# Chapter 7
# Rice Straw-Based Fodder for Ruminants

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**Abstract** Rice straw is a readily available, practical, and cheap source of fodder for feeding ruminants such as buffaloes, cattle, goats, and sheep. Livestock producers commonly haul and stack rice straw from their rice farm, which then forms reserved feed for their animals during lean months or when good-quality roughages are scarce. The feeding of pure rice straw to ruminants during the stages of fast growth and early lactation has been shown to affect both body condition score and animal performance. This is due to lower dry matter intake and protein content (from 4.0% to 4.7% crude protein) of the straw. The high silica and lignin contents of straw also contribute to poor nutrient (dry matter and protein) digestibility (<50%). So, pretreatment of straw is necessary to enhance its contribution to improving meat and milk production. Science- and technology-based farm strategies to optimize the nutritive and feeding values of rice straw had been developed with significant improvement on intake, nutrient digestibility, and animal performance. These technologies were also proven effective in contributing additional income to livestock producers from the sales of milk or live animals. This chapter presents and discusses current innovations and developed technologies on how the nutritive (nutrient composition and fiber fraction) and feeding values of rice straw can be improved.

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M. Gummert et al. (eds.), *Sustainable Rice Straw Management*,
https://doi.org/10.1007/978-3-030-32373-8_7

Specifically, this focuses on pretreatment (optimization process), enrichment, and recycling of rice straw by physical, chemical, and biological processes. Also covered are practical feeding protocols when rice straw—or its combination with other feed ingredients—is used in formulating a ration. The authors also share secondary information on the effect of rice straw as animal fodder on the improvement in animal performance and production efficiencies; as well as its impact on food production (meat and milk), increasing farmers' income, and on the protection of the environment.

**Keywords** Rice straw · Fodder · Ruminant · Buffaloes

## 7.1 Introduction

Livestock farming plays a significant role in agricultural development. Aside from being a source of income for the farmers, livestock also contributes to the production of food for the general public. Ruminant animals, such as buffaloes, cattle, sheep, and goats, are considered economically important in the production of meat and milk, among other derived products such as hides, manure as an organic fertilizer or as fuel/biogas for kitchen use by the livestock-farming families. Ruminants can be entirely dependent on crops for their nourishment to achieve normal growth, production, and reproduction. The dynamics of their rumen ecosystem provides a unique environment for microorganisms to grow and multiply so that these can degrade nutrients, especially fibrous components, from the ingested fodders that eventually are transformed into protein rich foodstuffs such as meat and milk. However, the efficiency of the animal to utilize and convert nutrients from dietary sources into nutritious food products are dependent mainly on the availability and quality of the fodder being offered to the animal.

The availability of quality forages for feeding ruminants is seasonal. Wet season is a time of feed abundance while dry season is a period of scarcity. In countries that experience feed scarcity or deficiency of good quality forages, rice straw remains as the practical, abundant and cheap source of fodder for feeding cattle, buffalo, goat and sheep. According to FAO (2000), the world produced approximately 2000 million tons of cereal straw annually. More than 200 million tons of rice straw was also produced annually in the Southeast Asian countries (see Chap. 1). The estimated quantity of rice straw production is based on the report of Maiorella (1985); and Doyle et al. (1986) that for every hectare of rice farm, the weights of rice grain and rice straw that can be harvested are the same. In many agricultural countries, rice straw and other agro-industrial by-products are available in large quantities immediately every after harvest seasons. These farm byproducts are utilized in many different ways such as fodder for ruminants, for mushroom production, for fuel (heating, biogas) source, for board or paper production and also for organic fertilizer production.

## 7.2 Rice Straw as a Feed Source

### *7.2.1 Availability and Carrying Capacity*

Rice straw is abundantly produced by rice farmers in many agricultural countries worldwide. In Southeast Asia, about 30–40% of the total rice straw production is commonly used to feed more than 90% of the ruminant population in the region including other countries such as China and Mongolia, (Devendra and Thomas 2002). Rice straw is lean-month stuff to ruminant when supply of good quality forages is inadequate. It can be fed as the sole diet to meet the dry matter requirement but it is not a guarantee that other essential nutrients needed for normal body functions by the animal are met. Rice straw can also be offered, up to 60%, in combinations with other feed ingredients, such as concentrates, molasses, or legumes to improve palatability, protein content, and intake and digestibility by the animals.

Every after rice harvest, livestock farmers collect and stock-pile rice straw in a simple shed usually made from locally available materials or stored in piles outdoors. The conserved straw is normally used as animal fodder during the lean months of January through May or when the paddies are already planted with rice in July and August. The extent of rice straw utilization as fodder is dictated by the availability of forage gardens as well as the number of animals being fed. Since the average landholding of the average crop farmer is 1–2 ha, the expected rice straw production annually is only about from 10 to 15 tons, which can support only three or four animal units whether cattle or buffalo. If a farmer has more animals, additional fodder should be sourced out, such as silage, corn stover or hay, or other feed supplements, such as concentrates or legumes, to achieve normal animal performance.

### *7.2.2 Nutrients in Rice Straw*

Basically, rice straw has low protein content ranging from 3% to 6%. Is has high cell walls, the neutral detergent fiber (ADF) and acid detergent fiber (ADF) which consisted of the degradable carbohydrate fractions such as starch, cellulose and hemicellulose. It also contains an indigestible phenolic substance called lignin. When used as fodder, rice straw primarily serves as bulk or filler to meet the dry matter requirement of ruminants. This contains 80% substances which are potentially degradable and a source of energy. It has high dry matter (DM) contents of 92–96% but with a low CP content ranging from 3% to 7% (Shen et al. 1998). The lignin and silica contents provide structure to the rice plant during the growing and fruiting stage but these components are in an indigestible form when ingested by animals.

As fodder, rice straw has low energy and protein contents. Its utilization is limited due to minimal contents of digestible nutrients and various characteristics such as palatability, variable nutritional values, high silica and oxalates, and sometimes presence of adulterants when not properly collected and stored. Nevertheless, rice straw still remains to be a practical fodder particularly in times of El Nino or in times of critical periods when sources of fresh fodders are insufficient. In addition, according to a dairy cow nutrient expert from Israel (Hanan Saggi, Feeding & Nutrition Director, TH True Milk Group), rice straw is a good feed component if pretreated properly, particularly when the milk cows are not producing fully.

Rice straw contains higher quantities of potassium (1.58% of DM), calcium (0.53%), and magnesium (0.24%). But it is low in phosphorus (0.12%), sodium (0.13%), iron (0.07%), and manganese (0.07%), (Shen et al. 1998). The bioavailability of these minerals is still to be investigated since most of these minerals are cross-linked to other substances in rice straw in the form of acid-insoluble ash.

The phosphorus (0.02–0.16%) content of rice straw is not sufficient to meet the required 0.3% for growth and normal fertility of animals (Jackson 1977). However, its calcium content of 0.4% is considered adequate to meet the daily requirement for livestock but this does not always hold true. The bioavailability of calcium from rice straw is important to consider since the report of Nath et al. (1969) showed that cattle fed with rice straw has a negative calcium balance even though the calcium content of the straw used in the feeding experiment was apparently adequate. In similar experiments by Joshi and Talapatra (1968), they have higher positive calcium balances with animals fed with wheat straw and sorghum stover diets than on rice straw diets, even though the calcium intake on rice straw diets was higher. According to the authors, when feeding rice straw, it is safe to provide calcium supplementation to the animals.

### *7.2.3 Rice Straw Intake by Ruminants*

Generally, the quantity of rice straw that the animal can eat each day is limited to less than 2% of its body weight. According to the report of Devendra (1997), the amount of rice straw that ruminants can consume can be as high as 1.2 kg DM 100 $\mathrm{kg}^{-1}$ of live weight $\mathrm{day}^{-1}$. The rice straw intake, however, varies among animals and this is also influenced by the proportion or parts of the rice straw used in the ration. The intake of rice straw also varies according to the manner in which it is prepared, processed, and fed to the animals. Physical processing, such as chopping or the use of chemical or microbiological treatments, considerably improves an animal's rice straw intake. When offered as is, rice straw intake is lower because it is bulky or occupies more space in the rumen. The digestibility of the straw is also affected due to the slow passage rate of ingested straw and its fermentation by microorganisms in the rumen. Chopping the straw provides more space in the rumen and allows more entries of microorganisms to ferment the straw's degradable components.

### 7.2.4 *Nutrient Digestibility of Rice Straw*

The leaf and stem ratio is essential when it comes to the digestibility of cereal straw. Relatively, rice straw has a higher proportion of leaves at 60% compared with other cereal straw, such as barley (35%) and oats (43%) (Sarnklong et al. 2010; Theander and Aman 1984). Having this high proportion of leaves to stems promotes lower in vitro dry matter digestibility (IVDMD) of the leaves at 50–51% compared to the stems at 61% (Vadiveloo 2000). These data were supported by Phang and Vadiveloo (1992) who observed that, in goats, IVDMD for rice leaves is 56.2% while for stems is at 68.5%. To increase the degradability of rice straw leaves, pretreating them with 4% urea solution for 21 days shows significant increase in the IVDMD of the leaves compared with the stems (Vadiveloo 2000). This improvement of the feeding value of rice straw should be taken into consideration to optimize digestibility.

Rice straw, when offered to ruminants, gave DM digestibility ranging from 45 to 50%. Various enzymes secreted in the reiculo-rumen, such as glucanase, cellulase, and hemi-cellulase—not including ligninase—have the potential capacity to degrade the cell wall components of rice straw, (Schiere and Ibrahim 1989). These enzymes are not produced by the animals themselves but are secreted by the rumen microorganisms. The degree of lignification or with higher the lignin content, this has a direct effect on the reduction of the rice straw's nutrient digestibility. In addition, Agbagla-Dohnani et al. (2003) pointed out that silica has a direct effect on cell wall digestibility of rice straw since silica forms a physical barrier that lowers microbial degradation resulting to poor enzymatic hydrolysis of the straw.

## 7.3 Pretreatment of Rice Straw as Ruminant Fodder

Developed technologies have been published and are available for farmers to help them enhance the utilization and improvement of the nutritive value of rice straw for animal feeding. These techniques include different physical, chemical, and biological processing methods and combinations of these (Ibrahim 1983). However, adoption of these technologies takes time since they require additional inputs and farmers need to see improvement to believe it.

### 7.3.1 *Physical Processes*

The physical process is a practical and inexpensive method to enhance utilization and recycling of nutrients from rice straw when used as fodder for ruminants. Physical treatment of rice straw aims to improve the palatability and increase intake as well as improve the potential digestibility of ruminants. These physical processes include soaking, grinding or chopping, pelleting, steaming pressure, and gamma irradiation. These processes promote physical changes in rice straw, such as reducing particle size, which lessens rumination time for the animal; enriching softness of the straw's fibrous components to make it more palatable to the animal; and hastening nutrient digestion.

Soaking is a common and economical process of treating rice straw. This is being done by soaking straw overnight in water which brings softness between the of lignin and cellulose component of rice straw. Soaking of straw promotes higher intake of the animal as well as nutrients digestibility. Soaking along with steaming technique have direct effect on the cell walls delignification of rice straw, (Walker 1984). The effect of steam or exposure of the lignocellulosic contents of rice straw under high pressure provides a good environment for the microbial enzymes for faster fermentation of nutrients, thus increasing the rice straw digestibility (Walker 1984). Milstein et al. (1987) suggested that heat treatment leads to an increase in cellulose digestibility from 20% to 40%.

Grinding, chopping or pelleting had beneficial effects in breaking down the cell wall contents of rice straw. These physical processes reduced the particle size of the straw thus, providing easy entries or access of the rumen microorganisms for degradation. The use of these techniques should properly consider the balance between the particle size and the retention time or passage rate of the ingested treated straw. The reduction in particles due to grinding or chopping of rice straw promotes animal intake and increase passage rate of the feed, however, this brings negative effect in terms of decreasing the nutrients digestibility of straw. This is because of the less time exposure of the feed materials for rumination and for microbial fermentation in the rumen.

Pressure steaming rice straw is another process to consider. However, the process may add cost for farmers due to the energy required during process. Rangnekar et al. (1982) and Liu et al. (1999) have tried steam treatment under high pressure of 15 bar for 5 min at a moisture level varying between 30% and 70% (w/w) using different roughages and rice straw. They observed that the different fractions of rice straw, such as hemicellulose, cellulose, lignin, and sugars were separated by steam pressure. Similar observations were also reported by Ooshima et al. (1984) when irradiated rice straw was subjected to 84% water content in microwaves (2450 MHz) using sealed glass vessels with accessible partitions into cellulosic materials and with increase digestible nutrients of the straw.

### 7.3.2 Chemical Treatment

The chemical method to improve the nutritive value of rice straw has been done for more than 100 years (Kamstra et al. 1958) with the aim to increase animals' intake and feed digestibility. The chemicals, which are commonly studied and used in treating rice straw to improve its palatability, intake, and digestibility, are sodium hydroxide, ammonia, and urea. The mode of action of these chemicals is to break the links between the lignin-cellulose structures of the straw, which are sensitive under alkaline or acidic conditions. Among the chemicals used, alkali agents are extensively explored and practically accepted under farm conditions. During straw treatment, basic chemicals, such as sodium hydroxide, urea, or ammonia are absorbed into the cell wall and react with the lingo-cellulosic contents of the straw to break the ester bonds between lignin and hemicellulose and cellulose. The alkali absorbed into the straw directly causes the structural fibers to swell making it free for microbial fermentation (Chenost and Kayouli 1997; Lam et al. 2001).

#### 7.3.2.1 Sodium Hydroxide (NaOH) Treatment

The use of NaOH in the treatment of cereal straw has been done since the 1940s (Mcanally 1942). The straw is treated using 1.5% NAOH w/w for 24 h in a container. The treated straw is rinsed with cold water and subjected to in vitro digestibility. Results showed that the NAOH treated straw is more digestible than the pure straw by as much as 28%. The Beckman method, which is similar to the procedures of Mcanally (1942) for the NAOH treatment of straw, has been recommended by FAO (2012). The Beckman method also uses 1.5% NAOH but the treatment period is within 18–20 h before rinsing with tap water. The NAOH acts on the straw by reducing proteolysis and increasing delignification by unlocking the linkage between the lignin and cellulosic contents of the straw to give more time for microbial enzymatic action to take place. Treatment of rice straw and other crop residues using NAOH has been reviewed by Jackson (1977), Berger et al. (1994), Arieli (1997), and Wang et al. (2004). These authors concluded that chemical reactions of NAOH on the cell wall contents of rice straw is advantageous for the breakdown of the esterified bonds between the phenols group and the cellulosic components of straw thus favoring the enzymatic hydrolysis.

Feeding NAOH-treated straw in cattle showed better performance than ammonia treatment of straw. Similar improvement in animal performance was also reported by Chaudhry and Miller (1996) and Vadiveloo (2000) when NAOH-treated rice straw was fed to cattle compared to untreated straw. This was due to the improvement in palatability and intake of the animals and increase in digestibility of treated straw. The adoption of NaOH treatment of rice straw, however; is not widely practiced by farmers. This is because NAOH costs more than urea treatment and it is not always available. In addition, NaOH, when used at higher concentrations, poses health problems for animals if the amount exceeds 10 g of the daily sodium requirement of mature animals. It can also cause pollution problems due to sodium accumulation in the environment (Sundstol and Coxworth 1984).

#### 7.3.2.2 Ammonia ($NH_3$) Treatment of Rice Straw

Treating rice straw using anhydrous and aqueous ammonia, urea, and other ammonia-releasing substances have been investigated and have been proven to enhance the degradability of the straw (Abou-EL-Enin et al. 1999; Selim et al. 2004;

Fadel-Elseed et al. 2003). The treatment of rice straw with ammonia ($NH_3$) is similar to treating with NaOH. $NH_3$ has been observed to be advantageous over the use of NAOH because it is readily available because it can be derived from the hydrolysis of urea. $NH_3$ treatment does not only increase degradability of rice straw but it also supplies nitrogen (Abou-EL-Enin et al. 1999), thereby increasing the protein content of the straw. It can also be used as a preservative agent since it inhibits the growth of molds in the treated straw (Calzado and Rolz 1990). Other benefits that can be derived from $NH_3$ treatment include reducing costs of buying protein-rich supplements and enhancing acceptability and voluntary intake of the treated straw by ruminants.

Liu et al. (2002) observed that the use of NAOH treatment is more efficient than $NH_3$ treatment in terms of improving the energy values of the straw. However; using $NH_3$ is usually more profitable for farmers than NAOH because it provides an additional source of nitrogen in the straw. Selim et al. (2004) studied sheep fed with $NH_3$-treated rice straw packed in polyethylene bags for 4 weeks with gaseous ammonia (3 g $NH_3$ 100 g dry matter$^{-1}$). $NH_3$ increased the N content of the treated rice straw from 8.16 to 18.4 g kg$^{-1}$ or with an equivalent increase of CP from 51 to 115 g kg$^{-1}$. A slight decrease in the NDF of treated straw (from 571 to 551 g kg$^{-1}$) was observed but with an increase in acid detergent fiber (ADF) from 303 to 327 g kg$^{-1}$. This further indicated positive changes on the cell wall content of the treated straw.

#### 7.3.2.3 Urea Treatment

Urea treatment is the most practical and widely used chemical method in treating rice straw. It is adoptable by both small-scale and commercial livestock farms. The main function of urea is to increase the protein content of the treated straw during the fermentation process. Urea or $NH_3$ is best used in combination with molasses (urea-molasses solution) at 30% moisture content of the treated straw. First, urea is hydrolyzed or undergoes ureolysis to produce ammonia-nitrogen (Sahnounea et al. 1991). The role of the molasses is to supply energy so that cellulosic fermentation of the treated straw is hastened. Urea or its combination with molasses can make rice straw a complete and safe basal ration for ruminants (Langar et al. 1985).

Rice straw can be effectively treated with urea using different concentrations i. e. from 1% to 5% w/w. Urea should be dissolved first in water at the desired proportion and it can be sprayed into the rice straw. The treated straw can be packed in the silo, empty drum or plastic bag. This treatment process is practical and can be easily adopted by farmers. Urea is a chemical which is a source of nitrogen to crops and a source of non-protein nitrogen to ruminants. It is a crystalline substance and it is easy to handle and locally available in the market, (Sundstøl and Coxworth 1984). Urea increases the nitrogen (crude protein or CP) content of the treated rice straw, (Schiere and Ibrahim 1989). It is cheaper than NaOH or pure $NH_3$. Vadiveloo (2003) reported that treating different rice varieties with low degradable carbohydrates responded positively compared to high-quality rice straw varieties after urea treatments as reflected by the increase in IVDMD from 45% to 55–62%. Numerous evaluations were done in the laboratory (Reddy 1996; Shen et al. 1998; Vadiveloo 2003) or in field trials (Prasad et al. 1998; Vu et al. 1999; Akter et al. 2004) in treatment of rice straw using pure urea or in combination with other chemicals or feed supplements and the results had clear improvement on the nutritive as well as feeding value of treated straw.

#### 7.3.2.4 Lime Treatment

Treatment of straw with lime solution [$CaO/Ca(OH)_2$] is expected to have the same effect on improving fiber degradability as NAOH. Lime is also a source of calcium for ruminants in low-calcium rations but it has longer solubility in water compared to NAOH or urea. Treatment of straw with lime can be done in two ways: by soaking and ensiling. Lime treatment provides complementary effects in combination with urea. The combination of lime and urea has been shown an advantage in increasing degradability and incrementing both the calcium and nitrogen contents of the treated straw (Nguyen 2000).

In a separate study of Pradhan et al. (1997), using 4% or 6% $Ca(OH)_2$ to treat rice straw, showed, after ensiling, a higher IVDMD. However; it is further suggested that a combination of lime and urea would give better results than either urea or lime alone. Sirohi and Rai (1995) used 3% urea plus 4% lime at 50% moisture for 3 weeks of incubation. They found this to be the most effective treatment process for rice straw. This was due improving the digestibility and degradable nutrients of the treated straw. Saadulah et al. (1981) and Hadjipanayiotou (1984) found that the use of lime and other alkali agents had additive effects on rice straw treatment and utilization in addition to being safer and more cost-effective to use than NaOH.

As cited by Trach et al. (2001), there are reports that treated rice straw with pure lime posed contradicting results in its effect on delignification or degradation of rice straw. There was a report that the dry matter intake of animals was reduced due a palatability problem of the treated straw. Lime treatment did not affect N content, but it appeared to be more powerful in delignification or reducing neutral detergent fiber (NDF) and hemicellulose contents of the treated straw. Increasing levels of lime and/or urea during rice straw treatment resulted in some negative interactions between the two chemicals. However, a level of 2% urea alone seemed to be too low for effective treatment and a level of 6% lime seemed to be too high for rumen cellulolysis.

### *7.3.3 Biological Treatment*

Biological treatment of rice straw involves the use of enzymes and different microorganisms, such as bacteria and fungi. Different fungi strains have the capacity to act on the cell wall contents of the straw thereby improving the degradation rates and making other nutrients available to the animal. As cited by Jalc (2002), the enzymes secreted by fungi had strong affinity to metabolize lingo-celluloses and these are biological agents in treating rice straw to improve its nutritional value through the selective action of delignification. Nevertheless, its current use in developing countries is still a big question due to limitation in technical skills and the availability of resources to produce and handle large quantities of fungi or their enzymes for practical and field application. Biological treatment of straw brings some concerns and problems to be addressed and overcome (Schiere and Ibrahim 1989). For example, there are fungi species that are not edible and produce toxic substances both to human and animals. Fungi also require an environment for them to grow and reproduce, such as pH, temperature, pressure, and $O_2$, and $CO_2$ concentrations before, during, and after the treatment period. With the current development in mycology, there are now simple protocols or guides to be used in growing fungi as well in enzyme production or purification for rice straw treatment. There are commercially available enzyme inoculants or additives available in the market such that the costs to purchase these substrates will continuously decline and can be used by ruminant raisers to increase their production efficiency as well as their farm income (Beauchemin et al. 2004).

#### 7.3.3.1 White-Rot Fungi Treatment

White-rot fungi are known to have degrading or decaying properties by acting ligno-cellulolytic components of farm byproducts including wood. These have the capacity to decompose and metabolize cellulose, hemicellulose, and lignin under favorable environments through enzymatic reactions to their substrates (Eriksson et al. 1990). Some of the significant characteristics of many white-rot fungi species involve their ability to effectively hydrolyze lignin hence they are considered to be lignin degraders. These species can improve the nutritive value of fodder by tendering more degradable carbohydrates for rumen microbial fermentation (Yamakava and Okamnto 1992; Howard et al. 2003). White-rot fungi secrete varieties of extracellular lignin-modifying enzymes that consist of lignin-peroxidase (LiP), manganese-dependent peroxidase (MnP), laccase (phenol oxidase), and $H_2O_2$-producing oxidase (aryl-alcohol oxidase; AAO and glyoxaloxidase) (Kirk and Farrell 1987; Arora et al. 2002; Novotny et al. 2004; Arora and Gill 2005; Lechner and Papinutti 2006).

Researchers have observed that some fungi species can decompose or directly act on free phenolic monomers to break the bonds or cross-links between lignin and polysaccharides of rice straw (Chen et al. 1996). Other fungal species improve the IVDMD of treated straw (Karunanandaa et al. 1995; Karunanadaa and Varga 1996a, b; Fazaeli et al. 2006). Karunanandaa et al. (1995) also reported that incubation of rice straw with 8–10% w/w for 30 days using three white-rot fungi species. *Pleurotus sajor-caju* enhanced IVDMD in both rice leaves and stems. However, results obtained using *Cyathus stercoreus* gave the highest IVDMD compared to other fungi species (Karunanandaa et al. 1992). The sequence by which the white-rot fungi act on its substrates is dependent on the fungal species. There are species that prefer to access first on readily degradable carbohydrates, such as simple sugars, cellulose, and hemicellulose and eventually degrade lignin, thus resulting in a lower energy supply for ruminants (Karunanadaa and Varga 1996a, b; Jalc 2002). The length of incubation in treatment of straw is dependent on the white-rot fungi species. During the early stage of incubation, some losses in energy are expected due to mycelial growth but after a certain time, some white-rot species preferably attack lignin without degrading cellulose and hemicellulose, thus supplying more degradable energy for the ruminants.

Nowadays, it is important to do research on mycology by selecting fungi species that prefer to attack lignin rather than the structural carbohydrates or cell walls of rice straw. Once these species are identified, mycologists can breed even better strains (Rodrigues et al. 2008). Growing edible mushrooms is a dual purpose of treating rice straw. As described elsewhere in this book, rice straw serves as a substrate to produce food (mushrooms) and feed from the mushroom-spent bedding. Some of the edible fungal species include *Pleurotis ostreatus* and *Volvarella* sp. These can be grown easily and the left-over mycelia from the mushroom bedding can increase the protein as well as the degradable carbohydrates of the rice straw. Continuous research on white-rot species has to be done and identification of new edible fungi species is necessary to explore the potential and characteristics to produce more fruiting bodies for farmers' harvest as well as achieving optimum feeding quality of the unutilized mushroom bedding.

#### 7.3.3.2 Treatment with Enzymes

The catabolic breakdown of any complex substance into its simplest component is brought about by chemical reactions and/or by enzymatic processes. Enzymes involved in the degradation of rice straw are mostly of microbial origin and their action is very specific to the substrates to be degraded. There are commercially-available fiber-degrading enzymes, such as cellulases, hemicellosi, glucanase, and xylanases and many others. However, their stability and potency are always affected by many factors, such as temperature and duration as well as how the enzyme products were processed and packaged. Commercial enzymes used in the livestock feed industry are generally of fungal (*Trichoderma longibrachiatum*, *Aspergillus niger*, and *A. oryzae*) or bacterial *(Lactobacillus* and *Staphylococcus species*) origins (Colombatto et al. 2003).

The degradability of cereal straw can be increased through enzyme treatment or any combination of other treatments (Liu and Ørskov 2000; Wang et al. 2004; Zhu et al. 2005; Eun et al. 2006; Fazaeli et al. 2006; Rodrigues et al. 2008). Additionally, using fibrolytic enzymes show improvements in the average daily gain of steers (Beauchemin et al. 1995), fleece weight and wool production of lambs (Jafari et al. 2005), and milk production of dairy cows (Yang et al. 2000). Enzyme treatment of rice straw is not yet very popular in raising ruminants under small-scale production systems because of the additional input costs involve as well as the limitation of skills for using enzyme products.

## 7.4 Effects of Feeding Pure or Pretreated Rice Straw to Ruminants

Generally, in feeding dry cows, rice straw can be used for about 50% of the ration. Additional urea-molasses mineral blocks could be used as supplements to support the requirement of the dry cows. Rations with rice straw greater than 50% would result in a declining body weight of the cows.

For cows with calves, the use of rice straw should not exceed 25% of the total ration, with the remaining 75% being good-quality hay or legumes or a concentrate supplement. When feeding lactating cows, rice straw alone is not adequate to support milk synthesis or milk production. Supplementary feeds, such as dairy concentrates or dried legumes, are required to augment the deficient nutrients in rice straw so that the goal of supporting normal milk production is achieved.

One consideration in feeding rice straw to ruminants is to balance the quantity of phosphorus and other trace minerals in the ration. Rice straw has lower phosphorus and trace mineral contents, thus supplementation with trace minerals and phosphorus, especially in high-yielding cows, is necessary.

### *7.4.1 Effects of Urea-Treated Rice Straw in Ruminants*

Aquino et al. (2016) reported on the effects of feeding urea-molasses-treated rice straw to dairy buffaloes through the community science and technology-based farm project involving 30 dairy buffalo farmers in the Philippines. The farmers were trained to produce treated rice straw using urea-molasses solution (UMS). The UMS consisted of 2% urea, 5% molasses, and 93% water at a 2-parts rice straw to 1-part UMS ratio. The treated rice straw was allowed to partially ferment in silage bags for 21 days before feeding to buffaloes. Results of feeding UMS-treated rice straw (UMTRS) to dairy buffaloes showed a total milk production of 974 kg cow$^{-1}$ in 210 milking days. In contrast, buffaloes fed no UMTRS produced 777 kg of milk during the same lactation period. Comparing the effect of UMTRS feeding with that of pure rice straw showed a difference of 147 kg milk production or with a milk yield difference of 0.7 kg milk cow$^{-1}$ day$^{-1}$. It was also noted that the UMS improves the crude protein content of treated rice straw from 4.7% to 7.9% and the DM digestibility of rice straw was increased from 47% to 55%.

In a separate study, Aquino et al. (2018) used fermented total-mixed rations (FTMRs) composed of rice straw (RS) in combinations with banana byproducts or water hyacinth (Table 7.1). The formulated FTMRs composed of other feed

**Table 7.1** ADG in weight of growing and lactating buffaloes fed fermented total mixed ration composed of rice straw and banana byproducts or water hyacinth

| Item | Control diet | Rice straw + banana byproducts | | Rice straw + water hyacinth | |
|---|---|---|---|---|---|
| | | 25% | 50% | 25% | 50% |
| **Growing buffaloes, #** | **5** | **5** | **5** | **5** | **5** |
| Initial weight, kg | 218.60 | 220.60 | 222.00 | 247.80 | 247.80 |
| Final weight, kg | 293.60 | 282.20 | 304.40 | 315.00 | 268.40 |
| **ADG, kg** | **0.81** | **0.68** | **0.96** | **0.67** | **0.28** |
| **Lactating buffaloes, #** | **5** | **5** | **5** | **5** | **5** |
| Total milk yield, kg $120d^{-1}$ | 800.40 | 752.40 | 764.00 | 812.00 | 793.20 |
| **Milk yield, kg $d^{-1}$** | **6.67** | **6.27** | **6.37** | **6.77** | **6.61** |

ingredients, such as rice bran, copra meal, molasses, mono di-calcium phosphate, and urea. The FTRMs had remarkable results in terms of ADG and milk production of dairy buffaloes. The FTMR, composed of 20% rice straw in combination with 50% banana byproducts, resulted in a 960-g ADG compared to a 810-g ADG of growing buffaloes in the control ration. This brought an 18.9% increase in the growth rate of the buffaloes. On the other hand, FTMR, composed of 28% rice straw combined with 25% water hyacinth, gave a 670-g ADG compared to only a 520-g ADG for the control diet, which is equivalent to an increase of 28.85%. The increase in ADG of growing buffaloes was attributed to the increase in daily feed intake from 1.7% (control) to 2.13% (50% banana + RS) and from 2.01% (control) to 2.65% (25% water lily +RS) of the body weight. In addition, there was an increase in DM digestibility (from 50.95% to 60.35%) and CP digestibility (62.30–66.33%) for rice straw with 50% banana byproducts. The combination of RS with 25% water lily also improved the DM (50.10% vs. 57.96%) and CP digestibility (58.08% vs 61.96%), respectively.

The FTMR with 28% rice straw plus 25% water hyacinth was recommended over the control diet as shown by a 100-g milk difference over the control (6.77 vs 6.67 kg day$^{-1}$) or FTMR with 50% banana byproducts with a 400-g milk difference (6.77 vs 6.37 kg) over the FTMR with 50% banana byproducts. The observations were also supported by the increase in the daily DM intake; 2.5% vs 2.3% of body weight of the cows.

The ration composed of rice straw with supplementary protein, energy, and/or minerals have been shown to optimize rumen function and maximize the utilization or intake of rice straw. Chenost and Kayouli (1997) emphasized that rumen microorganisms should be provided with needed nutrients for their growth and self-multiplication so that degradation of the cell walls of straw is maximized. This also leads to conditions for sustainable process of cellulolysis. In a field trial, Warly et al. (1992) showed that a rice straw ration with supplementary soybean meal increased both degradability and intake of the animals. Untreated rice straw is low in protein when this is supplemented with cottonseed meal (Wanapat et al. 1996) or urea molasses-multi-nutrient block (Vu et al. 1999; Wanapat et al. 1999; Akter et al. 2004); these significantly increase the cow's milk production.

### 7.4.2 *Effects of Biological Treatment of Rice Straw*

Zadrazil (1977) identified three species of fungi based on substrate preference and type of enzymes they secrete for the degradation rice straw cell walls. The first group has cellulolytic and hemicellulolytic activities of which they act on cellulose and hemicellulose. The second group of fungi preferentially acts on the lignin content while the third group of fungi decomposes cellulose, hemicellulose, and lignin simultaneously. The second group of fungi is the most recommended for rice straw treatment because of its peculiarity to break and degrade structural carbohydrates present in rice straw. It is suggested that screening new fungal strains is essential with desired characteristics to efficiently improve the nutritive and feeding value of rice straw.

Zayed (2018) evaluated different parameters for the improvement of the nutritional value of rice straw. During his evaluation, he used moist straw, soaked straw for 24 h without pasteurization, and soaked straw for 24 h with pasteurization at 100 °C for 1 h. The preprocessed rice straw samples were inoculated having three combinations of microbial inoculants. He also observed that moistened rice straw had the highest organic matter reduction at 74.21% if inoculated with *Azotobacter chroococcum* and *Saccharomyces cerevisiae*. Additionally, if inoculated with *Azospirillum brasilense* and *Saccharomyces cerevisiae,* significant reduction in crude fiber at 27.54%; neutral detergent fiber at 55.39%; and 42.47% acid detergent fiber can be observed. For rice straw soaked for 24 h and inoculated with *Azospirillum brasilense* and *Bacillus megaterium,* a significant increase in crude protein at 13.71% was observed. Zayed (2018) further concluded that interaction between microbial treatment and physical pretreatments of rice straw shows a significant decrease in organic matter, crude fiber, neutral detergent fiber, and acid detergent fiber as well as a significant increase in crude protein compared to the control.

## 7.5 Limitations of Rice Straw Utilization

Several factors were identified that limit the utilization of straw as animal fodder. These include poor digestibility, low animal intake, and very low protein content. Technologies to overcome the identified factors have been developed for pretreatment of straw before feeding to animals. However, its adoptability varies according to the capacity and capability of the farmers or its practicality including health and environmental concerns when used by the farmers.

In physical treatment of straw, the limitation is mainly on grinding of the straw into smaller particle size. The positive effect of reduced particle size is that it promotes higher intake due to an increase in the rate of passage of the ingested feed by the animal. The negative side of this is that it causes less time for rumination and less exposure to microbial degradation, thus in turn reducing degradation and digestibility of the straw components. Uden (1988) observed that grinding and pelleting of grass hay decreased dry matter degradability in cows from 73% to 67%, which was mainly due to a decreased fermentation rate (9.4–5.1% $h^{-1}$) and decreased total retention time of the solids from 73 to 54 h, resulting in an increased intake (Stensig et al. 1994). The use of machines in physical treatment and processing of crop residues is also not practical for small-scale farms because of their capacity to buy equipment and the benefits derived may be too low or even negative for the farmers (Schiere and Ibrahim 1989).

The costs involve can be one of the factors that limit the adoption of chemical treatment of straw. Although there are significant effects on the improvement of the nutritive value, animal performance, as well as an increase in income due to treatment of rice straw, the farmers should still balance their decision whether to adopt or not to adopt using treated straw. Hazard issues, such as toxicity and environmental pollution, are some of the limitations in using chemicals for straw treatment.

For microbial treatment of rice straw, one of the major drawbacks is the strain of the fungi to be used and its capacity to degrade lignin and other components of the straw, such as cellulose and hemi-cellulose. Incubation period is another limitation for its practical application in treating straw. There are species of fungi with very high affinity to degrade lingo-cellulosic materials, even in just 1 or 2 weeks of incubation and these have to be explored for its optimum incubation time to increase the feeding value of straw. In addition, some fungi produce toxins that may affect both human and animals so proper care should be considered in using these for rice straw treatment.

## 7.6 Summary and Recommendations

Among agricultural byproducts, rice straw is most abundant, low in cost, and a practical source of fodder for ruminants. Its utilization as a livestock feed is limited due to problems in collection, hauling, and storage. Rice straw has low nutritional value (low protein content and poor digestibility) compared to grasses, thus it cannot support the nutrients required by high-yielding milk cows and buffaloes. There are technologies that have been developed to increase the nutritive value, nutrient digestibility, and utilization of rice straw, such as physical processing, pretreatment using chemicals, and/or biological treatment. However, adoption of these developed technologies is still low due to farmers' limited skills and inputs (e.g., farm equipment) and their doubts regarding applicability to the farm situation and the benefits for the animals and livestock producers. To maximize the utilization of rice straw as fodder for ruminants, mechanization is most important to facilitate collection, hauling, and stacking or processing all available rice straw from the field.

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