Nutritive Value of Wheat Straw Treated with *Pleurotus* Fungi

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ABSTRACT : Soaked and pasteurised wheat straw was inoculated with five species of *Pleurotus* fungi (coded P-21, P-30, P-41, P-60 and P-90), packed in polyethylene bags and incubated in a fermentation chamber for 21 days. The chemical composition, *in vitro* digestibility and *in sacco* degradability of the treated and untreated straw were estimated using a complete randomised design consisting of six treatments and four replicates. In a feeding trial, *in vivo* digestibility and voluntary intake were determined in bulls, using a 3×3 change over design. Dietary treatments were: 1) untreated wheat straw (UWS) as control; 2) fungal treated (P-41) wheat straw before mushroom formation (FTWS); 3) spent wheat straw (SPWS) after mushrooms were harvested. Apart from P-90, fungal treatment significantly ($p<0.05$) increased the crude protein (CP) and reduced the cell wall components of the straw. The *in vitro* dry mater and organic mater digestibility significantly ($p<0.05$) increased in the treated straw particularly with the treatments of P-41 and P-60. The *in situ* degradability and *in vivo* digestibility of DM and OM were significantly ($p<0.05$) increased in treated straws with the highest values observed for treatment P-41. The intake of DM, OM and digestible organic mater (DOM) were significantly ($p<0.05$) increased in cows fed FTWS. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 12 : 1681-1688)***

Key Words : Fungal Treatment, Wheat Straw, Nutritive Value, *Pleurotus*

INTRODUCTION

In order to break down the lignocellulosic bond of straw the various methods that could increase its nutritive value, physical and chemical processing have been studied (Matsuzaki et al., 1994; Rahal et al., 1997). Although these methods have advantages, they are costly, low in effectiveness, not environmentally friendly and also require application of technology (Leng, 1991; Sharma et al., 1993). These factors limit their application, particularly at small farm levels.

Recently, biological delignification of straw by solid-state fermentation (SSF) has been considered because of its capacity to remove lignin preferentially (Moyson and Verachtert, 1991). Fungal treatment could be an approach to convert low quality wheat straw into a higher quality of ruminant feed (Arora et al., 1994; Zadrazil et al., 1997). Attempts had been made to identify species of white-rot fungi for their ability to grow on straws that improved their nutritive value (Yamakawa et al., 1992).

During the SSF of wheat straw by fungi, its organic mater (OM) and detergent fibre content could be reduced and the lignin selectively removed from the lignocellulosic complex (Singh et al., 1990; Kundu, 1994). The crude protein (CP) and ash were also increased in the treated straw (Moyson and Verachtert, 1991). Such changes were dependent on the strain of fungi and the cultural conditions (Tripathi and Yadav, 1991).

Among the edible white-rot fungi, the *Pleurotus* species have been shown to be more efficient (Zadrazil et al., 1996). The potential of some species of *Pleurotus* fungi such as *P. ostreatus* and *P. eryngii* to reduce indigestible cell wall components and increase dry mater digestibility (DMD) of straw has been reported (Agosin et al., 1986; Singh et al., 1990). Some strains of *P. ostreatus* increased *in vitro* digestibility of wheat straw up to 25.5 unit percent while some others decreased the digestibility by 13.8 unit percent (Zadrazil, 1997).

Utilisation of cereal straw treated with white-rot fungi as animal feed was studied by several workers, (Moyson and Verachtert, 1991; Fazeli et al., 2002; Fazeli et al., 2004). Jalc et al. (1998) noted that *in vitro* dry mater digestibility (IVDMD) of wheat straw increased from 7 to 10 unit percent when treated with *Pleurotus* fungi for a 30 day fermentation period. Calzada et al. (1987) found that during 30 days SSF of wheat straw by *P. ostreatus*, the lignin content decreased significantly and IVDMD increased from 14.3 to 29.5%. Karunanandaa and Varga (1996) reported that treating rice straw with *Cyathus stercoreus* in 30 days of SSF increased the apparent digestion of DM (44 vs. 35.1%) and OM (50.6 vs. 41.5%).

Due to the existence of many species and strains of fungi in nature and their possible different effects on the nutritive value of the substrates, there is an increased research interest on the characteristics of the species and strains including the ability of their growth on the straw and their effects the nutritive value of the straw. This study was

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conducted to assess the effect of five *Pleurotus* fungi on chemical composition, degradability and *in vitro* digestibility of wheat straw. Secondly, voluntary intakes and digestibilities of fungal treated wheat straw before and after the mushroom harvested, were compared by *in vivo* feeding trial.

MATERIALS AND METHODS

Experiment I

Treatment of wheat straw : Wheat straw was chopped into 5-10 cm length, packed in cotton bags (30×45 cm) and soaked in tap water for 24 h then pasteurised at 100°C for one hour. The pasteurised straws were inoculated with spawns (at a rate of 4% w/w) of five species of *Pleurotus* fungi (coded: P-21, P-30, P-41, P-60 and P-90) and re-packed in plastic bags (30×45 cm). The bags incubated in the fermentation chamber where temperature was automatically adjusted to 25°C and relative humidity was kept at 78±5% by spraying water. After 21 days of incubation, the straws were removed from the fermentation chamber allowed to dry by spreading on newspaper. The air-dried straws were milled through of 3 mm-sieved and stored at room temperature.

Chemical analyses : Sub-sample (about 20 g) were taken from each experimental unit and milled, through 1 mm sieve. Dry mater of air-dry samples was determined in 105°C for 48 h and the final DM of biomass were calculated through two-stage DM determination. Organic mater was measured by ashing the samples at 500°C for 4 h. Crude protein was analysed, by Kejltek Auto 1030 analyser (N×6.25), Swedish Tecator Company made, and crude fibre (CF) was determined according to the method represented in AOAC (1990). Cell wall component including neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined by using the methods of Van Soest et al. (1991). Acid detergent lignin (ADL) was measured according to AOAC (1990).

In vitro digestibility : Dry mater digestibility and OMD of samples were determined *in vitro* using acid pepsin two-stage method (Tilley and Terry, 1963) in which, 0.5 g of samples were placed into 100 ml flasks, then 50 ml of rumen fluid and buffer solution mixture were added into the flasks, fited with the Benson valves and incubated at 38°C for 48 h. In the second stage, the samples incubated with acid pepsin solutation for another 48 h. The rumen fluid was collected from rumen fistulated cattles that were fed wheat straw-based diet.

In sacco degradability : Solubility and degradability *in sacco* of DM, OM and ADF were conducted using four mature cattle fitted with rumen cannula. The animals were fed at maintenance level wheat straw-based diet, alfalfa hay and concentrate in the DM ratio of 70:15:15. Duplicate bags containing approximately 3 g of each sample were incubated at 0, 6, 12, 24, 48, 72 and 96 h. Bags were removed, washed and dried according to the procedure of Ørskov et al. (1980). Data obtained were fitted to the equation $P=a+b\ (1-e^{-ct})$ (Kibon and Ørskov, 1993).

Where:
a = soluble fraction.
b = not soluble but fermentable.
a+b = potential degradability.
p = effective degradability (outflow rate of 0.02/h).
c = constant rate. l = lag time.

Statistical analysis : The data obtained were analysed according to the complete randomised design model consisting of five treatments (fungi) plus one control and four replicates, using of SAS (1992) and tested with Duncans multiple range tes.

Experiment II

Treating wheat straw : Wheat straw was soaked for 24 h in tap water contained in concrete pool of size 0.6×1×8 m depth, width and length, respectively. For pasteurisation, the soaked straw was packed inside steel barrels (60 kg of soaked straw per 220 liter barrel) containing approximately 20 L of tap water at the bottom and generated for 1 h by heating the barrel at 100°C. Wheat grain spawn of *Pleurotus* (coded P-41, selected from experiment I) was used to inoculate the straw at a rate of 4 kg spawn per 100 kg straw (fresh weight basis). Then, the inoculated straw was packed in the polyethylene bags (65 cm length and 40 cm diameter and 100 gauge thickness and transferred to the fermentation chamber (10×20×3.5 m) where the temperature was maintained at a 25±3°C using automatic electric air condition and relative humidity at 80±5% by daily sprinkling of water inside the room.

After one week of incubation, when the mycelial running started, all sides of the bags were crashed, to provide an aeration that was necessary during the fruiting body formation. After three weeks of spawning and before mushroom fruiting body formation, half of the bags were removed from the fermentation room and dried under sun. The remaining bags were collected after seven weeks of fermentation when the mushroom was harvested two times. All treated straws were dried and chopped into 3-6 cm length.

Experimental design : A 3×3 change over design method consisted of three treatments and three time period was conducted, using three fistulated native bulls weighing about 300-350 kg. The treatments were; 1) untreated wheat straw (UWS), 2) fungal treated wheat straw before formation of mushroom (FTWS) and 3) fungal treated wheat straw after harvesting of mushroom i.e. spent wheat

Table 1. Chemical composition and *in vitro* digestibility of fungal treated straw (% of DM basis)

Item	Treatments						SEM (n=24)
	Control	P-21	P-30	P-41	P-60	P-90	
DM	27.1^{b}	29.7^{ab}	29.0^{ab}	30.0^{ab}	29.6^{ab}	31.6^{a}	1.39
OM	95.1^{a}	95.2^{a}	95.2^{a}	93.2^{b}	94.4^{ab}	94.9^{a}	0.33
ASH	4.9^{b}	4.8^{b}	4.8^{b}	6.8^{a}	5.6^{ab}	5.1^{b}	0.33
CP	1.7^{c}	3.0^{b}	3.0^{b}	3.5^{a}	3.4^{a}	2.7^{b}	0.36
NDF	83.5^{a}	77.0^{b}	76.0^{bc}	73.7^{c}	75.9^{c}	81.3^{ab}	0.83
ADF	62.8^{a}	56.5^{b}	56.6^{c}	55.0^{c}	56.4^{c}	59.9^{ab}	1.04
ADL	8.0^{a}	7.2^{b}	7.3^{b}	7.4^{b}	7.5^{b}	8.0^{a}	0.40
CL	54.8^{a}	50.3^{b}	49.4^{cd}	48.3^{d}	48.9^{d}	50.0^{bc}	1.07
HCL	20.7^{a}	18.5^{c}	19.4^{bc}	18.7^{c}	19.5^{bc}	20.3^{ab}	1.36
IVDMD	28.1^{c}	37.0^{b}	38.4^{ab}	40.3^{a}	40.6^{a}	-	2.21 (n=20)
IVOMD	27.5^{c}	36.8^{b}	38.2^{ab}	40.2^{a}	40.3^{a}		2.07 (n=20)

Means with the different superscripts within row are significantly ($p<0.05$) different.
SEM: Standard error of mean. CL: Cellulose. HCL: Hemi cellulose.
P-21=*Pleurotus eringi*. P-30=*P. eringi*×*P. local*. P-41=*Pleurotus florida*.
P-60=*Pleurotus* spp. (collected from local area). P-90=*Pleurotus* spp. (collected from local area).

straw (SPWS). Data obtained were analysed for parametric statistics, including analysis of variance using the general linear model procedure of SAS (1992).

$$Y_{ijk} = \mu+P_i+T_j+C_k+E_{ijk}$$

Y_{ijk} = response of cow k in treatment j of period i
μ = overall sample mean
P_i = period i effect
T_j = treatment j effect
C_k = cow k effect
E_{ijk} = ordinary least squares residual error

Feed intake and digestibility : The animals were fed the experimental diet (UWS, FTWS or SPWS) *ad libitum* with 500 g of concentrate supplement composed of ground barley, wheat bran, cottonseed meal and mineral supplement. Each change over period consisted of two weeks for adaptation and one week for measurement. Daily feed intake and residuals were measured and sampled during the collection period. Faeces from individual cows were collected and weighed every morning and sub-sampled. At the end of each collection period, the samples of feeds and residuals were dried at 65°C for 48 h and faeces were dried at 65°C until the weight was constant. The dried samples were ground through 1 mm screen. Aliquots of the samples from each day were pooled and analysed chemically as described in experiment I.

RESULTS

Experiment I

Chemical composition : Table 1 shows the chemical composition of treated and untreated wheat straw. Fungal treatment had significantly ($p<0.05$) increased the CP content of straw, but among the treatments, CP was higher for P-41 and P-60 (3.5 and 3.4%, respectively) compared to P-21 (3%), P-30 (3%) and P-90 (2.7%). Except P-90, all treatments significantly ($p<0.05$) reduced NDF and ADF contents of the straw. However, the ability of the fungi to degrade these components varied among the cultures. Cultures of P-21 showed significantly ($p<0.05$) lower ability than the others to degrade the NDF and ADF contents. Apart from P-90, other treatments have significantly ($p<0.05$) decreased the ADL content of the straw. Fungal treatment also significantly ($p<0.05$) reduced the concentration of cellulose and hemi-cellulose. Among the treatments, wheat straw treated with P-41 and P-60 had the lowest cellulose content while the hemi-cellulose content was lower in the straw treated with P-21 and P-41.

In vitro digestibility : Treatment P-90 was excluded from the *in vitro* digestibility and *in sacco* degradability studies due to its non-significance effect on the ADL content of the straw. Therefore, four *Pleurotus* fungi were evaluated for their potential to improve digestibility of wheat straw (Table 1). Effect of the treatments on IVDMD and IVOMD of the straw were significantly ($p<0.05$) greater than those of control. In comparison to the untreated straw, the straws incubated with all species of fungi showed significant ($p<0.05$) increase in IVDMD and IVOMD. The Duncan comparison test indicated that wheat straw treated with P-41 and P-60 had significantly ($p<0.05$) higher digestibility than the straw treated with P-21.

In sacco degradability : The DM degradability of FTWS was significantly ($p<0.05$) different at various times of incubation in the rumen (Table 2). The lowest degradability was shown in untreated straw at all incubation times. Among the fungal treatments, DM degradability at 24 h was highest in the straw treated with P-41. On the other hand, at 48 and 72 h incubation, the straw treated with P-21 showed the lowest DM degradability than the others. However, straw treated with P-41 and P-21 showed the

Table 2. Degradability (%) of DM at different incubation times and ADF degradation of treated straw at 48 h incubation

Incubation time (h)	Treatments					SEM (n=20)
	Control	P-21	P-30	P-41	P-60	
0	4[d]	15[ab]	12[bc]	11[c]	17[a]	2.3
6	10[c]	21[a]	20[a]	18[b]	20[a]	0.9
12	13[c]	26[b]	31[a]	27[b]	29[ab]	1.6
24	18[c]	32[ab]	31[b]	35[a]	30[b]	1.0
48	33[c]	46[b]	49[a]	51[a]	50[a]	2.8
72	38[c]	49[b]	52[ab]	57[a]	53[ab]	2.7
96	42[d]	50[c]	55[b]	60[a]	56[b]	3.0
ADF[1] degradation	22[d]	30[c]	41[b]	46[a]	42[b]	1.3

Means with the different superscripts within a row are significantly ($p<0.05$) different.
SEM: Standard error of mean.
[1] Degradability of ADF measured at 48 h of incubation.
P-21=*Pleurotus eringi*. P-30=*P. eringi*×*P. local.*
P-41=*Pleurotus florida*. P-60=*Pleurotus* spp. (collected from local area).

Table 4. *In vivo* digestibility and voluntary intake of fungal treated and untreated straw

Item	Treatments			SEM (n=12)
	UWS	FTWS	SPWS	
DMD (%)	34.8[b]	46.8[a]	45.0[a]	1.12
OMD (%)	33.8[b]	44.8[a]	44.3[a]	2.00
GED (%)	31.7[c]	45.4[a]	43.2[b]	1.15
DMI (kg/d)	4.26[b]	5.44[a]	4.84[ab]	0.57
OMI (kg/d)	3.90[b]	4.79[a]	4.28[ab]	0.51
DOMI (kg/d)	1.31[b]	2.15[a]	1.91[a]	0.21
DMI (g/kg $BW^{0.75}$)	62.9[b]	80.2[a]	71.6[ab]	8.38
OMI (g/kg $BW^{0.75}$)	57.5[b]	70.8[a]	63.1[ab]	7.54
DOMI (g/kg $BW^{0.75}$)	19.4[b]	31.7[a]	28.2[a]	3.14

Means with the different superscripts within a row are significantly ($p<0.05$) different.
UWS: Untreated wheat straw.
FTWS: Fungal treated wheat straw (before mushroom formation).
SPWS: Spent wheat straw (treated straw after harvesting of mushroom).
SEM: Standard error of mean.

highest and lowest degradability, respectively at 96 h of incubation.

The degradability of ADF at 48 h, was significantly ($p<0.05$) higher in fungal treated straw as compared to the control. Comparing the species of fungi, P-41 and P-21 resulted in the highest and the lowest degradability of ADF, respectively.

Table 3 shows the degradability parameters of the DM obtained from the fitted values. In comparison to the untreated straw, fungal treatment had a significantly ($p<0.05$) higher degradability of DM for all parameters (A, B, C, A+B and P). The (a) value for treatment P-41 was significantly ($p<0.05$) higher than that of the other treatments. On the other hand, the (a) value for P-21 was significantly lower than the others. The (b) value and the potential degradation (a+b) constants of P-41 (48.6 and 68.6%, respectively) were significantly ($p<0.05$) higher than those of P-21, P-30 and P-60 treatments. However, with exception to the treatment P-21, effective degradability (P) was not significantly ($p>0.05$) different among the treatments.

Experiment II

In vivo digestibility : Total tract digestibility of DM and OM were significantly ($p<0.05$) higher in FTWS and SPWS than UWS (Table 4). The digestibilities of DM and OM were 34.8 and 33.8%, respectively, in the initial straw whereas there were 46.8 and 44.8; in FTWS and 45.0 and 44.3 in SPWS, respectively. The digestibility of gross energy (GE) was also significantly ($p<0.05$) different among the treatments.

Nutrient intake : Daily consumption of DM, OM and DOMI (kg/d or g/kg $BW^{0.75}$) of fungal treated straw by cows were significantly ($p<0.05$) increased. The DOMI was also higher in cows fed treated straw than untreated straw (Table 4). The highest amount of DM, OM and DOM intake were obtained in cows fed FTWS and the lowest were observed in those fed UWS (5.44, 4.79 and 2.15 vs. 4.26, 3.9 and 1.31 kg/d, respectively). When DMI, OMI and DOMI were expressed as a g/kg $BW^{0.75}$, significant ($p<0.05$) differences were also observed. Intake of FTWS was highest and UWS was the lowest (80.2, 70.8 and 31.7 vs. 62.9, 57.5 and 19.4, respectively).

DISCUSSION

Experiment I

Chemical composition : With the exception of the treatment P-41, which contained significantly ($p<0.05$) lower OM (93.2%), the concentration of OM in the fungal

Table 3. Effect of treatment on the DM degradability of the fungal treatments

Treatment	A	B	C	A+B	P	L
Control	10[d]	35.6[d]	0.020[c]	45.6[d]	26.5[c]	8.9[a]
P-21	16.3[c]	40.8[c]	0.037[b]	57.1[c]	37.2[b]	5.0[c]
P-30	18.3[b]	37.0[cd]	0.039[b]	55.3[c]	41.4[a]	7.0[b]
P-41	20.0[a]	48.6[a]	0.044[a]	68.6[a]	43.9[a]	6.6[b]
P-60	17.5[bc]	44.0[b]	0.039[bc]	61.5[b]	42.0[a]	5.3[c]
SEM (n=20)	1.11	1.85	0.00	1.39	0.97	0.68

Means with the different superscripts within a column are significantly ($p<0.05$) different.
SEM: Standard error of mean. A: Soluble fraction. B: Not soluble but fermentable. A+B: Potential degradability.
P: Effective degradability (outflow rate of 0.02/h). C: Constant rate. L: Lag time.

treated and untreated straw was not significantly ($p>0.05$) different (Table 1). These results were not in agreement with some earlier works, where OM content decreased in comparison with the original straw (Sing et al., 1990). The fermentation period in this study was limited to 21 days, but 40 days in the other studies. During the fermentation period, the substrate is decomposed and fungal biomass is accumulated in which a considerable part of organic matter may be mineralised to CO_2. Additionally, in this study, the untreated and treated straws were soaked in water that could reduce ash and increase the OM ratio of the initial straw.

In comparison with the untreated straw, CP content in all treatments was significantly ($p<0.05$) increased after fermentation by fungi. The protein content of the mycelium was reported relatively high (Ragunathan et al., 1996), so it was expected that the treated straw, that contained fungal mycelium to have a higher concentration of CP. Among the treatments, CP contents of P-41 and P-60 were higher than the other species that may be related to the amount of growth and cultural differences. The CP content of the control straw was 1.7% whereas of the inoculated wheat straws were between 2.7 to 3.5%, increased by 1.8 to 2-folds. An increase of CP content in wheat straw incubated with *Pleurotus* species had also been reported (Ardon et al., 1996; Zadrazil et al., 1996). In this study, wheat straw was collected from a farm after being harvested by machinery and characterised by high stem to leaf ratio and low CP (1.7%).

All the fungi used to treat the straw showed significant ($p<0.05$) ability to degrade NDF and ADF. This was due to the natural habitats of the white-rote fungi that largely depend on organic carbon (for their energy requirement) including carbon in the form of structural material such as lignocellulosic (Jennings and Lysek, 1996). Among the five species of fungi, P-21 and P-90 showed the lowest ability to degrade NDF and ADF (Table 1). The losses of NDF and ADF from the straw suggested that these fungi could solubilise and utilise the cell wall as carbon source and thus changed the ratio of insoluble to soluble carbohydrates in the straw. The decrease in NDF and ADF contents of the treated straw has been supported by other reports (Singh, 1990). However, the potential of NDF degradation among these species of fungi could be different (Jalc et al., 1996; Zadrazil et al., 1996).

With the exception of P-90, all other species had the ability to significantly ($p<0.05$) reduce ADL content of the wheat straw. Decrease of ADL in wheat straw had been reported when it was treated with *P. pulmonarius* and *P. sajor-caju,* (Moyson and Verachtert, 1991). It could be a result of lignin degrading enzymes (Hong et al., 2003; Hititi et al., 2003), produced by the *Pleurotus* fungi during the fermentation (Morerira et al., 1997). The amounts of ADL losses were reported to be variable. The reason for such differences in the ADL degradation is probably due to the fungal species and cultural conditions, which could affect the lacase activity (Ardon et al., 1996) and lignin degradation (Tripathi and Yadav, 1992; Jalc et al., 1997).

A significant ($p<0.05$) decrease in cellulose content of the straw was observed in all treatments (Table 1). With exception of the treatment P-90, the hemicellulose content was also significantly ($p<0.05$) reduced in fungal treated straw. The fungi, which their life depends on lignocellulosic materials, mostly release and utilise the hemicellulose and cellulose as carbohydrate sources. They are able to produce lacase, cellulase, xylanase and glucosidase enzymes to degrade lignocellulosic compounds and utilise the releasing sugars (Azizi et al., 1990; Zadrazil et al., 1996).

In vitro digestibility : Fungal treatment had increasingly significant ($p<0.05$) effect on the digestibility of the straw (Table 1). Increase in IVDMD from 28.1 to 40.6% and IVOMD from 27.5 to 40.3% were observed in wheat straw treated with the four *Pleurotus* cultures. However, wheat straw treated with P-41 or P-60 had the highest IVDMD and IVOMD, whereas P-21 treated straw showed the lowest IVDMD and IVOMD. Lignin binds with hemicellulosic components of cell wall, and through covalent linkages and physical binding, prevents accessibility and biodegradation of straw carbohydrates by cellulolytic and hemi-cellulytic microorganisms (Eriksson et al., 1990). Improvement of the digestibility of the treated straw could be as a result of the solubilisation of the structural polymers by fungi, which made it more accessible to the rumen microorganisms. Similar results were reported by Gupta and Langara (1988) and Gupta et al. (1993). However, the ability of fungi to improve the digestibility of straw could be different. Increase in DMD of wheat straw fermented with *Pleurotus* fungi has been reported from 15 to 46% (Zadrazil et al., 1995). Beside the culturing conditions, the ability of various strains of white-rot fungi in cell wall degradation and digestibility improvement of wheat straw may be different (Tripathi and Yadav, 1992; Jalc et al., 1997).

In sacco degradability : In comparison to the untreated wheat straw, the degradability of DM was significantly ($p<0.05$) increased in the fungal treated straw in all ruminal incubation periods (Tables 2). The reason for such improvement in the degradability may be related to the breaking down of cell wall bonds during the fermentation of straw with the fungi (Jennings and Lysek, 1996; Call and Mücke, 1997). Improvement of the degradability was slightly varied among the fungal treatments. At most of the rumen incubation periods, the degradability of DM was higher for the straw treated with P-41 than the other treatments. The ADF degradability at 48 h was significantly ($p<0.05$) higher in all treated straws compared with the

control straw. Among the treatments, straw treated with P-41 and P-21 showed the highest and the lowest ADF degradability, respectively. These differences in degradability could be related to the species of fungi used in this study. Similar results were reported by Jalc et al. (1996) where they found that DM, OM, and ADF degradabilities of wheat straw at 48 h incubation were increased when treated with *Plyporus ciliatus.*

The mean values for all the parameters of the DM degradabilities (A, B, C and P) were significantly ($p<0.05$) higher in fungal treated than the untreated straw (Table 3). These higher values of degradability fractions in fungal treated straw may be explained by the lower NDF content in these treatments (Table 1). Valmaseda et al. (1991) and Gutierrez et al. (1996) noted that fermentation of straw with *Pleurotus* fungi decreased the cell wall components and increased the soluble fraction of the carbohydrates in the straw that could be as a result of the enzymatic degradation. Among the fungal treatments, B fraction was highest in straw treated with P-41 and lowest with P-21, which could be related to the fungi ability. The higher IVDMD and IVOMD of the treatments (Table 1) are in accordance with the degradability findings and support these results. However, Flachowsky and Klappach (1993) reported that inoculation of four species of fungi (*Chaetomium virescens, Trichoderma harzianum, Penicillium colony* 10 and a wild variety) to straw did not improve the rumen degradability. It may be attributed to the differences between species of fungi, the system of process and type of enzyme produced by the fungi.

Experiment II

Digestibility : Fungal treatment, either as FTWS or SPWS significantly ($p<0.05$) increased the total tract digestibility (Table 4). The digestibilities of DM and OM were 34.8 and 33.8% respectively in the UWS; 46.8 and 44.8% for FTWS; 45 and 44.3% for SPWS, respectively. The digestibility of gross energy was also significantly ($p<0.05$) increased in fermented wheat straw, as compared to the untreated straw. Such improvements could be as a result of the changes in non structural carbohidrate to stractural carbohidrate ratio of the starw (Tan et al., 2002). These results are supported by the findings of the *in vitro* digestibilities of this study and other reports (Zadrazil et al., 1996;1997). There are few reports in which digestibility of fungal treated straw was evaluated *in vivo.* However, these results are in agreement with those of Marwaha et al. (1990), who noted that treatment of wheat straw by *P. sajor-caju* led to an increase ($p<0.05$) in the digestibility of DM, CP, CF and ADF in Jersey calves. Yoshida et al. (1993) found an increase (by 11%) in the DM digestibility of straw cultivated with *P. ostreatus*. In contrast, Walli et al. (1991) fed fungal (*Cuprinus fimetarius*) treated straw to Holstein Friesian bulls and noted that no enhancement was found in DMI, DMD and TDN. Marwaha et al. (1990) reported that *in vivo* DM digestibility of wheat straw was decreased after fermented with fungi *P. sajor-caju*. It appears that the changes in the nutritive value of straw may be related to the type of fungi and cultural conditions.

Nutrient intake : As shown in Table 4, the intake of DM, OM and DOM as kg/d or g/kg $BW^{0.75}$ were significantly ($p<0.05$) increased in the FTWS. Higher DOMI was also observed when treated straw was fed to the cows. An improvement of DMI could be due to the physical (softness of the straw structure) and chemical (cell wall degradation) changes of wheat straw through the SSF process by fungi. In addition, fungal treatment increased the DM and OM digestibility of the straw, which increased the voluntary intake. Yamakawa et al. (1992) reported an increase of DM intake of *P. ostreatus* treated rice straw from 12-13 (in normal straw) to about 20 g/kg of $BW^{0.75}$ (in treated straw) by sheep. According to Fazaeli et al. (2002) inclusion of fungal treated wheat straw in the diet of lactating cows resulted in a higher amount of DMI when compared with untreated wheat straw. Among the treated straws, lower DM, OM and DOM intake was observed in SPWS compared to the FTWS. It may be due to the longer fermentation period (7 vs. 3 weeks), which led greater depletion of the carbohydrate source of the straw by fungi during the fruiting body formation. Calzada et al. (1987) fed either SPWS after harvesting the edible mushroom of *P. sajor-caju* or normal straw to lamb and found that both groups showed similar DMI. In buffalo, Dhanda et al. (1996) noted that the paddy straw fermented with *P. sajor-caju* (PAU-3), had no effect on the nutrient utilisation and nitrogen balance when compared with untreated straw. However, when the fermentation period of the straw was reduced to two weeks, the DMI was significantly ($p<0.05$) increased. Therefore, it showed that the duration of treatment was equally important as the species of fungi to improve the nutritive value of straw.

CONCLUSION

In conclusion, treatment of wheat straw with *Pleurotus* fungi particularly P-41, resulted in a reduction of its cell wall components and increasing of CP, *in vitro* digestibility and rumen degradability. In addition, treatment of wheat straw with the fungi of *Pleurotus* (P-41) for three to seven weeks under SSF system improved the *in vivo* digestibility and DOMI by cattle.

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