Role of White Rot Fungi as a Biological Treatment of Low Quality Animal Feeds: Review

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The shortage of feeds in general and protein in particular attract attention of many researchers to manipulate the unconventional sources of feeds. Crop residues are often referred to as ‘lignocellulosics’ as they are rich in cellulose which is bound with a biopolymer lignin which results in low digestibility, low protein content, high crude fiber and low palatability. Biological treatment of such crop residues using white rot fungi (WRF) can break the ligno-cellulose complexes, liberating free cellulose and thus enhancing their feeding value for ruminants. Biologically treated roughages have higher digestibility for most of the nutrients with an increase in crude protein content as compared to untreated material, besides ensuring more fermentable substrates in the rumen. Treatment of low quality animal feeds with white rot fungi species increases the protein and ash contents with a reduction of its fibrous components (NDF, ADF, ADL, cellulose and hemicelluloses). Treatment of feeds also increases feed intake, digestibility and ultimately animal performance in terms of growth and production either meat or milk. Nevertheless, its utilization may be hindered due to difficulties and lack of technology to produce large quantities of fungi or their enzymes. Loss of weight of the substrate is also a disadvantage of the technology. Dry matter (DM) losses of substrate can be as high as 40% in prolonged incubation with the fungus.

Key words: White Rot Fungi, Biological Treatment and Animal Feeds, ‘lignocellulosics’.

INTRODUCTION

The shortage of feeds in general and protein in particular attract attention of many researchers to manipulate the unconventional sources of feeds (Abdel-Azim et al., 2011). On the other hand, huge amounts of lignocellulostic wastes and residues, of agricultural, forest, industrial and domestic origin are generated annually. Such materials are comprised for the most part of cellulose, hemicellulose and lignin. Lignin is a main constituent of ADF, and is non digestible by ruminants and resistant to most of the microbial enzymatic systems as well. The presence of lignin and its hemicellulose binding matrix increases the unavailability of other energy-containing constituents present in the agricultural residues for the ruminants (Arora and Sharma 2009).

Clearly, the successful exploitation of the potential of lignocellulosic substances, as sources of animal or human feedstuffs or chemical feedstocks, requires that each of these polymers be utilized to the fullest extent possible (Colaço and Coughlan, 1990). The primary factors limit utilization of crop residues are low digestibility, low protein content, high crude fiber and low palatability. Their low digestibility due generally to the high fibrous contents consists mainly of 30-40% cellulose, 25-35% hemicelluloses and 10-15% lignin on DM base (Theander and Aman, 1984). Thus, to increase digestibility of crop residues, it is important to release the linkage between cellulose, hemicellulose and lignin or to modify the compact nature of these tissues, so that lignified tissue might separated from non-lignified one. There have been attempts to do that by mechanical, chemical or biological treatments (Shrestha et al., 2004; Mahmood and Rahman, 2008; Abedo et. al. 2009). For various reasons, including environmental considerations, biological rather than chemical conversion is the...
preferred route (Coliço and Coughlan, 1990). In recent years, much interest has been forwarded to develop new biotechniques for improving the nutritive value of lignocellulosic fibrous using biological treatment in solid substrate fermentation (SSF) under non-sterile conditions (Leopold et al., 2008).

Microorganisms such as the brown, white and soft-rot fungi have been used to breakdown lignin and hemi-cellulose in waste materials such as agricultural residues and even for cleaning of chemically uploaded textile waters (Seker et al., 2006). White rot fungi are known to degrade lignin to a great extent and at a fast pace when compared to any other group of organisms (de Koker et al., 2000). They are the only fungi that can take the complete lignin mineralization (Moore-Landecker , 1996). These organisms are also able of delignifying lignocellulosic substrate selectively, modifying or degrading the lignin and transforming the lignocellulose substrate of the decomposition to high quality feed for ruminants (Chaudhary, 1998), or utilizing the polysaccharides liberated by hydrolysis and fermentation, in order to produce fuels and other chemicals (Puniya and Singh, 1998). The fungi, which their life depends on lignocellulosic materials, are able to produce laccase, cellulase, xylanase and glucosidase enzymes to degrade lignocellulosic compounds and utilise the releasing sugars (Taniguchi et al., 2005).

Lignin-degrading fungi are ubiquitous. The most familiar are those that form mushrooms, brackets (conks) and other sporophores on decaying trees, wood, forest litter, and other lignocellulosics. These are fungi that cause the white-rot type of wood decay, and the closely related litter-decomposing fungi. The most vigorous lignin-degraders are white-rot wood decay fungi, which are mainly basidiomycetes. It is white-rot fungi that have been most intensively studied for bioremediation, and it is their lignin-degrading system that seems to be important in such application (Kirk et al., 1990). The objective of this paper was to review role of white rot fungi as a biological treatment of low quality animal feeds.

The white rot fungi

Fungi that are active in the biodegradation of wood can be classified into three main groups according to their methods of degrading biomass, specifically white-rot, brown-rot, and soft-rot fungi. White-rot and brown-rot fungi belong to Basidiomycetes, whereas soft-rot fungi belong to Ascomycetes (Hatakka, 2001). Brown-rot fungi preferentially attack cellulose and hemi-cellulose, leaving lignin intact, thus, decaying residue turning brown and causes only limited changes in lignin. These results in lower in vitro digestibility compared to untreated substrate (Mahesh and Mohini, 2013). Soft-rot fungi leave the attacked lignocellulosic material watery-soft and breaks down cellulose and hemicelluloses.

White-rot fungi, belonging to the wood-decaying basidiomycetes, as lignocellulolytic microorganisms are able to decompose and metabolize all plant cell constituents (cellulose, hemicellulose and lignin) by their enzymes (Eriksson et al., 1990). Many species of white-rot fungi which are effective lignin degraders have been used to assess their ability to improve the nutritive value of fodder for ruminant nutrition (Howard et al., 2003). Their extracellular lignin-modifying enzymes consist of lignin-peroxdase (LiP), manganese-dependent peroxidase (MnP), laccase (phenol oxidase) and H2O2-producing oxidase (aryl-alcohol oxidase; AAO and glyoxaloxidase) (Arora et al., 2002; Novotny et al., 2004; Arora and Gill, 2005; Lechner and Papinutti, 2006).

Some 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 straw thereby enhance digestibility (Fazaeli et al., 2006). The bio-conversion of straw is circumscribed to the group of white-rot fungi, which are capable to colonize on cereal straw and liberate water soluble substrates from the polymers during SSF and thus improve the digestibility (Fazaeli et al., 2003). Among the edible white-rot fungi, the Pleurotus species have been shown to be more efficient (Taniguchi et al., 2005). The potential of Pleurotus fungi such as P. ostreatus and P. eryngii to reduce indigestible cell wall components and increase the dry matter digestibility (DMD) of straw has been reported (Fazaeli et al., 2004). The Pleurotus fungi have different ability to grow on straw and decompose its structural carbohydrate because of the variation in culture behaviour and culturing conditions (Fazaeli et al., 2002).

Preparation and Conservation of Fungi

Fungal strains can be collected from the surrounding and maintained on solid media (for example Potato Dextrose Agar, Formedium, Hunstanton-UK) and stored at room temperature. The dose of application of fungus to feeds varies. Montañez-Valdez et al. (2015) added 250 g of the Pleurotus djamor strain to a 10kg of maize stover packed by polyethylene bag. The wheat grain spawn of two Pleurotus fungi including P. florida (PF) and P. ostreatus (PO), were used to inoculate the straw, at the rate of 3.5 kg spawn per 100 kg straw fresh weight basis (Fazaeli, 2007).

Application of Fungus to Low Quality Feeds

White rot fungi use enzymatic mechanisms to break down lignin, alter lignocellulose structures, and improve
Figure 1. White rot fungi

Figure 2. Location and arrangement of cellulose microfibrils in plant cell walls (Shaw, 2008)
the nutritive value of low quality feeds, which has been widely reported using rape straw (Tripathi et al., 2008), wheat straw (Tuyen et al., 2012), rice straw (Sharma and Arora, 2010), corn stover and sugarcane bagasse (Tuyen et al., 2013). The biodegradation of Bermuda grass stems was improved by 29-32%, after 6 weeks, using Ceriporiopsis subvermispora and by 63-77% using Cyathus stercoreus (Okano et al., 2005). Masayuki et al. (2005) reported three white rot fungi Pleurotus ostreatus, Phanerochaete chrysosporium and Trametes versicolor that cause 41, 21 and 37% lignin loss when grown on rice straw for 60 days at 25°C. Sirlene et al. (2002) reported white rot fungus Ceriporiopsis subvermispora caused higher loss of dry weight (32%) in bagasse when incubated for 30 days with 1% inoculum under solid state fermentation. Stropharia rugosoannulata and Pleurotus cornucopiae degraded wheat straw 60 to 65%; P. florida degraded 45% and A. aegerita degraded wheat straw up to 25% only in 17 weeks at 30°C incubation. P. chrysosporium when tested individually caused 26.45% weight loss of the substrate and 28.95% lignin loss when grown on wheat straw for six weeks, where as caused lignin loss upto 36% when combination of P. chrysosporium and D. flavida were used (Zadrazil and Brunnert, 1980).

**Chemical Composition of Fungal Treated Feeds**

Fungal treated straw contained higher CP, EE and ash contents and lower OM, CF, NFE, NDF, ADF, ADL, hemicellulose and cellulose contents than untreated straw. Fungal treatment of straw increased crude protein from 3.20 to 11.62% (El-Rahman et al., 2014). Treatment of rice straw by *P. pulmonarius* increases CP contents from 4.50% recorded in the control to 4.60% at day 10, 4.78% at day 20 and 9.36% after forty days of fermentation (Jonathan et al., 2012). Biological treatment of mixed straw (wheat and cotton) by three strains of fungus: Pleurotus Ostreatus, Pleurotus Cornicopia and Pleurotus Salmoneo, degraded 52.1%, 59.3% and 39.4% lignin and improved in vitro organic matter digestibility from 33.0% to 60.1%, 51.9% and 50.6%, respectively (Yosef et al., 2011). Corn stover inoculated with 15% *Trichoderma viride* and incubated for 21 days had increased protein from 6.52% to 10.28%, but decreased NDF from 64.27% to 55.39%, ADF from 44.49% to 37.77%, hemicellulose from 19.78 to 18.02% (Islamiyati et al., 2013). Fungal treatment of rice straw decreased crude fibre from 32.89 % in control to 19.96 % (Akinfemi and Ogunwole, 2012). The crude protein of cacao shell inoculated with *P. chrysosporium* and incubated for 15 days increased from 8.57% to 11.52%, with decreased crude fiber from 44.21% to 29.94%, and increase ash content from 6.79% to 7.12%. The increased protein content was due to bioconversion of organic materials that had been broken down into one of the fungi body components or due to the addition of microbial protein during fermentation process (Belewu, 2008). Bagasse inoculated with *Trichoderma viride* has an increase in protein, cellulose, hemicellulose, and ash content, and decrease in ADF, NDF, and acid detergent lignin (ADL) content (Azim et al., 2011).

The nutritive value of rice straw treated with *Pleurotus ostreatus* (POR), *Pleurotus pulmonarius* (PPR) and *Pleurotus tuber-regium* (PTR) were studied by Akinfemi and Ogunwole (2012) and the result is indicated in table 1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Control</th>
<th>POR</th>
<th>PPR</th>
<th>PTR</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter</td>
<td>93.00a</td>
<td>86.75b</td>
<td>84.21c</td>
<td>86.00b</td>
<td>0.03</td>
</tr>
<tr>
<td>Crude protein</td>
<td>4.69b</td>
<td>7.39a</td>
<td>7.18a</td>
<td>7.69a</td>
<td>0.12</td>
</tr>
<tr>
<td>Crude fibre</td>
<td>32.89a</td>
<td>20.96b</td>
<td>21.59b</td>
<td>19.96c</td>
<td>0.17</td>
</tr>
<tr>
<td>Ether extract</td>
<td>1.66b</td>
<td>2.09a</td>
<td>2.13a</td>
<td>2.33c</td>
<td>0.07</td>
</tr>
<tr>
<td>Ash</td>
<td>11.95a</td>
<td>8.26d</td>
<td>8.31c</td>
<td>9.26b</td>
<td>0.003</td>
</tr>
<tr>
<td>Nitrogen free extract</td>
<td>48.81b</td>
<td>61.30a</td>
<td>60.79a</td>
<td>61.38a</td>
<td>0.13</td>
</tr>
<tr>
<td>Neutral detergent fibre</td>
<td>69.96a</td>
<td>61.67c</td>
<td>62.79b</td>
<td>61.38d</td>
<td>0.003</td>
</tr>
<tr>
<td>Acid detergent fibre</td>
<td>56.28a</td>
<td>48.12c</td>
<td>49.78b</td>
<td>47.12d</td>
<td>0.003</td>
</tr>
<tr>
<td>Acid detergent lignin</td>
<td>12.54a</td>
<td>10.06c</td>
<td>10.15b</td>
<td>9.68d</td>
<td>0.003</td>
</tr>
<tr>
<td>Cellulose</td>
<td>43.74a</td>
<td>38.06c</td>
<td>39.63b</td>
<td>37.44d</td>
<td>0.005</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>13.68b</td>
<td>13.55c</td>
<td>13.01d</td>
<td>14.26a</td>
<td>0.005</td>
</tr>
<tr>
<td>OM</td>
<td>93.00a</td>
<td>86.75b</td>
<td>84.21c</td>
<td>86.00b</td>
<td>0.03</td>
</tr>
<tr>
<td>CF</td>
<td>32.89a</td>
<td>20.96b</td>
<td>21.59b</td>
<td>19.96c</td>
<td>0.17</td>
</tr>
<tr>
<td>NDF</td>
<td>1.66b</td>
<td>2.09a</td>
<td>2.13a</td>
<td>2.33c</td>
<td>0.07</td>
</tr>
<tr>
<td>ADF</td>
<td>11.95a</td>
<td>8.26d</td>
<td>8.31c</td>
<td>9.26b</td>
<td>0.003</td>
</tr>
<tr>
<td>ADL</td>
<td>48.81b</td>
<td>61.30a</td>
<td>60.79a</td>
<td>61.38a</td>
<td>0.13</td>
</tr>
</tbody>
</table>
| Components (g/kg-1 DM) of fungal treated rice straw.

Row means with different superscripts differ significantly at (P<0.05), n=3; POR = Pleurotus ostreatus treated rice straw, PPR = Pleurotus pulmonarius treated rice straw, PTR = Pleurotus tuber-regium treated rice straw, SEM = Standard error of mean
Table 2. Estimated organic matter digestibility (OMD), short chain fatty acid (SCFA) and metabolisable energy (ME) of fungal treated rice straw

<table>
<thead>
<tr>
<th>Component</th>
<th>Control</th>
<th>POR</th>
<th>PPR</th>
<th>PTR</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME (MJ.kg⁻¹ DM)</td>
<td>6.49d</td>
<td>7.54a</td>
<td>7.14b</td>
<td>6.86c</td>
<td>0.05</td>
</tr>
<tr>
<td>SCFA (µM)</td>
<td>0.657d</td>
<td>0.0848a</td>
<td>0.776a</td>
<td>0.729c</td>
<td>0.01</td>
</tr>
<tr>
<td>OMD (%)</td>
<td>51.17c</td>
<td>57.02a</td>
<td>54.32b</td>
<td>52.62c</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Row means with different superscripts differ significantly at (P<0.05), n=3; POR = Pleurotus ostreatus treated rice straw, PPR = Pleurotus pulmonarius treated rice straw, PTR = Pleurotus tuber-reguim treated rice straw, SEM = Standard error of mean.

Source: Akinfemi and Ogunwole (2012)

Table 3. The mean DM and OM digestibilities and feed efficiency for feeds containing fungal treated rice straw in sheep

<table>
<thead>
<tr>
<th>Parameter</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMD</td>
<td>65.96b</td>
<td>64.30b</td>
<td>67.14b</td>
<td>44.21a</td>
</tr>
<tr>
<td>OMD</td>
<td>67.07b</td>
<td>66.44b</td>
<td>65.92b</td>
<td>39.65a</td>
</tr>
<tr>
<td>Daily Weight Gain (g/h/d)</td>
<td>52.78</td>
<td>50.00</td>
<td>55.56</td>
<td>9.67</td>
</tr>
<tr>
<td>Efficiency of feed</td>
<td>0.09</td>
<td>0.10</td>
<td>0.15</td>
<td>0.04</td>
</tr>
</tbody>
</table>

a,b Means followed by different superscript at similar row were significantly different (P <0.05). R1 (100% Elephant grass), R2 (70% Elephant grass + 30% fermented Rice Straw), R3 (30% Elephant grass + 70% Fermented rice Straw Fermentation) and R4 (100% Fermented Rice Straw).

Source: Mustabi et al., 2013,

fungal-treated rice straw reduced the NDF and ADF content from 79.54 to 74.02% for NDF and 63.69 to 59.74% for ADF, respectively indicating the beneficial effect of EM in reducing hemicelluloses and cellulose content of rice straw. Ramirez-Bribiesca et al. (2010) reported that P. ostreatus treatment for 15 days on corn straw increased crude protein (39.5%) and soluble protein (165%), soluble carbohydrates (621%), ash (188.32%) and decreased neutral detergent fibre (14.5%). Shrivastava et al. (2011) also reported significant decrease in cell wall constituents like ADF, NDF, hemicelluloses, lignin and cellulose to the extent of 35.00, 38.88, 45.00, 37.48 and 37.86%, respectively in P. ostreatus fermented straw, while 30.04, 33.85, 39.90, 31.29 and 34%, respectively in T. versicolor fermented straw. Adenipekun and Dada (2013), carried out studies on the degradation of cotton waste, rice straw and cocoa pod husks using Pleurotus pulmonarius in cultures incubated for 0-60 days. Crude protein increased significantly throughout the incubation period from 1.27% in the control to 12.63% in cotton waste, 6.65% to 14.82% in rice straw and in cocoa pod husk from 39.88% to 34.95% respectively but an increase was observed in rice straw from 18.42% in control to 28.08% after 60days of incubation period.

Effect Fungal Treated Feeds on Intake and Animal Performance

Feed Intake and Digestibility

Calves fed ration contained fungal treated straw had higher in all nutrients digestibility (El-Rahman et al., 2014). Akinfemi and Ogunwole (2012), point out that fungal treatment of rice straw not only improved the CP contents but also enhanced digestibility. Fungal treated rice straw have a good potential as feed resources for ruminant animals and could be used in combination with other feedstuffs. Karunananda et al. (1995) reported the effect of incubation of rice straw for 30 days with three white-rot fungi, showing that Pleurotus sajor-caju enhanced IVDMD, in both leaves and stems of rice. Intake and digestibility of DM and OM was increased by more than 10% in cattle consuming fungal treated wheat straw diet (Fazaeli et al., 2002) and palm leaves treated with Pleurotus florida for sheep (Kabirifard et al., 2007).

Safa et al. (2011), studied the effect of solid state fermentation by Trichoderma Viride on nutritive values rice straw (RS) and corn stalks (CS). Total feed intake and total dry mater (TDM) of rations containing either treated rice straw or treated corn straw were higher than intake of either untreated rice straw or untreated corn straw.
The digestibility of DM and OM were 34.8 and 35.0%, respectively, in the initial straw, whereas there were 45.2 and 44.8% in FTWS; 41.0 and 41.5% in SPWS respectively (Fazaeli, 2007).

Effect on Performances of Animals

Majority of the animal trials on utilization of fungal treated crop residues reported a positive response in terms of nutrient utilization, nitrogen (N) balance as well as gain in body weight (Fazaeli et al., 2002; Mahesh, 2012; Omer et al., 2012) although it is not consistent with all types of white rot fungi. Intake and digestibility of DM and OM was increased by more than 10% in cattle consuming fungal treated wheat straw diet (Fazaeli et al., 2002) and palm leaves treated with Pleurotus florida for sheep (Kabirifard et al., 2007). Ramirez-Bribiesca et al. (2010) evaluated the influence of P. ostreatus spent corn straw on the performance of feedlot lambs and found that average daily gain (ADG) increased to 17.5% in treatment group which received 9% of pro-farming straw from P. ostreatus. A significantly increased DM intake and growth rates were noted by Akinfemi and Ladipo (2011) in West African dwarf lambs fed with biologically treated maize cobs replacing wheat offal in guinea grass (Panicum maximum) based diets. Omer et al. (2012) had shown that biologically treated corn stalks (using Trichoderma reesei) can completely replace clover hay in the ration of growing sheep which was evident by a favourable increase in DM intake, and an improvement in the digestibility of all nutrients with higher ADG. Inclusion of fungal treated straw up to 30% of the total mixed ration in late lactating Holstein cows improved the nutrients digestibility and also noted an increase in fat corrected milk yield by 13% and daily average body weight gain by 2.7 times (Fazaeli et al., 2004).

Mahesh (2012) observed a linear reduction in CH4 (%) from fungal treated wheat straws which contained lesser fibre fractions (NDF and ADF) than untreated straw. Enteric CH4 emissions are highest when the animal is fed with poor quality forages. Thus, by fungal treatment, an improvement in the forage quality with respect to cell wall digestion and overall enhancement in carbohydrates digestibility as well as increased DM intake will be expected to reduce the CH4 emissions relative to nutrients digestibility, in ruminants (Mahesh, 2012). Safa et al. (2011), also reported positive effects of solid state fermentation on rice straw (RS) and corn stalks (CS)by Trichoderma Viride in terms of feed intake and body weight gain by sheep. The improvement in daily gain as a result of adding biological treatments may be due to its effect on microbial efficiency and organic matter digestibility.

Ibrahim (2001) found that the chemical and biological treatments of rice straw and corn stalks decreased the cost of feeds used to produce one kg live body weight gain by 15.54 and 16.82% for rations including corn stalks, respectively. Abd El-Rahman (2014) studied the effect of Phanerochaete chrysoporium treatment on nutritional value of rice straw in which chopped rice straw was treated with fungi under aerobic condition 14 days as fermentation period. The treated straw were fed to calves with concentrate mixture and found that addition of treated straw in growing calves ration, improved nutrient digestibility, body weight gain and economic efficiency. The DMI as (kg/h/d) of calves was insignificant higher for calves fed treated than those fed untreated rice straw (8.96 vs. 9.10 kg/h/d), respectively. The feed conversion (kg DM/kg gain) showed that the fungus treatment of rice straw recorded the best value (6.87) compared to untreated rice straw (7.16). Rice straw that has been fermented using white rot fungi can be used to substitute elephant grass up to 70% in the ration of goats (Mustabi et al., 2013).

The average body weights gain of cows fed with fungal (Pleurotus ostreatus) treated wheat straw in a total mixed ration was 743 g per day (Fazaeli et al., 2004).

Factors affecting broader utilization of fungal treatments

The use of fungi and/or their enzymes that metabolize lignocelluloses is a potential biological treatment to improve the nutritional value of straw by selective delignification (Sarnklong et al., 2010). Nevertheless, its utilization may be hindered due to difficulties and lack of technology to produce large quantities of fungi or their enzymes to meet the requirements particularly in developing countries. There are also a number of serious problems to consider and overcome. Fungi may produce toxic substances. It is also difficult to control the optimal conditions for fungal growth, such as pH, temperature, pressure, O2 and CO2 concentration when treating the fodder. With recent developments in fermentation technology and alternative enzyme production system, the costs of these materials are expected to decline in the future. Hence, new commercial products could play important roles in future ruminant production systems (Beauchemin et al., 2004). The effect of white rot fungi on the lignocellulose matrix is a complex phenomenon controlled by many variables and their interactions.

Loss of substrate dry matter

Loss of weight of the substrate is one disadvantage of fungal treatments of low quality feeds. Dry matter (DM)
Table 4. Mean values of feed intake and growth performance of treated rice straw and corn stalk with Trichoderma Viride

<table>
<thead>
<tr>
<th>Item</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total feed intake(g)</td>
<td>1434</td>
<td>1447</td>
<td>1364</td>
<td>1470</td>
<td>-</td>
</tr>
<tr>
<td>Crud protein intake(g)</td>
<td>175</td>
<td>208</td>
<td>172</td>
<td>220</td>
<td>-</td>
</tr>
<tr>
<td>Average daily gain (g)</td>
<td>129.80</td>
<td>141.60</td>
<td>126.60</td>
<td>156.60</td>
<td>9.97</td>
</tr>
</tbody>
</table>

T1=concentrate feed mixture (CFM) plus ad lib untreated rice straw, T2 concentrate feed mixture (CFM) plus fungal treated rice straw, T3= concentrate feed mixture (CFM) plus ad lib untreated corn straw, T4= concentrate feed mixture plus fungal treated corn stover.

Source: Safa et al. (2011)

losses varied widely from 6 to 40% depending on the organism used, duration of fermentation, type of substrate and environmental conditions (Agosin and Odier, 1985). Jonathan et al. (2012) reported that dry matter reduced significantly from 88.74% in control to 86.80% in Lentinus subnudus and 86.55% in Pleurotus tuber-regium treatments. Weight loss caused by Oxyporus latemarginatus and Rigidoporus vinctus fungi were reported to be 27.6%, and 13.7% respectively (Mohamed et al., 2013). High degradation rate of wheat straw was observed with the fungus D. quercina, which achieved a 43% loss of dry matter after 30-day incubation (Dusan et al., 1997). SSF for a period of 6-8 days has been recommended as the maximum time of fermentation in order to reduce DM loss (Owen et al., 2012).

Temperature and humidity

In a typical WRF pre-treatment procedure, incubated temperature ranges from 25 to 35oS, which are mild and optimum for WRF growth, but far below the temperature applied in chemical and physiochemical pre-treatments. Fungal primary growth and secondary metabolism require appropriate moisture in biomass (Shi et al., 2008). In previous work, 60–90 % moisture usually served as the inchoative humidity. It was revealed that insufficient humidity in biomass may even cause fungal death, whereas excess moisture inhibits fungal growth, especially in the deep layers with little air and mycelia. Heat removal and respiration of mycelia may lead to an uneven distribution of water in the system as a result of water evaporation (Nigam and Pandey, 2009)

SUMMARY AND CONCLUSION

Biological pre-treatment using various types of rot fungi is a process that does not require high energy for lignin removal from a lignocellulose biomass, despite extensive lignin degradation. Biological pre-treatments are safe, environmentally friendly and less energy intensive compared to other pre-treatment methods. Biologically treated roughages have higher digestibility for most of the nutrients (both cell walls and cell solubles) with an increase in crude protein content as compared to untreated material, besides ensuring more fermentable substrates in the rumen.

Although several treatments have been used to improve the degradability and voluntary intake of rice straw, such as physical or chemical treatments, the practical use of these treatments is still restricted in terms of safety concerns, costs and potentially negative environmental consequences. Using ligninolytic fungi, including their enzymes, may be one potential alternative to provide a more practical and environmental-friendly approach for enhancing the nutritive value of rice straw. The cost of exogenous enzymes is at present too high to be applied by smallholder farms, but this may change in the future. Moreover, the application of ligninolytic fungi or their enzymes combined with chemical pre-treatments to rice straw may be an alternative way to shorten the period of the incubation times and (or) decrease the amount of chemicals, effecting some synergy.

The most desirable situation would be that the mushrooms of the fungi are edible and can be harvested by farmers, after which the remaining straw can be fed to their herd. There are some edible white-rot fungi, like Pleurotus ostreatus. Suitable white-rot species have to be identified and breeding programs will possibly be needed to improve their characteristics. Also, the optimal conditions to incubate straw with a fungus have to be investigated, not only with the purpose of harvesting quality mushrooms, but also achieving optimal feeding quality of the remaining straw-fungi mixture. To achieve optimal feed qualities of the straw, incubations with fungi in combination with other treatments, such as physical and chemical treatments, have to be investigated.

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