penn State particle separator, the distribution of particle for rice straws and TMR on different sieves also, were significantly different. However, in this system, the geometric means of particle for rice straws and TMR were similar (Table 4). In addition, the values for $pef_{>8}$ and $peNDF_{>8}$ were significantly greater for rice straws than alfalfa; however these values were similar for all TMR that contained one variety of rice straws. Also, the values of $pef_{>1.18}$ and $peNDF_{>1.18}$ had a similar trend. Comparison of $pef_{>8}$ and $pef_{>1.18}$ showed that $pef_{>1.18}$ were significantly greater than $pef_{>8}$ for alfalfa, rice straws and TMR that confirmed with pervious researchers (Teimouri *et al.* 2004). The distribution of particle size showed that regardless the system, rice straws were more physically effective than alfalfa because they had greater geometric mean and $pef_{>8}$, $pef_{>1.18}$, $peNDF_{>8}$, and $peNDF_{>1.18}$ than alfalfa (Table 4). These characteristics confirmed that different varieties of rice straws had no significant difference on $pef_{>8}$, $pef_{>1.18}$, $peNDF_{>8}$, and $peNDF_{>1.18}$. Therefore, their physical properties especially physically effectiveness were similar, measured using the original version of Penn State particle separator (Lammers *et al.* 1996) and the new version of Penn State particle separator (Kononoff, 2002). Rice straws had greater lignin and silica and were limiting factor to rice straw quality. As a viewpoint, rice straws are good source of indigestible NDF of effective NDF that may retain in the rumen, made a consistence ruminal mat, stimulate rumination, chewing activity, and saliva secretion, and ultimately buffer rumen pH and increase concentration of ruminal acetate and milk fat. Contrarily, they had a great ruminal filling factor; therefore, it is often considered as low-quality forage.

Alfalfa had greater soluble, slowly degradable, potential degradable fraction, and rate of degradability for NDF in the rumen, pdNDF and total-tract NDF digestibility (TTDNDF) than four rice straws. Also, the slowly degradable, the potential degradable fraction, and rate of degradability for NDF in the rumen, the content of NDF, ADL, $iNDF_{288}$, pdNDF and TTDNDF four rice straws were similar (Table 5). The TMR that contained four different varieties of rice straw were similar in rate of degradability, NDF, ADF, ADL, $iNDF_{288}$, $iNDF_{2.4}$, and TTDNDF but the ration that contained Taroum Neda had lesser soluble, slowly degradable, and potential degradable fraction than other rations. Although $iNDF_{288}$ (% of DM) of four rations had not significantly different but the $iNDF_{288}$ as proportion of NDF were significantly different. Taroum Asgari and Taroum Neda had the greatest and lowest the iNDF288 as proportion of NDF, respectively. Fiber digestion occurs primarily in the rumen and is the result of a dynamic process that is affected by the chemical nature of the plant fiber that controls the digestion and passage of fiber within the animal's digestive tract. Rate of fiber digestion (K_d) and the proportion of NDF that is pdNDF vary considerably between and within forage types (Van Soest, 1994). Rate of passage of fiber is primarily affected by level of intake of the animal, and, consequently, fiber digestibility increases with longer retention time of feed in the rumen. Recently, a model was developed to use an *in vitro* NDF fermentation assay to measure the proportion pdNDF and rate of digestion of NDF to predict TTNDFD (Cotanch *et al.* 2014). The digestibility of forage and the capacity of ruminants to consume it are largely influenced by its content of NDF that is directly related to pdNDF as the NDF fraction which disappears after a long incubation period and leaving the iNDF which is unavailable for microbial digestion. According to some studies, the determination of iNDF should be included in all basic feedstuff analysis because it is an ideal fraction which has zero digestibility, uses for the estimation of pdNDF, and recommended that there should be a defined proportion of iNDF in the diet (Cotanch *et al.* 2014; Zali *et al.* 2015). In addition, Lippke (1986) suggested that maximum iNDF consumption is about 20 g/kg $BW^{0.75}$ per day, however, more research is required to resolve if this value is relevant for different production systems and different forages.

The forages can have the same NDF content but differ vastly in iNDF. In the current experiment, without significant differences, four varieties of rice straw had high NDF and iND_{F288} content. Nutritional models predict dietary iNDF to rumen digesta load and feed intake because there are strongly negative relationships between iNDF and feed intake when iNDF content exceeds 15% of TMR (Raffrenato and Van Amburgh, 2010), and the iNDF as a predictor of OM digestibility in forage-based diets (Cotanch *et al.* 2014; Zali *et al.* 2015). The relationship between DM intake and NDF is greater than just NDF content in the diet but also dependent on the pdNDF (Lippke, 1986). The pdNDF fraction is the difference between the NDF and iNDF. The iNDF component is the rate-limiting constituent of forages at greater NDF level. The iNDF is unavailable to microbial digestion in ruminants even if the total tract residence time of fibre is extended to effectively an infinite time.

Table 3 Functional specific gravity of alfalfa and rice straws according to incubation time (h) in pycnometer

Feeds	Incubation time in pycnometer (h)										
	0.1	0.5	1	2	4	6	12	24	36	48	72
Alfalfa hay	1.116^{a}	1.237^{a}	1.258^{a}	1.275^{a}	1.299^{a}	1.318^{a}	1.367^{a}	1.443^{a}	1.475^{a}	1.443^{a}	1.455^{a}
Taroum Neda	1.005^{b}	1.009^{b}	1.011^{b}	1.021^{b}	1.020^{b}	1.024^{b}	1.026^{b}	1.029^{b}	1.031^{b}	1.047^{b}	1.046^{b}
Taroum Neamaat	1.004^{b}	1.013^{b}	1.019^{b}	1.026^{b}	1.021^{b}	1.021^{b}	1.023^{b}	1.025^{b}	1.024^{b}	1.034^{b}	1.045^{b}
Taroum Sangi	1.003^{b}	1.012	1.018^{b}	1.028^{b}	1.034^{b}	1.035^{b}	1.038^{b}	1.040^{b}	1.042^{b}	1.044^{b}	1.046^{b}
Taroum Asgari	1.006^{b}	1.009^{b}	1.017^{b}	1.024^{b}	1.033^{b}	1.039^{b}	1.043^{b}	1.047^{b}	1.049^{b}	1.052^{b}	1.057^{b}
SEM	0.023	0.033	0.032	0.021	0.016	0.023	0.041	0.054	0.045	0.044	0.034
P-values	0.005	0.001	0.032	0.023	0.022	0.001	0.001	0.002	0.003	0.001	0.003

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 4 Determination of particle size distribution using Penn State particle separators

Separator sieves	Feeds							Total mixed rations that contained different rice straw					
	Alfalfa hay	Taroum straw				SEM	P-value					SEM	P-value
		Neda	Neamaat	Sangi	Asgari			Neda	Neamaat	Sangi	Asgari		
Using original Penn State particle separator													
19 mm	15.0^{c}	16.0^{b}	15.0^{c}	17.0^{a}	15.0^{c}	0.30	0.0001	13.0^{b}	14.0^{a}	13.0^{b}	14.0^{a}	0.27	0.0001
8 mm	35.0^{e}	56.0^{b}	57.0^{a}	54.0^{d}	55.0^{c}	0.21	0.0001	35.0^{b}	36.0^{a}	34.0^{c}	35.0^{b}	0.19	0.0001
pan	50.0^{a}	28.0^{d}	28.0^{d}	29.0^{c}	30.0^{b}	0.12	0.0001	52.0^{b}	50.0^{c}	53.0^{a}	51.0^{bc}	0.55	0.0012
GM (mm)	7.80^{e}	8.21^{c}	8.13^{d}	8.45^{a}	8.21^{b}	0.003	0.0001	6.34^{b}	6.21^{b}	7.35^{a}	7.38^{a}	0.03	0.0001
SDGM (mm)	3.33	3.33	3.51	3.61	3.54	-	-	3.32	3.22	3.40	3.14	-	-
$pef_{>8}$[2]	0.50^{b}	0.72^{a}	0.72^{a}	0.71^{a}	0.70^{a}	0.240	0.0001	0.48	0.50	0.47	0.49	0.28	0.0342
$peNDF_{>8}$[1]	34.04^{b}	54.53^{a}	55.53^{a}	55.58^{a}	55.04^{a}	0.082	0.0001	25.54	26.47	24.82	26.03	1.95	0.3441
Using new Penn State particle separator													
19 mm	15.0^{b}	15.0^{b}	14.0^{c}	13.0^{d}	17.0^{a}	0.28	0.0001	14.0^{a}	12.0^{c}	13.0^{b}	14.0^{a}	0.22	0.0003
8 mm	35.0^{c}	55.0^{b}	57.0^{a}	58.0^{a}	54.0^{b}	0.57	0.0001	34.0^{a}	33.0^{b}	33.0^{b}	31.0^{c}	0.23	0.0011
1.18 mm	35.0^{a}	28.0^{b}	25.0^{b}	24.0^{b}	25.0^{b}	1.97	0.0001	37.0^{b}	38.0^{a}	36.0^{c}	37.0^{b}	0.26	0.0034
pan	15.0^{a}	2.0^{b}	4.0^{b}	5.0^{b}	4.0^{b}	1.76	0.0001	15.0	17.0	18.0	18.0	0.43	0.0003
GM (mm)	7.68	8.85	9.03	9.04	9.28	0.986	0.0653	7.40	7.07	7.30	7.27	0.321	0.1239
SDGM (mm)	2.56	2.39	2.36	2.34	2.42	-	-	2.55	2.51	2.54	2.57	-	-
$pef_{>1.18}$[2]	0.85^{b}	0.95^{b}	0.96^{b}	0.95^{b}	0.96^{b}	0.51	0.0001	0.85	0.87	0.82	0.82	0.25	0.0733
$peNDF_{>1.18}$[3]	41.34^{b}	72.96^{a}	74.04^{a}	74.11^{a}	74.70^{a}	0.987	0.0054	45.22	46.05	43.30	43.57	1.654	0.0603

[1] $pef_{>8}$= physically effective factor determined as the proportion of DM retained on sieves of the original version of Penn State particle separator (Lammers *et al*. 1996).
[2] $pef_{>1.18}$= physically effective factor determined as the proportion of DM retained on sieves of the new version of Penn State particle separator (Kononoff, 2002).
[3] The peNDF was calculated by multiplying NDF content of each portion on each sieve on each pef.
GM: geometric mean and SDGM: standard deviation of geometric mean.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 5 Ruminally degradability parameters of NDF and NDF fractionation of feeds and total mixed rations that contained four different varieties of rice straws

Item	K_d[1]	a[2] (% of DM)	b[2] (% of DM)	$a+b$[2] (% of DM)	NDF (% of DM)	ADF (% of DM)	ADL (% of DM)	$iNDF_{288}$[3] (% of DM)	$iNDF_{288}$ (% of NDF)	$iNDF_{2.4}$[4] (% of DM)	pdNDF[4] (% NDF)	TTDNDF[5] (% of NDF)
Alfalfa hay	0.076^{a}	21.34^{a}	43.6^{a}	64.94^{a}	48.63^{b}	44.92^{a}	6.76^{a}	23.34^{b}	48^{b}	16.22^{a}	52^{a}	46.54^{a}
Taroum Neda	0.032^{b}	14.61^{b}	34.55^{b}	49.16^{b}	76.8^{a}	40.33^{c}	5.23^{b}	39.94^{a}	52^{a}	12.55^{b}	48^{b}	12.30^{b}
Taroum Neamaat	0.033^{b}	14.21^{b}	35.21^{b}	49.42^{b}	77.13^{a}	41.32b^{c}	4.98^{b}	41.65^{a}	54^{a}	11.95^{b}	46^{b}	12.31^{b}
Taroum Sangi	0.031^{b}	14.33^{b}	33.22^{b}	47.55^{b}	77.2^{a}	42.43^{b}	5.43^{b}	40.92^{a}	53^{a}	13.03^{b}	47^{b}	11.49^{b}
Taroum Asgari	0.033^{b}	13.44^{b}	35.12^{b}	48.56^{b}	78.63^{a}	42.87^{b}	5.13^{b}	40.89^{a}	52^{a}	12.31^{b}	48^{b}	12.85^{b}
SEM	0.008	1.542	2.543	2.432	3.388	0.934	0.51	0.333	0.621	1.306	0.388	0.126
P-values	< 0.0001	< 0.0001	0.212	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0208	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Total mixed rations that contained four different varieties of rice straw												
Taroum Neda	0.038	17.45^{b}	45.34^{b}	62.79^{b}	53.13	34.23	5.65	34.53	65^{c}	13.56	35^{a}	11.53
Taroum Neamaat	0.042	19.55^{a}	46.32^{a}	65.87^{a}	52.8	34.54	5.76	35.38	67^{b}	13.824	33^{b}	12.63
Taroum Sangi	0.0391	18.56^{a}	47.43^{a}	65.99^{a}	52.93	35.12	5.61	34.93	66^{bc}	13.464	34^{ab}	11.68
Taroum Asgari	0.041	19.03^{a}	46.31^{a}	65.34^{a}	53.2	36.32	5.69	36.71	69^{a}	13.656	31^{c}	11.44
SEM	0.008	0.581	0.731	1.271	0.637	2.643	0.947	1.584	0.527	0.688	0.637	0.111
P-values	0.0761	0.0371	0.0471	0.0423	0.9213	0.3291	0.2518	0.4366	< 0.0001	0.6738	0.0021	0.3279

[1] pdNDF K_d= potential digestible NDF fraction digestion rate calculate from TTNDFD model.
[2] *a*, *b*, *and a + b* are the soluble, slowly degradable, and potential degradable fraction of NDF in rumen.
[3] The indigestible NDF that determined after 288 h ruminal incubation of samples and the $iNDF_{2.4}$ was calculated as 2.4 × ADL.
[4] The estimation of potentially digestible NDF (pdNDF=NDF–iNDF; Raffrenato and Van Amburgh, 2010).
[5] TTNDFD= predicted total-tract NDF digestibility using *in vitro* TTNDFD model.
NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin and DM: dry matter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

The lack of digestibility in the iNDF fraction of forage is attributable to the cross-linking between cell wall lignin and hemicellulose. Also, a greater iNDF intake limits a ruminant's ability to consume sufficient forage to meet nutrient requirements (Cotanch *et al.* 2014; Lippke, 1986). The intake of forage-based diets by ruminants is often controlled by rumen fill and the rate of disappearance. The rate of disappearance is largely influenced by the inherent rate of digestion and passage rate. The indigestible portion is removed from the rumen by passage only and will accumulate in the rumen relative to the potentially digestible portion, therefore having a longer rumen retention time (Cotanch *et al.* 2014; Van Soest, 1994; Zali *et al.* 2015). A longer retention time in the rumen results in a lesser intake.

CONCLUSION

Chemical composition of four different rice straw had not significant differences, except on EE and ash content, but there was significant difference among alfalfa and rice straws. Rice straw had greater NDF and ash, and lesser NFC and CP than alfalfa. Bulk density and WHC of rice straws were similar and lesser than alfalfa. Alfalfa hay had significantly greater FSG than four varieties of rice straw at all incubation times. Rice straw varieties were more physically effective than alfalfa because they had greater NDF, geometric mean, $pef_{>8}$, $pef_{>1.18}$, $peNDF_{>8}$ and $peNDF_{>1.18}$ than alfalfa. However, the physical properties especially pef were similar. Alfalfa had greater soluble, slowly degradable, potential degradable fraction, and rate of degradability for NDF, pdNDF and TTDNDF in the rumen than the four rice straws. Also, the slowly degradable, the potential degradable fraction, and rate of degradability for NDF in the rumen, content of NDF, ADL, $iNDF_{288}$, pdNDF and TTDNDF of four rice straws were similar. The total mixed rations that contained four different varieties of rice straw were similar in rate of degradability for NDF in the rumen, NDF, ADF, ADL, $iNDF_{288}$, $iNDF_{2.4}$ and TTDNDF but the ration that contained Taroum Neda had lesser soluble, slowly degradable, and potential degradable fraction than other rations. In conclusion, for high yielding ruminant the ratio of forage to concentrate is decreased to enhancement of energy and nutrients content, and for physical effectiveness, fibre also increased. Under the circumstances, inclusion of rice straw even at low level may be useful to balance high yielding dairy rations and meeting physical effectiveness.

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