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Improved paddy straw as ruminant feed: A review

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ABSTRACT

Paddy straw is a major agro-residue fed to ruminants in India. Feeding only rice straw does not provide enough nutrients to the ruminants even for maintenance due to the low nutritive value of this highly lignified material containing high concentration of anti-nutrition factors like lignin, silicates and oxalates. Despite the improvements of crop residues through various processing methods such as physical and chemical, the efficient utilization to desirable extent is still awaited. So utilization of paddy straw in association with concept of complete feed along with biological agents is need of the hour to maximize advantage from given feeds in animal production systems.

Key words: Biological treatment, Paddy straw, Ruminant feed.

In tropical zones of the world, ruminants depend on grazing on natural pastures usually during summer months when these pastures have abundant biomass or these animals are fed with cut grass and crop residues. Most of these areas face seasonal periods in which there is decrease in availability of herbages in these pasture. There is also reduction in the content of digestible energy and crude protein. In these areas rice straw is abundantly available from paddy cultivation and farmers offer rice straw as the main roughage source to their animals. This is particularly the case in developing Asian countries such as Thailand, Vietnam, Indonesia and India (NARC newsletter, 2004). Approximately 80% of the world's rice is grown by small scale farmers in many developing countries including South East Asia (Table 1) and it is common to use rice straw for animal feeding. As per reports of Devendra, (1997) that of the total rice straw production, 30-40% is utilized for animal feeding in South East Asia, including China and Mongolia, as rice straw being the principal crop residue fed to more than 90% of the ruminant livestock in this area (Devendra and Thomas, 2002). Rice straw becomes especially important during periods when other feeds are deficient. In general, the maximum intake of rice straw by ruminants is about 1.0 to 1.2 kg per 100 kg live weight (Devendra, 1997). As per Saritha *et al.*, (2012), the major agro-residues in terms of volumes generated in India (in million metric tons, MMT) were rice straw (112.00), rice husk (22.40), wheat straw (109.90), sugarcane tops (97.80) and bagasse (101.30).

A. Chemical composition of paddy straw and constraints in feeding to ruminants: The chemical composition of paddy straw varies between varieties and growing seasons, with higher nitrogen and cellulose contents in early season rice compared to others (Shen *et al.*, 1998). Paddy straw contains 25-45% cellulose, 25-30% hemi-cellulose and 10-15% lignin with low nitrogen, vitamins, minerals and high quantities of silica which hinder the nutrient availability to rumen microbes and eventually limits the necessary nutrient uptake for a satisfactory performance of the animals (Ganai *et al.*, 2006, Sharma *et al.*, 2001). Presence of anti-nutritional factors like silicates and oxalates in rice straw with low nutritive value, poor palatability and limited ruminal degradation render paddy straw as non-maintenance type of fodder, so cannot support nutrient requirement of the animals when fed alone (Ganai and Teli, 2010, Van Soest, 2006). The chemical and mineral compositions of rice straw, cited by different workers, are illustrated in Table 2.

Rice straw consists predominantly of cell walls, comprised of cellulose, hemicellulose, and lignin. To break down these components cellulase, hemicellulase and ligninase are required (Schiere and Ibrahim, 1989). In ruminants cellulase and hemicellulase are produced by rumen microorganisms however, lignin cannot be broken down in the rumen due to the lack of ligninase. Lignin, however, has important effects on livestock production through effects on degradability and feed intake. Theoretically, lignin located between the cellulose microfibrils is regarded as the most abundant natural aromatic organic polymer that plays a role in resisting compressing forces, providing protection against consumption by insects and mammals, and also inhibiting the rate and degree of microbial degradation (Iiyama *et al.*, 1990). Silica, one element of the rice cell walls, can be present in high concentrations ranging from 5% to 15%, depending on the rice variety (Vadiveloo, 1992) and the availability of this mineral in the soil (Agbagla-Dohnani *et*

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Table 1: Rice production and byproducts of top 10 rice producing countries in the world in 2013.

Country	Rice production (million t)	Rice husk (million t)	Rice straw (million t)
China	166.00	38.18	74.70
India	133.51	30.71	60.08
Indonesia	51.85	11.93	23.33
Bangladesh	38.06	8.75	17.13
Vietnam	34.61	7.96	15.57
Thailand	27.00	6.21	12.15
Myanmar	21.90	5.04	9.86
Philippines	13.17	3.03	5.93
Brazil	10.22	2.35	4.60
Japan	9.86	2.27	4.44

Calculated data (Adapted from NARC newsletter, 2013).

al., 2003). Silica reduces palatability and the degradability of rice straw in the rumen due to its direct action in preventing colonization by ruminal microorganisms (Bae *et al.*, 1997; Agbagla-Dohnani *et al.,* 2003). The role of silica on the quality of rice straw was also reviewed by Van Soest (2006), in an attempt to put into perspective the problems of silicon metabolism. Besides cell wall polymers, rumen organisms need other nutrients for growth and metabolism (Hoover, 1986).

Since rice straw does not contain enough sugars, amino acids and minerals for efficient microbial growth, feeding ruminants with only rice straw, without any supplementation of other required nutrient sources, will result in poor performance of the animals (Doyle *et al.*, 1986). The combination of low intake, low degradability, low nitrogen content and an unbalanced mineral composition means that rice straw alone may not even meet the animal's maintenance needs. Poor degradability is caused by a series of factors (Schiere and Ibrahim, 1989). The fiber is very difficult to degrade, which is partly an intrinsic characteristic of the straw fiber (higher lignin and silca content). The degradation of the straw fiber is also complicated by the poor functioning of the rumen due to the unbalanced availability of nutrients, the low protein content, the lack of easily available energy and the low content of essential minerals such as phosphorus and sulphur. Hence, due to the low degradability and the poor rate of degradation, animals will tend to consume less. The generally accepted theory of feed intake regulation for poor quality roughages is that the capacity of the rumen to process the feed is the major factor determining voluntary feed intake (Conrad, 1966; Baile and Forbes, 1974). The rumen processing capacity is characterized by rumen fill, the rate of degradation of potentially degradable matter and the rate of passage out of the rumen. Devendra (1997) summarized that the main determinants of intake and degradability of rice straw depend on their morphological characteristics, such as the proportion of the different plant parts (leaves and stems), their chemical composition and the distribution of the different chemical components in the tissues, their relative amounts of cell contents and cell walls and the physical and chemical nature of the cell walls. These factors influence the chewing behavior of animals and the extent of fragmentation in the reticulo-rumen. As per Theander and Aman, (1984), rice straw contains a relatively high proportion of leaf (60%), compared to other cereal straws such as barley (35%), oats (43%) and wheat (20-41%). Vadiveloo, (2000) reported that leaves of rice straw contain less NDF than the stems, but more ash and acid-insoluble ash, resulting in a lower *in vitro* dry matter digestibility (IVDMD) of the leaves (50-51%) compared to the stems (61%). In goats, Phang and Vadiveloo (1992) observed an *in vivo* dry matter digestibility of 56.2% for rice leaf and68.5% for the stem. However, treatment with a 4% urea solution for 21d increased the IVDMD of the leaf fraction more than that of the stem fraction (Vadiveloo, 2000). Since rice straw consists of approximately 60% leaves (Vadiveloo, 1995), which are less degradable than stems, improving the feed value of rice straw should focus on improving the degradability of the leaves.

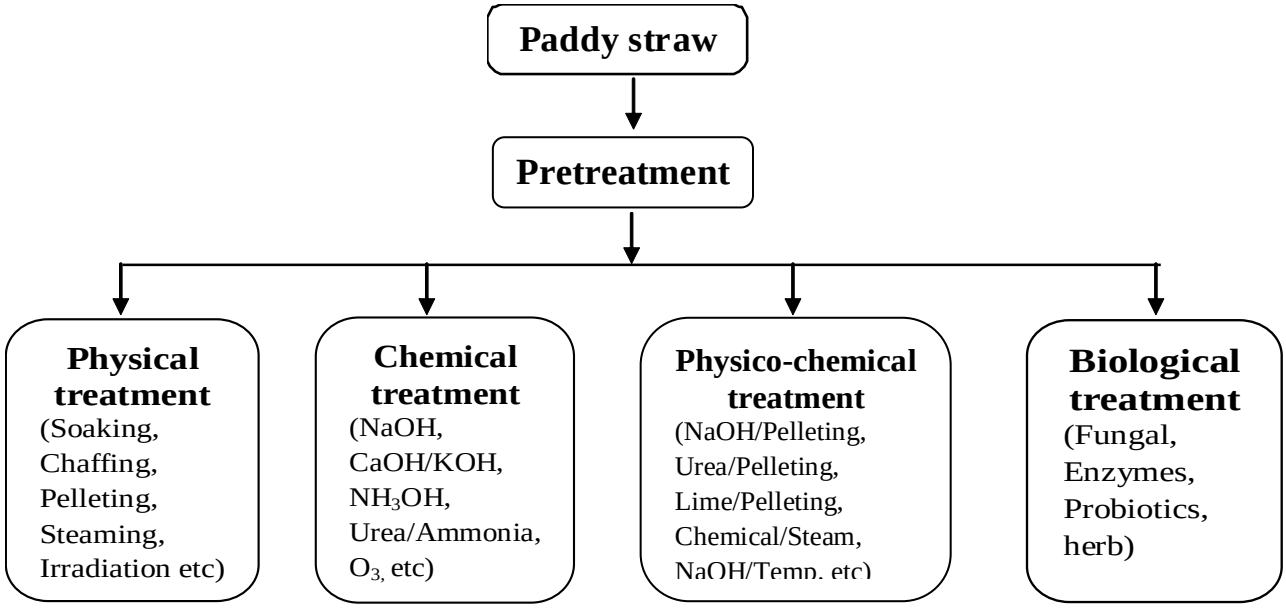
B. Possible strategies to improve rice straw utilization in ruminants: Feeding only rice straw does not provide enough nutrients to the ruminants even for maintenance due to the low nutritive value of this highly lignified material. Basically, the key to improving the use of crop residues for ruminants

Table 2: Chemical composition of rice straw.

Particular (%)	Range
	Chemical composition
DM	88.00-96.87
OM	83.00-90.00
CP	2.00-6.50
CF	30.00-40.00
ADF	49.00-73.01
NDF	39.83-85.00
NFE	40.00-46.00
Hemi-cellulose	13.00-32.24
Cellulose	31.96-60.00
Ash	11.00-16.00
AIA	3.00-5.00
ADL	4.63-13.00
Si	4.25-13.00
Major minerals	
Ca	0.52-2.24
P	0.13-0.39
K	0.95-2.21
Mg	0.91-2.35
Na	0.06-0.09
Minor minerals	
Fe	0.04-0.45
Mn	0.07-
Cu	0.005
Zn	0.02

Compiled from Prasad *et al.,* (1993), Singh and Oosting (1993), Shen *et al.,* (1998), Van Soest (2006), Wanapat *et al.,* (2009), Ganai and Teli (2010), Akinfemi and Ogunwole (2012), Hossain *et al.,* (2010), Gomma *et al.,*(2012), Hussein *et al.,* (2012), Sheikh *et al.,* (2014, 2017)

is to overcome their inherent barriers to rumen microbial fermentation. In the case of rice straw, the important factors that restrict bacterial degradation in the rumen are its high levels of lignification and silicification, and its low contents of nitrogen, vitamins and minerals (Ganai and Teli, 2010). The high level of lignification and silicification, the slow and limited ruminal degradation of the carbohydrates and the low content of nitrogen are the main deficiencies of rice straw, affecting its value as feed for ruminants (Van Soest, 2006). To improve the feeding value of rice straw, it can be treated with different means and methods and other required nutrients can be supplemented in the ration of the animal. Strategies to improve the utilization of rice straw are summarized as



Physical and chemical treatment: Extensive work has been done to improve nutritive value of crop residues by chemical and physical treatments. In physical treatment crop residues can be ground, soaked, pelleted or chopped to reduce particle size or can be treated with steam or X-rays or pressure cooked. Many of these treatments are not practical for use on small-scale farms, as they require machines or industrial processing. This makes these treatments in many cases economically unprofitable for farmers as the benefits may be too low or even negative (Schiere and Ibrahim, 1989).

By treating rice straw with urea or calcium hydroxide or by supplementing rice straw with protein, the intake, degradability and milk yield can be enhanced as compared to feeding untreated rice straw alone (Fadel Elseed, 2005; Wanapat *et al.,* 2009). In past years, several studies have been reported on the physical and chemical characterization and utilization of rice straw as ruminant feed (Shen *et al.,* 1998; Abou-El- Enin *et al.,* 1999; Vadiveloo, 2003). In addition, numerous methods of physical, chemical and biological treatments have been investigated, including supplementation with other feed stuffs or components in order to improve the utilization of rice straw by ruminants (Reddy, 1996; Karunanandaa and Varga, 1996; Shen *et al.,* 1999; Vu *et al.,* 1999; Liu and Ørskov, 2000; Selim *et al.,* 2004). The most commonly used alkaline agents are sodium hydroxide (NaOH), ammonia (NH_3) and urea. Chemical treatments appear to be the most practical for use at farmers level, the chemicals are relatively cheap and the procedures to use them are relatively simple. However, safety precautions are needed for their use as these chemicals themselves are not harmless. Warly *et al.,* (1992) showed in a field trial that a ration of rice straw supplemented with soybean meal increased both degradability and intake. Because of the poor quality of untreated rice straw, supplementation easily can increase milk production, as shown for supplementation with cottonseed meal (Wanapat *et al.,* 1996); with an urea molasses- multi-nutrient block (Vu *et al.,* 1999; Wanapat *et al.,* 1999; Akter *et al.,* 2004) and urea molasses treatment (Sheikh *et al.,* 2014).

Rice straw is usually fed untreated without supplements in spite of the fact that many methods for improved utilization of rice straw have been developed and recommended. There are several reasons for farmers not to adopt the already developed methods for improved utilization of straw, such as physical, socio-economic conditions and practical reasons (Devendra, 1997).

Biological methods: Despite the improvements of crop residues through various processing methods such as physical and chemical, the efficient utilization to desirable extent is still awaited. Hence, it is the need of the hour to utilize these crop residues available in appreciable quantum locally in association with concept of complete feed technology and

use of biological agents (feed additives) to maximize advantage from given feeds in animal production systems. Biological treatment is a much favorable option and is believed to be more eco-friendly and safer than the use of chemicals. Various methods of biological treatment/ fortification of paddy straw to enhance its utilization in animals include treatment with white rot fungi, ensilage with agro-industrial byproducts like apple pomace or fortification with proteins, greens or enzymes (Tiwari *et al.*, 2008; Jahromi *et al.*, 2011; Khattab *et al.*, 2013 and Khatooni *et al.*, 2014). Although the use of white rot fungi causes significant loss of dry matter and organic matter (Ganai and Teli, 2010; Shrivastava *et al.*, 2014) besides needs much more technical know and sometimes beomes impracticable at farmers level. The ensiling of straw with fruit pommace or poultry excreta or rumen liquor does not need sophisticated infrastructure with such facilities available at farmers level, but the advantage of these methods lies in fact of improving digestibility of nutrients, gain in body weight and overall performance of animals. Despite being safe and environmental friendly these biological agents have potent effect on digestibility of fodder by manipulating rumen environment. Gado *et al.*, (2011) reported decrease in the total phenolics, saponins and aqueous fraction with higher average daily gain, TDN and digestibility coefficients for DM, OM, CP, CF, NDF and ADF in Ossimi male lambs fed paddy straw ensiled orange pulp treated with exogenous enzymes diet than control. In other study Gado *et al.*, (2013) suggested a strong potential in improving digestibility and degradation of NDF and ADF of rice straw pre-treated with exogenous enzymes. Karunanandaa *et al.*, (1992, 1995) also reported enhanced IVDMD in both leaves and stems of rice straw by incubation with white-rot fungi (*Pleurotus sajor-caju*) for 30 days. However, entire rice straw (leaf and stem) treated with *Cyathus stercoreus* had the highest IVDMD compared to the other fungi. This improved digestibility of biologically treated straw is result of improvement in chemical composition as Akinfemi and Ogunwole (2012) evaluated chemical composition and *in vitro* digestibility of rice straw treated with *Pleurotus ostreatus*, *Pleurotus pulmonarius* and *Pleurotus tuber-regium* found significant increase in the crude protein and significant decrease in crude fibre, cellulose, neutral detergent fibre, acid detergent fibre and acid detergent lignin of fungal treated rice straw than control. Fungal treated rice straw showed higher values of minerals (Ca and Mg), gas volume, metabolisable energy, organic matter digestibility and short chain fatty acid were also higher in fungal treated straw than control. White rot fungi efficiently degraded the lignin and enhanced the *in vitro* digestibility of paddy straw (Sharma and Arora, 2010). In another study Ganai and Teli (2010) reported increase in CP, DCP and TDN content and nitrogen balance in Corriedale sheep fed paddy straw treated white rot fungi (*Pleurotus ulmarius*). Similarly Abdel-Azim *et al.* (2011) reported that treating rice straw and corn stalks with *Trichoderma viride*, improved feeding value resulting in higher intake, N balance and growth rate in cross-bred lambs. The author also reported that DM consumption of fungal treated paddy straw was significantly higher than untreated straw. Bassiouni *et al.*, (2011) studied the effect of fibrolytic enzymes supplementation on *In Situ* degradability of DM, CP and CF of different rations consisted of concentrate feed mixture + berseem hay, dried sugar beet tops, corn silage, rice straw or wheat straw in different ratios 60:40or 40:60 incubated in canulated multiparous Friesian cows. Rations contained rice straw showed the lowest ($P<0.05$) values of *in situ* DM, CP and CF disappearance. In support of these findings Khattab *et al.*, (2013) studied chemical composition, nutritive value, *in vitro* digestibility and scanning electron microscopy (SEM) of rice straw (RS) and *Pleurotus ostreatus* spent rice straw (SRS) and reported higher protein, amino acids (mg/ 100 g) content, *in vitro* dry matter disappearance (IVDMD) and *in vitro* organic matter disappearance (IVOMD) for SRS compared to RS while, DM, OM, NFE, CF, NDF, ADF, ADL, hemicellulose and cellulose were less for SRS than for RS. Pothiraj *et al.*, (2006) reported that fibrolytic enzymes of *A. niger*such as cellulase, β-glucosidase and xylanase had reduced the lignocellulose compound of the rice straw.

Some studies, using fibrolytic enzymes alone could not significantly increase the degradability of rice straw because the ability of these enzymes to break down the esterified bonds within lignin-carbohydrate complexes may be limited. However, when using in combination with other pre-treatments they could increase degradability and *in vitro* fermentation characteristics, as shown by Eun *et al.*, (2006) treated rice straw with xylanase or cellulase in combination with ammonia, Hussein *et al.*, (2012) treated rice straw with urea and commercial effective microorganisms, Liu and Ørskov (2000) treated rice straw with cellulase in combination with steam pre-treatment, Wang *et al.*, (2004) treated rice straw with multi-enzymes (xylanase, β-glucanase, carboxymethyl cellulase and amylase) in combination with NaOH, found that the use of combinations of fibrolytic enzyme with these pre-treatments is expected to have a synergistic effect on the nutritive improvement of rice straw. Bansi *et al.*, (2012) evaluated use of rumen liquor, chicken manure and commercial probiotic to improve nutritional value of rice straw and reported that crude protein level of rice straw fermented with chicken manure was the highest followed by that of rumen liquor treatment and significantly different from those of commercial probiotic and control treatments. Crude fiber level of rice straw fermented with manure showed the lowest level but not significantly different from rumen liquor and commercial probiotics. These values were significantly lower than control. While assessing the effect of incorporation of wheat straw-rice straw (WS-RS in 50:50 ratio) or *Pleurotus florida* harvested spent WS-spent

RS (50:50) in kids, Kaur *et al.,* (2010) observed a higher DM intake (0.80 vs. 0.65 kg d-1), digestibility of majority of nutrients (except cellulose which was depressed), N-retention (5.36 vs. 4.87 g), apparent biological value (63.08 vs. 53.43%) and daily live weight gain were comparable in both the groups. Apart from enzymatic treatment Maqbool *et al.,* (2001) reported the microbial application of rice straw degraded the lignocellulosic contents, thus improving the rumen DM degradability which would affect the weight gain of animal. By degrading the lignocellulosic contents of rice straw, more nutrients are made available for ruminal microflora, which in turn will sustain the longevity of the microbes. More importantly, harmful microorganisms such as toxin-producing fungi that contaminate the rice straw could be suppressed by application of microbials on the feedstuff, proving its ability to restrain the growth of the harmful toxin-producing fungi. Gomaa (2012) verified the potential benefits of supplementing rice straw with exogenous anaerobic bacterial enzymes (ZAD) and orange pulp for Ossimi sheep found significant ($P< 0.05$) decreases in %CF, %NDF; while %CP, %ADF and %ADL values increased for rations containing either ZAD, orange pulp or both. Rams fed rations containing either ZAD, orange pulp or both significantly increased ($P<0.05$) ruminal ammonia-N, total volatile fatty acids plasma total protein with low level of gas production post feeding values. Similarly Salehpor *et al.,* (2012) evaluated the effect of rice straw processing by Lactobacillus, multi enzymes and calcium hydroxide on the digestibility and nutritional value. Each of three processing operation, reduce the amount of ADF, cellulose and hemicelluloses in the straw. The same trend also has been in the NDF and bacterial processing has the lowest and enzymatic, chemical and control straw have the greatest amount of NDF, respectively. The amount of gas production rate in the bacterial methods was more than the other methods and with increasing incubation time, shows upward trend. Addition of lignocellulolytic enzymes and bacterial lignocellulolytic on rice straw resulted in significant improvement of all the fermentation products (volatile fatty acid, acetate, propionate, butyrate, and ammonia) between control and treatment groups. Lignocellulolytic enzymes @ 5% of dry matter dose rate resulted in optimal products of volatile fatty acid and ammonia (Lamid *et al.,* 2013). Similarly Samsudin *et al.,* (2013) found improved nutritive values of rice straw fed to goats when treated with *Aspergillus niger*, fungal and effective microbes (EM). No significant ($P>0.05$) difference was observed on the chemical composition of rice straw treated with *A. niger* except the CP content increased significantly ($P<0.01$) when compared with untreated rice straw. However, when the fungal-treated rice straw was inoculated with EM, significant ($P<0.01$) improvement was observed in DMD, CP, OM, NDF, ADF and cellulose content of the rice straw compared with control. In other study Elmoghazy *et al.,* (2015) evaluated effect of sheep diets containing lignolytic microbiological treated (*Bacillus licheniformis*, *Ruminococcus albus*, *Aspergillus oryzae*, *Rhizopus nigricans* and *Saccharomyces cerevisiae*) rice straw on blood parameters and nitrogen balance. Results exhibited that the microbiological treatments significantly decreased the DM and CF while CP was significantly increased. Regarding nitrogen balance, haemato-biochemical and serum enzymes (aspartate transaminase and alanine transaminase) were not affected with microbiological treatment. The use of combinations of fibrolytic enzyme with these pre-treatments is expected to have a synergistic effect on the nutritive improvement of rice straw. Especially, the use of lignin-degrading enzymes, originating from fungi, seems a promising development. Although, application of enzymes has proven to increase the feed value of poor quality feedstuffs, its use by smallholder farmers is, for the time being, economically unattractive. However, it becomes a promising technology when used at commercial level.

CONCLUSION

Rice straw being the principle agro-residues in terms of volumes generated in India, is poor in nutritive value with high level of lignification and silicification. So feeding of rice straw to livestock does not provide enough nutrients even for maintenance. Rice straw is usually fed untreated without supplements in spite of the fact that many methods for improved utilization of rice straw have been developed and recommended such as physical, chemical and biological treatments. Among these methods, biological treatment is a much favorable option and is believed to be more environmental friendly and safer.

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