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Review Article
The Current Utilisation and Possible Treatments of Rice Straw as Ruminant Feed in Vietnam: A Review

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Abstract
This review provides an overview of the availability, nutritive value and possible strategies to improve the utilisation of rice straw as a ruminant feed. Although, rice straw is the most abundant agricultural by-product and can consider as a sustainable source for ruminant feed in Vietnam, only a small proportion of rice straw is fed to ruminants. Rice straw is rich in polysaccharides and has the high levels of lignin and silica, limiting voluntary intake and reducing degradability by ruminal microorganisms. Some physical treatments are not practical because they require machinery application or are not economically feasible for the farmers. Chemical treatments, such as urea, ammonia or lime, currently seem to be more practical for on-farm use. The application of chemical agents can be hard to handle, harmful to the habitat. The use of white-rot fungi, exogenous enzymes and lactic acid bacteria to enhance the nutritive value and digestibility of rice straw are expected to be a practical and environmental-friendly approach in the future. It is recommended that combinations of these biological treatments with traditional methods are promising for having a synergistic effect on the nutritive improvement of rice straw. Future research should focus on the optimisation of biological and economic effects of different treatments and development in alternative enzyme production and fermentation technologies to obtain the higher nutritive value and digestibility of rice straw.

Key words: Rice straw, ruminant feed, nutritive value, ruminant production, exogenous enzyme, Vietnam

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INTRODUCTION

Rice (*Oryza sativa*) is the staple crop for livelihood in Southeast Asia and more specifically in Vietnam. In 2018, Vietnam produced 44.0 million tonnes of rice[1] and the equivalent amount of dry rice straw was generated. However, a large amount of rice straw is burned in the field hampering sustainable management in intensive rice systems in Vietnam[2]. Meanwhile, ruminant production with approximately 11.2 million heads mainly depends on cut grasses and agricultural by-products since lack of grazing land[3]. Although, in dry or winter season, cut grasses and pastures only meet about 35-57% total forage demand leading to the death of thousands of ruminants, the percentage of rice straw using in ruminant production is really limited compared to its annual yield[4]. In Vietnam, rice straw has not been maximally utilised for ruminant production yet. It is usually fed as part of the forage component in cattle diets during the time when fresh forage is insufficient[5]. For maintaining optimal production levels, feeding only rice straw does not provide enough nutrients to the ruminants[6]. Therefore, increasing the nutritive values of rice straw is very beneficial in the sustainable development of ruminant production.

Low and unbalanced nutritive contents, low voluntary intake and slow rate of digestion are mainly limited the use of rice straw in ruminant production[7,8]. For many years, various extensive research have attempted to improve the nutritional quality of rice straw as a sustainable source of ruminant forage. The possible alternative for better utilisation of rice straw is to improve its nutritive value and digestibility through breaking lignocellulose bonds or at least loosening them to free the major portions of cellulose and hemicellulose to be digested by ruminal microorganisms[9]. In Vietnam, numerous methods of physical (grounding, steaming and pelleting) and chemical (urea, ammonia and lime) treatments have been investigated. Some, however, focus on making rice straw silage by biological treatments (white-rot fungi, enzymes, lactic acid bacteria) or supplementing with other feedstuffs or (and) high soluble carbohydrate sources in order to improve the utilisation of rice straw by ruminants. Although, many methods for improving rice straw utilisation have been developed and recommended, the majority of ruminant farms still feeds untreated rice straw t o their animals[5]. Therefore, the objectives of this paper were to provide an overview of current situation of ruminant production and rice straw utilisation as a source of ruminant feed and highlight some possible techniques used to improve the utilisation of rice straw in ruminant production in Vietnam.

CURRENT RUMINANT PRODUCTION AND RICE STRAW UTILISATION

In 2018, Vietnam had totally about11.2 million ruminants including 5.7 million beef cattle, 0.3 million dairy cattle, 2.5 million buffaloes, 2.5 million goats and 0.2 million sheep[3]. It is widely accepted that each large ruminant daily needs approximately 20-30 kg of forage. Thus, about 62-93 million tonnes of forage are annually needed for raising cattle and buffaloes across the country. The demand of forage, which accounts for around 60-85% total weight of feed, is huge. However, in dry or winter season, natural and grown grasses only provide about 35-57% total forage demand of cattle[5]. In the last decade, the serious deficiency of forage combined with harsh winter have resulted in the death of thousands of cattle and buffaloes per annum in northern mountainous provinces. Especially, in 2008 winter, approximately 200,000 cattle and buffaloes were dead and the amount of dead large ruminants in 2010 winter were about 100,000 heads[10]. Lack of forage also reduces animal productivity capacity and farmers economic profit.

Numerous studies agreed that dry rice straw yield is equal to rice yield[4,11,12]. As a result, Vietnam has about 44.0 million tonnes of dry rice straw per annum. Hung *et al.*[2] reported about 90% of rice production area is harvested by combine harvesters which only cut 1/3 upper top of rice tree. This part of rice straw is collectable and can use as ruminant feed. Therefore, rice production annually generate approximately 13.0 million tonnes of dry collectable rice straw. This is an abundant and sustainable feed source for ruminant feed. Rice straw can be used directly or treated by different preserved methods to store and improve nutritive value of the rice straw for animal feed during forage-shortage periods. However, there is a fact that the proportion of rice straw using in ruminant production is really low. Both Truc *et al.*[13] and Nam *et al.*[4] reported that in southern Vietnam, less than 1% of total rice straw was used as ruminant feed. Furthermore, Nguyen[5] observed that in southern Vietnam, the highest percentage of rice straw using for ruminant feed was 1.4% in dry season, while the percentage of rice straw using for ruminant feed was highest (5.6%) in winter in northern Vietnam. Rice straw are also used for other activities such as cooking fuel, mushroom cultivation, compost, mulching and bio-char with low proportions[5,14]. Currently, the majority of rice straw (54.1-87.0%) has been burned on fields during and soon after harvest seasons in Vietnam[2,5,15]. Most of the farmers stated that burning on fields is the cheapest and fastest mode of rice straw disposal. Burning rice straw causes environmental pollution, accelerates the climate change due to increasing greenhouse gas emissions, traffic accidents thanks to smoke, have detrimental effects on human health. Furthermore, it wastes resource and reduces economic benefit and soil fertility[16]. Small cultivation fields, limited time between crops, lack of labor and consumed market, high transportation cost, use of gas and electric stoves for cooking are main reasons explaining the limited utilisation of rice straw using for ruminant feed and other economic activities[2,14]. The low nutrient value and voluntary intake, slow rate of digestion of rice straw also constrains the use of rice straw in the ruminant production[7,8].

CHEMICAL COMPOSITION AND NUTRITIVE QUALITY OF RICE STRAWIN FEEDING TO RUMINANTS

The chemical composition and nutritive values of rice straw are dependent upon different factors. They are influenced by intrinsic factors such as variety, plant health and maturity status[8,17]. The environmental conditions such as light, temperature, soil moisture, fertiliser and growing season also affect chemical compositions and digestibility of rice straw[6,18]. The height of harvested cutting, morphological fractions (leaves, stems), threshing and post-harvested storage methods and time have considerable effects on the quality and digestibility of rice straw[6]. The chemical and mineral compositions of rice straw, compiled from previous studies in Vietnam, are presented in Table 1.

Silica is a cell wall component in rice, grasses and many other plants. In rice straw, silica can be present in high concentrations ranging from 4.4-13.0% (Table 1), depending on the rice variety[27] and the availability of this mineral in the cultivated soil[28]. The high silica accumulation in rice straw plays a vital role in increasing rice growth, improving plant rigidity and grain quality, reducing lodging and mitigating plant biotic and abiotic stresses, protecting from heavy metal toxicity and pathogens[29]. The role of silica on the quality of rice straw was also reviewed by Van Soest[8]. Song *et al.*[30] concluded that the high silica content of rice straw makes it more poorly digestible to livestock. Silica reduces palatability and the degradability of rice straw in the rumen due to its direct action in preventing colonisation by ruminal microorganisms[28] and negative effects on cellulose enzymes[31].

Apart from silica, the rice straw cell walls predominantly consist of cellulose, hemicellulose and lignin. Enzymes including cellulase, hemicellulase and ligninase are required to break down these components[32]. Cellulase and hemicellulase are not produced by the ruminants themselves but microorganisms in the rumen do produce these enzymes. However, in rice straw, lignin accounts for about 4.3-12.5% (dry matter basis) and it cannot be broken down in the rumen due to lack of ligninase[9]. Theoretically, lignin located between the cellulose micro fibrils is regarded as the most abundant natural aromatic organic polymer. Lignin is primarily composed of three types of monolignols/hydroxycinnamyl alcohols (p-coumaryl, coniferyl and sinapyl alcohols) linked with each other by different types of ether and carbon-carbon bonds like β-O-4, 4-O-5, β-β, β-1 and β-5 to make phenylpropanoid units such as p-hydroxyphenyl, guaiacyl and syringyl. Among these, the β-O-4 linkage is the most predominant ether bond (about 40-60%) in rice straw lignin[18]. Lignin is proposed to be attached to carbohydrates by benzyl esters, benzyl ethers and phenyl glycosides. It is quite difficult to remove lignin in its native form. Even if, lignin could be degraded in the rumen it would not provide much energy for

Table 1: Chemical and major mineral compositions of rice straw in Vietnam

Compositions	Units	Fresh rice straw	Dry rice straw
pH		6.1-6.4	5.9-6.4
Dry matter (DM)	%	26.3-34.4	81.5-92.1
Organic matter	%DM	82.6-89.5	83.7-90.0
Crude protein	%DM	3.2-7.3	2.0-6.6
Crude fat	%DM	0.7-1.6	0.6-1.7
Crude fibre	%DM	27.4-43.2	30.1-42.5
NDF	%DM	63.4-72.5	66.3-73.2
ADF	%DM	34.8-43.5	36.3-42.6
Hemicellulose	%DM	23.0-32.2	26.6-33.5
Cellulose	%DM	30.4-35.8	32.8-47.0
Lignin	%DM	4.3-12.5	4.0-13.2
Silica	%DM	4.4-13.0	5.9-12.8
Total Ash	%DM	10.5-17.5	10.0-16.3
Calcium	g kg^{-1} DM	4.9-5.6	3.7-5.4
Phosphorus	g kg^{-1} DM	1.2-1.9	1.7-2.3

Compiled from Nguyen[19], Tuyen *et al.*[20], Nguyen *et al.*[21], Vinh *et al.*[22], Vu *et al.*[23], Trach *et al.*[24], Dinh *et al.*[25], Nguyen and Dang[26] the animals because rumen microorganisms require a large amount of energy from other sources to break down its chemical linkages and tight physical bonds[9]. In nature, lignin plays a role in resisting compressing forces, providing protection against consumption by insects and mammals. It also inhibits the rate and degree of microbial degradation[33]. Thus, lignin has detrimental effects on livestock production through adversely influencing degradability and feed intake and must be removed to make the carbohydrates available for further hydrolysis processes.

As mentioned before, cellulose and hemicellulose are the digestible parts of rice straw cell walls. Cellulose in the plant is composed of both crystalline and amorphous structures. Satlewal *et al.*[18] stated that the level of crystallinity of cellulose is believed to affect the rate of its decomposition by the cellulolytic bacteria. Moreover, accessibility of the rumen microorganisms to cellulose and hemicellulose can be restricted by direct (covalent) or indirect (ester or ether) linkages between lignin and cellulose, hemicellulose[34]. Van Soest[35] suggested that feed intake is limited by the amount of fibre in diets when cell wall content lies between 50 and 60% of forage dry matter. Voluntary feed intake is also expected to be inversely related to the fibre content of forage because further intake is limited as the slower digesting fraction becomes large in relation to the volume of digestive tract. In the same way, particle passage is expected to decrease with increasing neutral detergent fibre (NDF) intake, particle size, coarseness of forage and decreasing forage digestibility[36].

Besides cell wall polymers, rumen microorganisms and in turn ruminants need other nutrients for growth and metabolism. Rice straw contains only 2.0-7.3% crude protein, while 8.0-10.0% of crude protein in ruminant feed is required for improved consumption and good growth. Furthermore, rice straw has low content in fat, calcium (Ca) and phosphorus (P) compared to other forage sources. Malik *et al.*[6] stated that animals need diets containing about 0.3% of P and 0.4% of Ca for their normal growth and fertility. It is clear in Table 1 that feeding animals with only rice straw may not provide enough P levels. The Ca content in rice straw (0.37-0.56%) appears to be met normal Ca requirement. However, rice straw contains about 0.20-0.66% oxalate[37,38]. In native grass and cereal hays, oxalate might bind 38-44% of calcium to generate calcium-oxalate compound[38]. Rahman *et al.*[39] reported that most of the ingested calcium-oxalate appear to pass intact through the ruminant digestive tract because they cannot be degraded by most rumen or intestinal bacteria. Furthermore, the presence of oxalate and silica in rice straw exacerbate the Ca absorption and utilisation of ruminants[37]. As a consequence, there is in a negative balance in Ca when cattle are fed only untreated rice straw[9].

Generally, anti-nutritional factors such as silica and lignin are the primary limitations to rice straw digestibility in ruminant animals[8]. Rice straw nutritive values are unbalanced with high energy content and poor in protein. A number of studies stated that feeding only rice straw does not provide enough nutrients to the ruminants to maintain high production levels due to the low nutritive value of this highly lignified material[6,8]. Animals fed with unsupplemented rice straw diet only will very often lose weight. In the past, many attempts have been made towards increasing the nutritive value, digestibility and utilisation of rice straw[40-42]. The improvement of this valuable fodder crop is of great importance so as to create economic profits and be friendly with environment rather than the cultural practices of burning.

POSSIBLE TREATMENTS TO IMPROVE RICE STRAW UTILISATION IN RUMINANTS

Rice straw typically is a poor-quality feed in its natural state because of low digestibility and protein content, poor palatability and bulkiness, although it contains enough cellulose and hemicellulose to make it an excellent source of dietary energy for ruminants. The key to improving the use of crop residues for ruminants 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. Numerous treatment processes, including physical, chemical and biological are used to increase the acceptability of rice straw to animals, thus increasing palatability, daily feed intake, nutritive value and maintained the health quality of ruminants as compared to untreated rice straw.

Physical treatment: Globally, the mainly used physical methods are grinding, soaking, pelleting and chopping or steaming, pressured cooking or X-rays. Physical treatments of biomass with the purpose of increasing available surface areas and reducing crystallinity of cellulose, being better degradable by enzymes[9,43,44]. Reducing particle size of rice straw usually decreases dry matter digestibility, which was mainly due to a decreased fermentation rate and decreased total retention time of the feedstuff and resulting in an increased intake[45]. However, at the same time these methods increase the net energy value of the straw somewhat because the nutrients that are digested are utilised more efficiently by the animal[46]. Liu *et al.*[47] reported that the use of steam treatment in a high pressure vessel at different pressures and for a range of different treatment times increased the *in vitro* degradation in rumen fluid after 24 h and the rate of degradation but could not enhance the potential degradability of the fibrous fractions such as NDF, ADF and hemicellulose. Steam and/or pressure treatment of rice straw increases solubilisation of cellulose and hemicellulose and/or by freeing digestible materials from lignin or silica[48]. Various studies agreed that only using physical treatment is not satisfactory to the improvement of rice straw nutritive values. Moreover, almost all physical treatments are not for practical use on small-scale farms, because they require machines or industrial processing. This makes these treatments economically unprofitable for farmers as the benefits may be too low or even negative[32]. The treatments also require the significant amount of high energy making it a cost intensive and difficult to scale up for industrial purposes[49]. However, small machines to grind or chop rice straw in combination with other treatments such as chemical and biological treatment in order to improve the efficiencies may be feasible.

In Vietnam, soaking dry rice straw in water before feeding animals is a traditional method using by many small-scale farmers[5]. They supposed that soaking will make rice straw softer and more desirable for animal eating. Recently, several enterprises have used industrial grinder and pelletiser systems to produce enriched-rice straw pellets supplying to large-scale cattle farms. Rice straw was chopped, ground and then mixed with ground processed cattle feed and/or other feedstuffs at different ratios. The mix was pelletised and packed before transporting to cattle farms. Hieu *et al.*[50] reported that the pelletising technology resulted in reducing transportation costs due to increase in its density and improving rice straw eating desirability for cattle. Although, the method increased the cost of densified product by 40-50%, it may create a new market for rice straw with more alternative options which cause reducing greenhouse gas emission from rice straw burning in the field.

Chemical treatment: Chemical treatments have received an appreciable amount of research and been popular methods of improving the nutritive value of rice straw. Chemicals may be alkaline, acidic or oxidative agents. Among these, alkali agents such as urea, ammonia and lime have been most widely investigated and practically accepted for application on farms. The chemicals are relatively cheap and procedures to use them are relatively simple. However, safety precautions are needed for their use as these chemicals themselves are not harmless[48]. Basically, alkali agents can disrupt cell wall structure by chemically breaking down the ester bonds between digestible carbohydrates and lignin for solubilisation of significant amount of hemicellulose and decrystallising cellulose[49]. Moreover, they physically make structural fibres swollen and thereby increase the amount of accessible surface of particles for microbial attachments to have higher degradability and better feed intake by ruminants[51].

Urea treatment is a conventional method of increasing the nitrogen level of ensiling materials through increasing the nitrogen content and digestibility[24,52]. Since urea is a solid chemical, which releases ammonia after dissolving in water, it is easy to handle and transport. For practical use by farmers, urea is cheaper and safer than using anhydrous or aqueous ammonia. It serves as a delignifying agent through ammonification[49]. In addition, urea treatment results in the removal of silica polymerised cuticle waxes from the surfaces of leaf sheath and blade[53]. Shen *et al.*[54] stated that urea treatment lead to a decrease in hemicellulose contents and an increase in extractable biogenic silica contents of rice straw. It also exposes the underlying tissues of straw to bacterial colonisation[55].

In Vietnam, treating rice straw by urea has received a great attention from both researchers and farmers. Since 1970s, rice straw treated by urea has fed to animals and cattle fed 2.5% urea-treated rice had 23.7% average daily gain higher than animals fed untreated rice straw[56]. Trach *et al.*[24] also concluded that cattle fed urea-treated rice straw improved average daily gain by 55-60% compared to that fed untreated rice straw. Trach[7] and Trach and Tuan[57] recommended that treating rice straw by up to 4% urea is an economic and effective preserved method to improve its nutritive value and digestibility. It in turn increases animal feed intake and performance. Trach *et al.*[58] and Thu and Dong[59] also observed that more rice straw cell wall fibres were solubilised and more rice straw dry matter was degraded in both *in sacco* and *in vitro* conditions when treating the straw by up to 5% urea in comparison with untreated rice straw. Similarly, there was an increase in voluntary feed intake and dry matter, organic matter, crude protein and NDF digestibility in urea treated rice straw when feeding to swamp buffalo bulls[22]. Man and Wiktorsson[52] concluded that the substitution of elephant grass (*Pennisetum purpureum*) by up to 75% fresh rice straw treated with 5% urea in lactating cow diets had no detrimental effect on milk yield and composition. They also suggested that the urea preservation of fresh rice straw for dairy cattle can reduce the cost of buying grass in forage-shortage periods, which is common practice in dairy production in Vietnam. Nguyen[5] observed that urea is the most popularly used treatment of rice straws.

Treating rice straw with anhydrous and aqueous ammonia (NH_3) has been widely investigated to improve degradability[40,60]. The principle of ammonia treatment is supposed to be similar to that of urea treatment. Ammonia treatment not only increases the degradability of rice straw but also adds nitrogen[9]. The urea and ammonia treatments increase the pH of silage above 8[57,61]. With this high pH and ammonia effect on silage, the growth of mould and yeast is inhibited specially in high moisture forage and consequently increases aerobic stability of the silage materials. Addition of ammonia also restrains plant proteases which diminishes the rate of protein degradation during preservation[48]. Besides, improvement in degradability of structural carbohydrates, ammonia treatment is an effective method to reduce the amount of supplemental nitrogen, in turn reduce the costs of purchasing protein-rich feedstuffs and enhance acceptability and voluntary intake of the treated straw by ruminants[62].

In Vietnam, a limited number of research use NH_3 as an alkali agent to treat rice straw and farmers prefer using urea to NH_3 to treat rice straw because of following reasons: (1) As mentioned before, urea is actually an ammonia source because it releases ammonia after dissolving in water, (2) Urea can be obtained easily in both urban and rural areas whereas NH_3 is not popularly sale, (3) Aqueous NH_3 is more technically difficult to handle and may expose the handler to health hazards while urea does not pose such problems. When using urea and ammonia, caution must be taken because excess ammonia may result in poor fermentation (because of a prolonged buffering effect) and low animal performance[63]. Since ammonia is corrosive to zinc, copper and brass, materials made of these substances should be avoided while ensiling ammonia treated forage.

Lime ($CaO/Ca(OH)_2$) is a weak alkali agent with a low solubility in water. It has been suggested that lime can be used to improve the utilisation of straw and also can be used to supplement rations with calcium. Lime is cheap and possible to easily find in many places. Moreover, lime treatments are simple, safe and almost harmless to environment[11]. Soaking and ensiling are two methods of treating straw with lime. In Vietnam, MARD[64] suggested farmers soaking rice straw with lime feeding to cattle during winter when forage is not enough. The straw is soaked in1% $Ca(OH)_2$ solution for three days, then it is either directly fed or dried before feeding[11]. Giang and Trach[65] reported that ensiling rice straw with either 6% CaO or 8% $Ca(OH)_2$ had higher apparent organic matter digestibility and metabolisable energy content compared to those of untreated straw. Trach *et al.*[58] concluded that lime treatments appeared to be more powerful in delignification than urea treatments. However, treating rice straw with lime at high level ($\geq$6%) maybe toxic to microorganism in the rumen and decrease voluntary dry matter intake, due to a reduced acceptability of the treated feed by animals. Furthermore, ensiling rice straw with lime should not be recommended for practical application because it cannot inhibit mould growth[11,65]. Numerous studies suggested that a combination of lime and urea would give better results than urea or lime alone. This combination has the advantage of increased degradability, increased both calcium and nitrogen contents and mould growth prevention.

In the world, other chemical agents such as sodium hydroxide, formic acid, propionic acid and acetic acid have been used to improve the use of crop residues for ruminant feeding[66,67]. The principal advantages of sodium hydroxide treatments are increased degradability and palatability of treated straw, compared to untreated straw[66]. Acids are used during ensiling to initiate rapid drop in pH to inhibit growth of undesirable microbes. They also reduce fermentation losses of carbohydrate and protein[63]. However, such chemicals are not widely available as a resource for small-scale farms and may be too expensive to use[68]. In addition, the application of these agents can be a cause of environmental pollution, resulting in a high content of sodium and inorganic acids in the environment[69,70]. It is difficult to handle these chemicals and they are toxic to human and animals. Therefore, they are limitedly applied and not recommended for use in developing countries[68].

Biological treatment: The biological treatments including lactic acid bacteria (LAB), white-rot fungi and their enzyme extracts have great potential in improving the nutritive value of rice straw[20,71,72]. Recently, perhaps no other area of silage management has received as much attention among both researchers and livestock producers as biological treatments. Table 2 summarises different microorganisms involved in treatment strategies and their effects on the nutritive value and degradation of rice straw.

White-rot fungi, as lignocellulolytic microorganisms, are able to degrade and metabolise plant wall cell constituents (lignin, cellulose and hemicellulose) by their enzymes[91]. Lee *et al.*[92] stated that lignin degradation by white-rot fungi occurs due to the presence of peroxidases and laccases (lignin-degrading enzymes).Numerous species of white-rot fungi have been used to improve the nutritive value of fodder

Table 2: Bacteria, fungi and their enzyme production studied to improve the nutritive value of rice straw for ruminant feed

Species	Determined enzyme	Main results	References
Ceriporiopsis subvermispora, *Lentinula edodes*, *Pleurotus eryngii*, *Pleurotus ostreatus*	Lignocellulolytic enzymes	Improved degradation of cell wall components, especially lignin	Tuyen *et al.*[20];
Pleurotus eryngii	Lignocellulolytic enzymes	Enhanced content of crude protein and reduced ADF, NDF and ADL contents; Increased the *in vivo* digestibility, N retention and microbial protein synthesis	Huyen *et al.*[73]; Huyen *et al.*[74]
Pleurotus ostreatus	Lignocellulolytic enzymes	Enhanced delignification, softness and the contents of protein and free sugar	Khan *et al.*[41]; Khattab *et al.*[75]; Sherief *et al.*[76] Chalamcherla *et al.*[77]
Trichoderma reesei, *Trichoderma viride*	Fibrolytic enzymes	Increased dry matter degradability and protein contents, decreased fiber contents	Eun *et al.*[78]; El-Bordeny *et al.*[79]; Gomaa *et al.*[80]
Phlebia brevispora	Xylanase	Minimised loss in total organic matter, improved crude protein content, lignin degradability and *in vitro* DM digestibility	Sharma and Arora[81]
Aspergillus terreus	Lignocellulolytic enzymes	Improved hemicellulose and lignocellulose degradation	Jahromi *et al.*[82]
Aspergillus niger	Cellulase and xylanase	Improved *in vitro* digestibility of nutrients	Cuong *et al.*[83]
Exogenous enzymes	Cellulase and xylanase	Improved rumen fermentation, dry matter and NDF digestibility, enhanced the rumen bacterial population	Mao *et al.*[84]; Sujani *et al.*[71]
Exogenous enzymes	Cellulase, xylanase, protease and alpha amylase	Improved the dry matter, NDF and ADF degradability	Gado *et al.*[85]
Exogenous enzymes	Fibrolytic enzymes	Improved *in vitro* digestibility of nutrients and rumen fermentation	Sheikh *et al.*[86]; Adesogan *et al.*[87]
Bacillus licheniformis	Proteolytic enzymes	Increased dry matter, NDF degradability	Eun *et al.*[78]
Lactobacillus bulgaricus		Quickly reduced pH to repress the growth of unexpected microorganisms, increased palatability	Wang *et al.*[88]
Lactobacillus fermentum		Quickly reduced pH to improve preservation efficiency	Yanti *et al.*[89]
Lactobacillus buchneri and *Pediococcus pentosaceus*		Significantly improved rumen fermentation and silage quality	Zhang *et al.*[90]
The mix of lactic acid bacteria		Improved lactic acid production and *in vitro* digestibility of dry matter	Liu *et al.*[72]

including rice straw. Tuyen *et al.*[20] treated rice straw with 4 white-rot fungus species and concluded that *Ceriporiopsis subvermispora*, *Lentinula edodes* perform the best and have a significantly high potential to improve the degradation of cell wall components, especially lignin in rice straw. Using oyster mushrooms (*Pleurotus ostreatus*) to increase the degradability of rice straw were employed by many studies (Table 2). White-rot fungi are able to decompose free phenolic monomers and to break the bonds with which lignin is cross-linked to the polysaccharides in rice straw[82], enhance *in vitro* dry matter digestibility[78,80] and minimise loss in total organic matter[79,81].

In the last decade, concerted efforts have been devoted of using exogenous enzymes to improve forage quality and ruminant animal performance. In rice straw, Sujani *et al.*[71] and Mao *et al.*[84] concluded that a combination of cellulase and xylanase effectively improve rumen fermentation, increase rice straw DM and NDF digestibilities and enhance the rumen bacterial numbers. Sheikh *et al.*[86] and Gado *et al.*[85] treating rice straw with fibrolytic enzymes also observed an improvement in *in vitro* rumen fermentation and nutrient digestibility. However, other studies, using fibrolytic enzymes, could not significantly increase the degradability of rice straw[9,93]. Enzyme additives vary in effectiveness (efficiency of fiber-degrading) depending upon forage types, moisture content, temperature, incubation time, its own characteristics[42]. To optimise fibrolytic activity, Adesogan *et al.*[87] suggested the enzymes need to: (1) Contain appropriate amounts of cofactors, co-enzymes and activators, (2) Be resistant to degradation by ruminant proteases, (3) Have a robust composition that does not vary appreciably with the enzyme batch, (4) Be sourced from a readily culturable fungus, (5) Exhibit optimal and steady activity under a wide range of ambient conditions, (6) Be in liquid form or dissolve rapidly and completely in water, (7) Be thermo-stable in cases it will be added during feed manufacturing and (8) Maintain its hydrolytic activity when appropriately stored for long durations.

Recently, bacteria have become one of the main additives to during silage preparation and making. Lactic acid bacteria are commonly investigated and used to improve the fermentation quality of rice straw silage. The LAB associated with silage belonging to the genera of *Lactobacillus*, *Enterococcus*, *Pediococcus* and *Leuconostoc*[94].

The whole base of LAB in silage is centralised on their ability to reduce the pH value which can be reduced to 3.7 and 4.2 and contain high concentration of lactic acid[42]. Anaerobic bacteria fermentation converts sugary compounds in the straw into lactic acid inhibiting normal aerobic bacterial action. If the air is kept out of the silage, it is preserved efficiently and stably. Yanti *et al*.[89] reported that fermenting rice straw with *Lactobacillus fermentum* resulted in better silage quality compared to bacillus and fungi (*Aspergillus niger* and *Saccharomyces cerevisiae*). Other studies also confirmed that ensiling rice straw with LAB is one of the methods for quickly reducing pH to oppress the growth of unexpected microorganisms[88]; improving lactic acid production[72]; achieving a proper rumen fermentation and nutrient preservation[90].

Numerous studies have recommended that combinations biological treatments with other methods are promising for having a synergistic effect on the nutritive improvement of rice straw[9,17,95]. Abdel-Aziz *et al*.[42] concluded that combination microorganisms with actions including chopping, moisture changing and pressing improved the fermentation quality. The similar results were observed by Wang *et al*.[88], who treated wilted rice straw with LAB in combination with chemical additives and by Eun *et al*.[78] who treated rice straw with xylanase or cellulase in combination with ammonia. In theory, these additives complement each other by utilising additional substrate provided by the enzymes during the fermentation process.

In Vietnam, the number of studies using biological additives alone or combining with other methods to treat rice straw for ruminant feed still remain limited and inconsistent. When treating fresh rice straw with LAB (mainly *Lactobacillus plantarum*, *Lactobacillus pentosus* and *Enterococus lactis*) and/or multi-enzymes for 60 days, Hung *et al*.[93] did not observe any improvement in the *in sacco* degradability of dry matter and NDF in the straw. In contrast, Cuong *et al*.[83] concluded that the *in vitro* degradability of nutrients was improved when dried rice straw was treated with the mix of cellulase and xylanase (extracted from *Aspergillus niger*) alone or in combination with microbial additives. Huyen *et al*.[73] and Huyen *et al*.[74] reported that fermenting rice straw with *Pleurotus eryngii* increased the content of crude protein and the *in vivo* digestibility of nutrients in the straw feeding to sheep. As of now, several small-scale farms have treated fresh rice straw with multi-purposed effective microorganisms (containing *Lactobacillus plantarum*) in combination with molasses and salt to produce silage for ruminants[5]. However, no on-farm research on rice straw biological treatments affecting ruminant performance have been recorded.

The biological treatments have great potential and advantages in comparison to other methods. They do not require machine or industrial processing and safer to handle. Biological treatments are low-energy processes, non-corrosive to machinery and regarded as environmentally friendly viable alternatives[6,49]. Nevertheless, there are also a number of serious problems to consider and overcome if these treatments are applied on-farm and industrial scales in developing countries[17,95]. In an on-farm application, it is difficult to control the optimal environmental conditions for fungal growth, such as temperature, pH, pressure, oxygen and carbon dioxide concentration when treating rice straw. Currently, it is also difficult and lack of technology to produce large quantities of fungi or their enzymes to meet the requirements, leading to expensive in price[95]. Furthermore, sterile conditions, time consuming and major portion of dry matter loss in fungal treatments should also be taken into account[70]. With recent developments in alternative enzyme production and fermentation technologies, the costs of these materials are expected to decline and commercial products may become viable in the future[49,95].

Supplemented with other additives: It is necessary to provide the rumen microbes with the nutritive elements which they need for self-multiplication and for degradation of the cell walls of rice straw and to ensure all conditions for maintenance of good cellulolysis. The supplementation of locally available additives should be an effective and inexpensive strategy for better use of rice straw. As aforementioned, rice straw is low in crude protein and difficult to degrade, it is obvious that supplementation of rice straw with a protein source and a more easily accessible energy source will improve the performance of the animals. Supplementation of rice straw with protein, energy and/or minerals may optimise rumen function, also maximise utilisation of the rice straw, increase intake and reduce the time taken to attain desirable market weight[96]. Apart from

Table 3: Feeding rice straw supplemented with other components in Vietnam

Supplements	Animals	Effects	References
Leucaena leaf pellet	Swamp buffaloes	Improved rumen ecology, N-retention and microbial N supply	Hung *et al.*[98]
Urea-molasses cake	Swamp buffaloes	Increase in rumen NH_3-N concentration, microbial population and feed intake	Thu and Udén[99]
Ensiled or pelleted cassava foliage	LaiSind heifers	Improved growth rate	Khang and Wiktorsson[100]
Cottonee seed cake and water hyacinth silage	LaiSind heifers	Improved crude protein intake and digestibility of nutrients	Tham and Udén[101]
Cassava root meal and groundnut cake	LaiSind cattle	Increased dry matter intake and live weight gain	Trung *et al.*[102]
Elephant grass and cassava powder	LaiSind cattle	Increased digestibility of nutrients and live weight gain	Ba *et al.*[96]
Cassava leaf meal and the mixture of molasses and urea	LaiSind cattle	Improved growth performance and feed conversion	Tham *et al.*[103]
Urea-sprayed and wet brewers' grains	LaiSind cattle	Improved feed intake and growth rate	Trach and Thom[104]
The mixture of cassava chips, rice bran, crushed rice grain, fish meal, urea	Crossbred Brahman cattle	Increased digestibility of nutrients, live weight gain	Quang *et al.*[105]
Mulberry leaf meal	Crossbred Brahman cattle	improved dry matter intake, ruminal NH_3-N and rumen ecology	Tan *et al.*[106]
Molasses urea block, beverage residue, soybean meal	Holstein-Friesian crossbred cows	Increased milk yield and fat content, reduce the time of calving interval	Vu *et al.*[107]
Leucaena silage	Dairy steers	Improved microbial population and microbial protein synthesis	Giang *et al.*[108]
Molasses and protein-rich forage	Phan Rang lambs	Increased dry matter intake, nutrient digestibility and feed conversion	Hue *et al.*[109]
Cassava foliage hay, molasses urea block, cassava root	Lactating goats	Increased milk yield and quality, growth rates of kids	Dung *et al.*[110]

commercial concentrate, a huge number of studies on untreated or treated rice straw diets supplementing with locally available by-products have been conducted around the world and recently reviewed elsewhere[6,97].

In Vietnam, a wide range of supplements have been used such as molasses, brewers' grains, cassava chips, green leaves, multi-nutrient blocks and other crop residues in ruminant diets with rice straw as a main forage. It is evident in Table 3 that the growth performance of animals and their product quality were considerably increased. LaiSind beef cattle dramatically increased their feed intake and growth rate when feeding rice straw diet supplemented with cassava roots and/or ground nut cake[96,102]. Protein-rich leaves (leucaena, cassava and mulberry) were commonly used to supplement into rice straw basal diet and had more benefits as indicated by an increased feed intake, live weight gain in beef cattle[100,106]; increased milk yield and quality in lactating goats[110], less consumption of commercial concentrate and other expensive protein sources and therefore an increased income[108,109]. The rice straw supplemented with molasses urea block increased both the nutritive values of the degradability of diets and the production performance of ruminants[99,107].

Although, there have already been numerous laboratory studies, *in sacco* experiments, on-station and on-farm trials in Vietnam, most of the research works have so far been conducted separately. There is still a lack of systematic research into straw treatment and supplementation from laboratory to production. The majority of studies recommended that suitable treatment techniques in combination with nutrient supplementation could result in improved utilisation of rice straw and better feeding value. However, the percentage of rice straw using as ruminant feed is really low and farmers usually feed untreated rice straw without supplements to animals. In this respect, future research should focus on optimisation of biological and economic effects of different treatments and supplement inputs including locally available sources to suggest the best or alternative solutions.

CONCLUSIONS AND FUTURE RECOMMENDATIONS

In Vietnam, ruminant production plays a crucial role but its further development is confronted with major issues related to forage because of the shortage of grazing land and grown grasses and the low quality of crop residues. Rice straw is the most abundant and sustainable source for ruminant feed in terms of volumes annually generated. However, the majority of rice straw has been burned on fields, only a small proportion is fed to ruminants.

Rice straw is typically poor and unbalanced in nutritive values high levels of lignification and silicification and low contents of crude protein and minerals. So feeding only rice straw to ruminants does not provide enough nutrients even for maintenance.

Although, numerous treatments have been employed to improve the utilisation of rice strawin ruminant production by increasing its degradability and voluntary intake. The practical use of single physical or chemical treatment in small-scale farms is still restricted in terms of costs, safety concerns and potentially negative environmental consequences. The question is arisen that what are the strategies which can be technically and socio-economically relevant and acceptable to farmers under local conditions. The use of fungus and exogenous enzyme treatments is expected to be a practical, cost-effective and environmental-friendly approach for enhancing the nutritive value and digestibility of rice straw. In addition, the application of ligninolytic fungi or their enzymes combined with locally available inputs such as urea and/or lime, protein-rich sources, nonstructural carbohydrates may be an alternative ways to shorten the period of the incubation times and/or decrease the amount of chemicals, effecting some synergy. It can be concluded that till date a difficulty in controlling optimal environmental conditions for fungal growth and alack of technology to produce large quantities of fungi or their enzymes are the main obstacles of biological treatments applied in small-scale farms. Further studies are needed on optimisation of biological and economic effects of different treatments and development in alternative enzyme production and fermentation technologies.

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