Effects of substitution of Bermuda grass hay with *Trichoderma* fermented rice straw on growth, blood, and rumen fluid parameters in Barbados sheep

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**ABSTRACT**

The study was to ascertain the feasibility of using rice straw fermented by *Trichoderma* as ruminant roughage. Three species or three strains of *Trichoderma* (NTLg-Te S5-1, NTLg-Te S9-1, and Tien Chung Ca6-1) were used to inoculate hot water-sterilized rice straw. Result showed that straw fermented with *Trichoderma* NTLg-Te S5-1 had the highest cellulase and xylanase activity. Antioxidant ferulic acid content of water extract was improved after fermentation. Eighteen Barbados sheep were randomly distributed into one of three dietary groups. Ration of Bermuda hay group (BER) is 90% Bermuda hay with 10% concentrate. Unfermented rice straw (RS) group and fermented rice straw (FRS) group substituted 25% of Bermuda hay with rice straw or fermented rice straw. Dry matter intake, daily weight gain, blood analysis, and feed conversion ratio were not significantly different among groups after 4 weeks of trial. Dry matter digestibility of BER was the highest, and of FRS was significantly higher than RS. Malondialdehyde (MDA) content in serum of FRS and BER was lower than RS. These results indicated that 25% substitution of Bermuda hay with *Trichoderma*-fermented rice straw in the diet of Barbados sheep could increase digestibility and inhibit lipid oxidation when compared to unfermented rice straw.

1. Introduction

Rice (*Oryza sativa*) straw is a by-product from rice production, and a common problem in Taiwan, where production could reach 1.58 million tons per year. Burial and incineration were common solutions for consuming the rice straw, though the firm structure of rice straw made it hard to be degraded in landfills and could carry plant disease to the next cultivation (Ifan et al., 2014). Though rice straw could be consumed as feed by ruminant animals, the low digestibility owing to its high fibre and lignin content is the main drawback to widespread application.

The nutrient value of the rice straw could be elevated after solid state fermentation by lignocellulolytic fungi, owing to the ability of fungi to excrete cell wall degrading enzymes (Chu et al., 2017; Lin et al., 2017). *Trichoderma* has become famous in the bio-fuel industry in recent years due to its outstanding fibrolytic enzyme-producing characteristics. Helal (2005) compared *Trichoderma* to 58 other fungi species for their cellulase-production ability and *Trichoderma* species showed the highest endoglucanase and exoglucanase enzyme activities. Other specific enzymes like swollenin and acetyl xylan esterase have also been proven to possess synergy activity with cellulase and xylanase, which may be the factors accounting for its high enzyme activity (Zhou et al., 2011; Neumüller et al., 2014).

Recent studies indicate that feeding of agricultural by-products fermentation with *Trichoderma* had beneficial effects on ruminants. Mohamed and Abou-Zeina (2008) supplied *Trichoderma*-fermented sugar beet pulp (SBP) in goat kid diet and showed improved dry matter intake and total weight gain compared to the control group. Omer et al. (2012) replaced clover hay with *Trichoderma*-fermented corn stalk in the rations of growing sheep; feed conversion, and all nutrient digestibilities were significantly improved, while blood plasma parameters remained within the normal range. There are still few studies on using rice straw as the fermentation substrate in ruminant diet. Therefore, in this study, we substitute Bermuda hay with *Trichoderma*-fermented rice straw, in the pursuit of beneficial effects on Barbados sheep growth performance, nutrient digestibility, and blood profiles.

2. Material and methods

2.1. Rice straw fermentation

All of the *Trichoderma* strains (NTLg-Te S5-1, NTLg-Te S9-1, and Tien Chung Ca6-1) were procured from the Department of Biotechnology, National Formosa University, Yunlin, Taiwan. Fermentation substrate was a mixture of rice straw (*Oryza sativa japonica*) grown in Taichung, Chia-yi, and Tainan in Taiwan. The rice straw was cut to about 5–10 cm in length, and sterilised by immersing in boiling water for 30 min; after the boiling water sterilization. Every bag of 1 kg of the rice straw was inoculated by 200 ml (107 spores/ml) of *Trichoderma* spore suspension...
obtained from the 7-day subculture of each *Trichoderma* on Potato-Dextrose Agar (PDA). The moisture of the rice straw was adjusted to 75% by tap water. Silicone centre sponge (Shin-etsu Chemical Co., Ltd.) was tied to the opening of the container. In this study, Agitation was performed once a day after 3 days of inoculation.

### 2.2. Enzyme assay

Enzyme of the fermented substrate was extracted with cold water and stirred for 30 min to obtain the extract solution. The crude enzyme extract was centrifuged at 3000 rpm (Himac CF 15RX, Hitachi, Koki, Japan) for 10 min, and then filtered using Whatman No. 1 filter paper. The filtrate was collected for further assay. Cellulase and xylanase activities were assayed by measuring the reducing sugars using the dinitrosalicylic acid (DNS) method (Miller 1959). One international unit (IU) of cellulase and xylanase activity was defined as the quantity of enzyme required to liberate 1 µm of reducing sugar of crude enzyme extract per minute under standard assay condition (50°C, 1% carboxymethyl cellulose, pH 4.8 for cellulase, and 50°C, 1% beechwood xylan, pH 5.0 for xylanase).

### 2.3. Water-soluble carbohydrate determination

Five grams of rice straw and fermented rice straw were subjected to 10-fold dilution with de-ionized water and stirred for 30 min to obtain the crude extract. The crude extract was centrifuged at 3000 rpm (Himac CF 15RX, Hitachi, Koki, Japan) for 10 min, and then filtered using Whatman No. 1 filter paper. The pentose and hexose contents were determined by a slightly altered phenol-sulfate method (Rao and Pattabiraman 1989). An aliquot of 1 ml extract solution was mixed with 1 ml 5% phenol solution and 5 ml 98% H2SO4. Absorbance was measured at 485 nm for pentose and 475 nm for hexose. The results were expressed as mg xylose or glucose equivalence/g extract.

### 2.4. Proximate chemical analysis

Rice straw and fermented rice straw were analysed for proximate chemical analysis according to AOAC (2000). NDF, ADF, and ADL contents were determined according to Van Soest et al. (1991).

### 2.5. Scanning electron microscopy observation

Rice straw and rice straw fermented by *Trichoderma* NTLg-Te SS-1 for 6 days were dried at 50°C. The dried samples were observed using a scanning electron microscope (SEM) (Bausch & Lomb Ltd. Nono lab 2100).

### 2.6. Transmission electron microscopy observation

Rice straw and rice straw fermented by *Trichoderma* NTLg-Te SS-1 for 6 days were dried at 50°C and fixed overnight in 50 mM sodium phosphate buffer (pH 7.5) containing 2.5% glutaraldehyde. After several rinses with the sodium phosphate buffer, the samples were post-fixed in sodium phosphate buffer containing 2% OsO4 for 2 h. Dehydration was carried out in a graded ethanol series from 50% to 100%, and the samples were embedded in LR-White resin. Specimen sections of 75 nm were mounted on Formvar-coated nickel grids. After mounting, the sections were stained with uranyl acetate and lead citrate and observed under a transmission electron microscope (TEM) (Model 1200 EXII; JEOL, Tokyo, Japan) at 100 kV.

### 2.7. Ferulic acid content and DPPH inhibition

Ferulic acid and esterified ferulic acid content was measured according to Micard et al. (1994). Rice straw and fermented rice straw were extracted with de-ionized water for 30 min. The crude extract was centrifuged at 3000 rpm (Himac CF 15RX, Hitachi, Koki, Japan) for 10 min, and then filtered using Whatman No. 1 filter paper. After the addition of 1 ml of citric acid buffer (pH 10, 0.1 M), equal to the amount of each water extract, absorbance was measured at 345 (375) nm, and the concentration was determined using molar absorption coefficients (M−1 cm−1) of 19,662 (7630) and 23,064 (31,430) for free ferulic acid and esterified ferulic acid, respectively. The free radical scavenging activity of the water extracts was measured via DPPH, according to the method described by Wen et al. (2013). Briefly, an aliquot of 0.1 ml extract solution was mixed with 0.4 ml Tris-HCl buffer solution and 0.5 ml DPPH (250 mM) solution. After 20 min, absorbance was measured at 517 nm, and de-ionized water was used as control. Lower absorbance of the reaction mixture indicated a higher free radical scavenging effect and was calculated by

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\text{DPPH scavenging effects (\%)} = \left[1 - \frac{\text{ABS}_{\text{sample}}}{\text{ABS}_{\text{control}}} \right] \times 100\%.
\]

### 2.8. Animal trial

The animal experiment was approved by the Animal Care and Use Committee (IACUC No.: 105-017) of National Chung Hsing University, Taiwan. Eighteen cross-bred Barbados sheep with around 20 ± 1.05 kg body weight were randomly assigned to three groups for three different feeding rations. The ration of BER was 90% Bermuda hay with 10% concentrate (11.0% CP, 35.8% NDF, and 71.7% ADF). The RS and the FRS rations substituted for 25% of the Bermuda hay with unfermented rice straw and fermented rice straw, respectively. Water, salt block, and feed were given ad libitum. Feed was given at 8:00 am and 8:00 pm every day. Leftover was weighed and cleaned every 8:00 am. Dry matter of the leftover was measured every week. There were two weeks of adaption period and four weeks of experimental period. A total 8 weeks at this experimental. The weight of the sheep was recorded after the 4 weeks of adaptation period and after the 4 weeks of the experimental period. Feed and water were withdrawn for 12 h before the weight measurement. Feed composition is shown in Table 1.

### 2.9. Blood sampling and assay

Blood was collected by jugular vein puncture at 4 h after morning feeding at the end of the experiment. Blood was centrifuged at 3000 rpm (Himac CF 15RX, Hitachi, Koki, Japan) and serum was obtained from the supernatant. The serum was stored at −20°C for biochemical and antioxidant content.
Table 1. Ingredients and chemical composition.

| Item                  | Treatments                                                                 |
|-----------------------|---------------------------------------------------------------------------|
|                       | BERa | FRSb | RSc |
| Ingredient, %         |      |      |     |
| Bermuda hay           | 90   | 67.5 | 67.5 |
| Concentrate           | 10   | 10   | 10   |
| Rice straw            | 0    | 22.5 | 0    |
| Fermented rice straw  | 0    | 22.5 | 0    |
| Calculated constituentsd, % |      |      |      |
| Crude protein         | 11.0 | 10.3 | 10.3 |
| Ether extract         | 2.14 | 1.94 | 1.85 |
| Neutral detergent fibre | 35.8 | 43.7 | 44.2 |
| Acid detergent fibre  | 71.7 | 64.5 | 64.9 |

aBer: Bermuda hay group.
bFRS: Fermented rice straw group.
cRS: Rice straw group.
dn = 3.

Glucose, blood urea nitrogen (BUN), aspartate aminotransferase, alanine aminotransferase, total protein (TP), albumin (ALB), high-density lipoprotein (HDL), and low-density lipoprotein (LDL) were assayed using an automated blood analyser (7150 auto-analyzer, Hitachi, Tokyo, Japan). A spectrophotometer was used to calorimetrically assay the malondialdehyde (MDA) concentration and superoxide dismutase (SOD) activity. The procedures were conducted with assay kits purchased from Cayman Chemical Co. Ltd. (Ann Arbor, MI, USA). Serum samples were measured at the appropriate dilutions allowing the enzymatic activities to achieve the linear range of the standard curves.

2.10. Rumen fluid sampling and assay

Rumen fluid was collected by stomach tube at the fifth week 4 h after morning feeding. After being strained through four layers of cheesecloth, the VFA concentration of the rumen fluid was determined in the following way: 200 μl of metaphosphoric acid (25%) and formic acid (3:1) mixture was added to 1 ml of rumen liquid (Cottyn and Boucq1968). After 30 min of centrifugation, the clear supernatant was collected and the VFA concentration was determined after separation in Nukol capillary column (30 m × 0.25 mm).

2.11. Digestibility assay

A digestibility assay was conducted using acid insoluble ash as an internal indicator determined by a slightly altered method from Van Keulen and Young (1977). Cross-bred Barbados sheep were individually housed in concrete floors. All feedstuffs were fed twice daily at 08:00 am and 08:00 pm for a 21-day adaptation period followed by a 3-day collection period. Faeces were oven dried at 75°C for storage and 105°C to assay for dry matter; 3 g of samples was weighed in the crucible and ashed at 650°C; 30 ml of 2 N HCl was added to the crucible; and the HCl was boiled for 5 min. HCl and the sample were filtered through Whatman® No. 1 filter paper; hot water was used to wash the crucible; the residue and filter paper were ashed again; the acid insoluble ash was calculated; dry matter, NDF, and ADF digestibility were determined using the acid insoluble ash content (modified from Van Keulen and Young, 1977). The NDF, ADF, and ADL of calculation model used was

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1 - \frac{\text{Acid-Insoluble Ash (AIA), %in diet} \times \text{nutrient content in diet}}{\text{AIA, %in feces} \times \text{nutrient content in feces}}
\]

2.12. Statistical analysis

Data were subjected to ANOVAs as a completely randomized design using Proc GLM, the general linear model procedure for the analysis of variance of the SAS statistical software (2004, Cary, NC, USA). For the determination of the significant differences among the mean values of the three treatment groups, Duncan’s multiple range test was used, with a significance level of P < .05 (Duncan 1955).

3. Results

3.1. Comparison of the effectiveness of the Trichoderma species

Table 2 shows the enzyme activity and carbohydrate concentration of water extract from rice straw fermented by three different species of Trichoderma. Rice straw fermented by *Trichoderma* NTLg-Te S5-1 had the highest cellulase (14.0 U/g DM) and xylanase (278.2 U/g DM) activity, as well as the highest concentration of pentose (38.2 mg/g DM) and hexose (60.3 mg/g DM); therefore, *Trichoderma* NTLg-Te S5-1 was used for further fermentation.

3.2. Effect of Trichoderma treatment on chemical composition of rice straw

Table 3 shows the change of RS chemical composition after fermentation by the *Trichoderma* NTLg-Te S5-1. NDF content was reduced from 74.0% to 67.5%, and ADF content from 47.8% to 44.2%

| Item                  | Control         | NTLg-Te S5-1 | NTLg-Te S9-1 | Tien Chun Ca6-1 |
|-----------------------|-----------------|--------------|--------------|-----------------|
| Enzyme activity       |                 |              |              |                 |
| Cellulase             | 0±               | 14.0 ± 0.63a | 2.11 ± 0.26b | 10.2 ± 0.20b    |
| Xylanase              | 0±               | 2782 ± 19.0  | 683 ± 15.8   | 135 ± 12.3c     |
| Carbohydrate concentration |             |              |              |                 |
| Hexose                | 4.57 ± 2.54d    | 60.3 ± 7.4a  | 46.4 ± 0.16b | 32.9 ± 4.79d    |
| Pentose               | 3.83 ± 2.44d    | 38.2 ± 4.56a | 31.6 ± 0.6b  | 18.2 ± 1.4c     |

Table 3. Effect of *Trichoderma* NTLg-Te S5-1 fermentation on rice straw chemical composition.

| Item                  | Unfermented | Fermented |
|-----------------------|-------------|-----------|
| Dry matter            | 19.08 ± 1.22| 16.97 ± 1.44 |
| Ash                   | 4.74 ± 1.53 | 6.92 ± 0.59  |
| Crude protein         | 6.14 ± 0.23 | 7.44 ± 0.53  |
| NDFd                  | 74.0 ± 0.83  | 67.5 ± 0.27b |
| ADFd                  | 47.8 ± 0.55a | 44.6 ± 0.30b |
| ADLc                  | 4.4 ± 0.77  | 3.5 ± 0.42   |

|                  | Unfermented | Fermented |
|------------------|-------------|-----------|
| Ash               | 4.74 ± 1.53 | 6.92 ± 0.59  |
| Crude protein     | 6.14 ± 0.23 | 7.44 ± 0.53  |
| NDFd              | 74.0 ± 0.83  | 67.5 ± 0.27b |
| ADFd              | 47.8 ± 0.55a | 44.6 ± 0.30b |
| ADLc              | 4.4 ± 0.77  | 3.5 ± 0.42   |

Results expressed as %.

aNeutral detergent fibre.
bAcid detergent fibre.
cAcid detergent lignin.
a Means without the same superscripts within the same row under treatment differ significantly (P < .05)
to 44.6%, while the ADL content remained unchanged after the solid state fermentation with *Trichoderma* NTLg-Te S5-1.

### 3.3. Microscopic characterization

The microscopic characterization using SEM (untreated in Figure 1(A) and treated in Figure 1(B)) and TEM (untreated in Figure 2(A) and treated in Figure 2(B)) showed the changes of rice straw before and after the fermentation with *Trichoderma* NTLg-Te S5-1. The cracks and wrinkles of fermented rice straw structure occurred with *Trichoderma* hypha and spores, which may be due to the degradation activity of *Trichoderma* enzymes during fermentation.

### 3.4. Antioxidation profile

Table 4 shows the ferulic acid and esterified ferulic acid concentration in the water extracts of RS and FRS. Ferulic acid and esterified ferulic acid concentration were both significantly elevated after the fermentation; the DPPH inhibition of the water extract also increased from 15.5% to 30.9%.

### 3.5. Growth performance

The effect of fermented rice straw substitution on the growth performance of Barbados sheep is shown in Table 5. There were no significant differences in weight gain, feed intake, and feed conversion ratio among all treatment groups, although FRS tended to decrease the average feed conversion ratio when compared to the average value of RS. Digestibility was assayed by using acid insoluble ash as the internal indicator; the result showed significantly improved dry matter digestibility of FRS compared to RS (46.3–52.3%); however, the values were significantly lower when compared to the BER (57.5%). NDF and ADF digestibility of FRS was also significantly improved compared to the RS (50.4% vs. 54.0% and

![Figure 1](image-url). Scanning electron micrographs of rice straw (A) and rice straw fermented by *Trichoderma* (B).
35.9% vs. 41.0%, respectively), while showing no significant difference with BER.

### 3.6. Rumen fluid parameters

Table 6 shows the effect of dietary substitution of Bermuda hay by fermented rice straw on Barbados sheep rumen fluid parameters. Volatile fatty acid concentration and protozoa count were not significantly different among the treatment groups.

### 3.7. Blood parameters

Table 7 shows the effect of the dietary substitution of Bermuda hay by fermented rice straw on Barbados sheep blood parameters. There were no significant differences in serum glucose, BUN, GOT, GPT, TP, ALB, HDL, LDL concentrations, and SOD activity among all the treatment groups; however, the lipid peroxidation product MDA concentration was significantly higher in RS (19.0 µM) than BER (8.3 µM) and FRS (10.2 µM).

### 4. Discussion

The lignocellulosic composition of rice straw cell wall could have induced the cellulase production of the fungi. Yoon and Kim (2005) found that the production of cellulase by fungi could be induced when incubated with a high degree of crystalline cellulose but not pure glucose, which was similar to our study. All three Trichoderma-fermented rice straw possess higher enzyme activity compared to unfermented rice straw; this could be due to the induction of cellulase by the highly crystalline cellulose (56.8%) of rice straw physical characteristics (Kim et al., 2014).

The suitable particle size could also affect enzyme production. Raghuwanshi et al. (2014) used Trichoderma for rice straw solid fermentation, and the cellulase activity (5.56 U/g) was lower compared to Trichoderma NTLg-Te S5-1 in our study, which used ground rice straw; our study used 5–10 cm rice straw. Small particle size may lead to the clumping of substrate, resulting in reduced accessibility to nutrients and lead to anaerobic cultural conditions causing lower yield of the enzyme (Maurya et al., 2012).

The fibre content of the agricultural by-product could be reduced after the solid state fermentation of the Trichoderma due to the activity of fungal enzymes. Begum and Alimon (2013) used Pleurotus fungi to ferment rice straw. NDF and ADF were significantly reduced and ranged from 82.53% to
Table 7. Effect of treatments on Barbados sheep blood parameters.

| Items         | BER (g/dl) | FRS (g/dl) | RS (g/dl) | SEM |
|---------------|------------|------------|-----------|-----|
| Glucose       | 62.7       | 69.7       | 73.3      | 4.85|
| BUN*          | 12.3       | 16.3       | 15.3      | 1.33|
| GOT†          | 39.7       | 42.3       | 41.0      | 3.68|
| GPT†          | 10.3       | 4.0        | 9.3       | 2.23|
| TP*           | 6.53       | 6.67       | 6.77      | 0.31|
| ALB*          | 3.10       | 3.13       | 3.13      | 0.15|
| HDL*          | 38.0       | 31.7       | 31.0      | 2.09|
| LDL†          | 18.0       | 17.3       | 14.3      | 1.55|
| MDA*          | 8.3b       | 10.2b      | 19.0a     | 2.02|
| SOD*†         | 1.55       | 1.79       | 1.42      | 0.16|

1Blood urea nitrogen.  
2Glutamic oxaloacetic transaminase.  
3Glutamic pyruvic transaminase.  
4Total protein.  
5Albumin.  
6High-density lipoprotein.  
7Low-density lipoprotein.  
8Malondialdehyde (MDA) is a naturally occurring product of lipid peroxidation.  
9SOD activity is an major antioxidant enzyme in blood against O2·−.  
10Total protein content.

63.99% and 55.12% to 47.19%, respectively. The results in this study showed that rice straw fermented by *Trichoderma* NTLg-Te S5-1 had a lower level of NDF (74.0–67.5%) and ADF (47.8–44.6%, Table 3), respectively. This could be due to the higher cellulase and xylanase activity produced by *Trichoderma* throughout the fermentation period that degraded the cellulose and hemicellulose of the rice straw more efficiently.

Reduction of fibre content leads to elevated water-soluble carbohydrate (WSC) by the action of cellulase and xylanase. Rahnama et al. (2014) used cellulase from *Trichoderma harzianum* SNRS3 to hydrolyse rice straw; WSC content (mainly hexose) was elevated after the fermentation (0–30.7 g/L), while Bandi-kari et al. (2014) used *Trichoderma koeingi* xylanase to hydrolyse milled rice straw; water-soluble xylose (pentose) content was elevated within 4 h (1.5 mg/mL) to 6 h (2.7 mg/mL). The elevation of WSC may be caused by the breakdown of structural carbohydrate, composed of cellulose and hemicellulose, into WSC by the enzyme activity when solid state fermentation was applied on agricultural by-product (Yoon et al., 2013). This is similar to our study that water-soluble pentose and hexose content was elevated after the fermentation, and the treatment (*Trichoderma* NTLg-Te S5-1) produced the highest cellulase and xylanase, giving rise to the highest hexose (4.57–60.3 mg/g DM) and pentose (3.83–38.2 mg/g DM) content.

In a previous study, Kholif et al. (2014) used fermented rice straw to replace Egyptian berseem clover by 25% in Lactating Goats diet; the replacement group showed no significant difference in milk yield and feed efficiency compared with the control groups, and no significant difference in total dry matter intake; however, the DM and NDF digestibility was significantly higher compared to the unsubstituted control group, which was similar to our study, in that there was no significant change in feed efficiency or DM intake but increased DM and fibre digestibility when compared to the unfermented rice straw group. Other studies suggest that the nutrient value of agricultural by-product could be improved after *Trichoderma* fermentation by enhancing nutrient digestibility of the ruminant. Okab et al. (2012) used SBP treated biologically with *T. reesei* in Barki lambs; the results showed improved dry matter, crude fibre, and protein digestibility. Abo-Donia et al. (2014) reported that Ossimi sheep fed agricultural by-product peanut hulls treated with *T. viride* significantly improved dry matter, NDF, ADF, and digestibility. The improved digestibility in the current study may be due to the activity of the fibrolytic enzymes in fermented rice straw produced by *Trichoderma* during solid state fermentation. Adding exogenous enzymes to the diet increases the hydrolytic capacity of the rumen mainly due to increased bacterial attachment, stimulation of rumen microbial populations and the synergistic effects with hydrolases of ruminal microorganisms (Beauchemin et al., 2004). In this study shows that the diet by fermented on NDF and ADF levels had significant lower than the group of control. The breakdown of structural carbohydrate by *Trichoderma* fermented, which cause lower level of NDF and ADF in fermented rice straw.

Ferulic acid is a common antioxidant in agricultural materials, which could be liberated from arabinoxylan into a bioactive form, such as free ferulic acid and esterified ferulic by the action of the xylanase. Malunga and Beta (2015) reported that using xylanase from *T. viride* could yield higher content of feruloylated arabinoxylan oligosaccharide (esterified ferulic acid) than free ferulic acid from aleurone flour due to the lack of feruloyl esterase in *Trichoderma* fibrolytic enzymes. Our study indicates that the free and esterified ferulic acid of the water extract increased after fermentation; however, the free ferulic acid content was elevated higher than the esterified ferulic acid, which may have been caused by the natural hydrolysis of esterified ferulic acid during the solid state fermentation.

Esterified ferulic acid could be degraded into free ferulic acid by microorganisms from the rumen or intestinal tract, and free ferulic acid could be absorbed by the ruminant. Soberon et al. (2012) reported that ferulic acid was observed in the urine and faeces of sheep fed free ferulic acid after 5 h of administration. This could explain the significant reduction of MDA concentration of FRS compared to RS which may be due to the radical scavenging effect of ferulic acid in blood circulation and prevention of lipids from radical attack; the reduction of animal oxidation stress could prevent excessive energy usage and promote growth performance. Yue et al. (2009) used antioxidant selenomethionine supplied in goat diet; serum MDA concentration was significantly reduced and feed efficiency significantly improved in the experimental group compared to the control group, which is similar to our study, that the FCR of FRS (12.3 w/w weight gain) was improved compared to RS (16.1 w/w weight gain) in average value, although not at a significant level.

5. Conclusion

The nutritional value of rice straw in Barbados sheep diet was elevated after the solid state fermentation by *Trichoderma* NTLg-Te S5-1. The higher enzyme activity and water-soluble sugar content could improve fibre degradation and thus promote dry matter digestibility. On the other hand, the higher water-soluble antioxidant content after the fermentation
could influence the lipid oxidation level in the serum. The results revealed that the 25% FRS group was characterized by increased digestibility and inhibited lipid oxidation than the control group, but differences in body weights for these groups were not significant. The 25% FRS group did not differ in feed conversion ratio and consumption either in Barbados sheep diet.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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