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Degradation Characteristics of Rubbed Rice Straw from Different Harvest Periods in the Rumen of Dairy Cows Postprint

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Abstract

This experiment aimed to investigate the effects of shredding treatment on the nutritional composition and rumen degradation characteristics of rice straw harvested at different periods. Experimental samples were collected at the end of September and early November. After identical pre-experimental processing, four groups of samples were established: rice straw from late September, shredded rice straw from late September, rice straw from early November, and shredded rice straw from early November. The nutritional composition of the samples was determined, and the degradation rates of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) in the aforementioned samples in dairy cow rumen were measured using the nylon bag method to obtain dynamic degradation parameters for each nutrient component. The results indicated that the CP content of rice straw from late September was higher than that of rice straw from early November, while the crude ash content was lower. The rumen degradation rates of CP, NDF, and ADF in rice straw from late September were significantly higher than those in rice straw from early November ($P<0.05$).

Shredding treatment had no significant effect on the effective degradation rate (ED) of DM, CP, and ADF in rice straw from late September ($P>0.05$), but significantly enhanced the ED of DM, CP, and ADF in rice straw from early November ($P<0.05$). In conclusion, rice straw harvested at the end of September is more suitable as a roughage for animal feeding compared to rice straw harvested in early November; shredding treatment of rice straw from early November can improve its nutritional value and rumen degradation rate.

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Full Text

Ruminal Degradation Characteristics of Kneaded Rice Straw at Different Harvest Periods in Dairy Cows

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Abstract

This study was conducted to investigate the effects of kneading treatment on the nutrient composition and ruminal degradation characteristics of rice straw harvested at different periods for dairy cows. Samples were collected in late September and early November, with identical pretreatment applied to all materials, resulting in four experimental groups: rice straw from late September, kneaded rice straw from late September, rice straw from early November, and kneaded rice straw from early November. Nutrient contents were determined, and the degradation rates of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) in the rumen of dairy cows were measured using the nylon bag technique to obtain dynamic degradation parameters for each nutrient. The results showed that rice straw harvested in late September had higher CP content and lower crude ash content compared to early November straw. The ruminal degradation rates of CP, NDF, and ADF for late September rice straw were significantly higher than those for early November rice straw ($P<0.05$). Kneading treatment did not significantly affect the effective degradability (ED) of DM, CP, and ADF for late September rice straw ($P>0.05$), but significantly improved the ED of DM, CP, and ADF for early November rice straw ($P<0.05$). In conclusion, rice straw harvested in late September is more suitable as a roughage for feeding animals compared to early November straw, and kneading treatment of early November rice straw can enhance its nutritional value and ruminal degradation rate.

Keywords: rice straw; kneading; rumen degradation; dairy cows

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Preamble

Rice has a long cultivation history in China and represents the country' s most important grain crop. Mechanical harvesting and kneading treatment of rice straw can be performed promptly without affecting normal planting of the subsequent season, allowing utilization as feed in dairy cow diets. If this technology can be promoted and further developed for rational feed utilization, it could alleviate the shortage of roughage in Jiangsu Province and southern China to some extent, while also reducing environmental pollution from straw burning.

The feeding value of rice straw is determined by its utilization method, with research focusing on its inherent nutritional limitations. Rice straw contains high levels of lignin and silicon, resulting in poor digestibility and palatability. The digestion rate of rice straw by ruminants is typically only 20%~30% [6]. Currently, common treatment methods for rice straw include silage [7], ammoniation [8], and alkalization [9], with recent studies investigating steam explosion treatment [10-11]. However, kneading treatment has not been previously reported. This experiment compared the effects of kneading treatment on rice straw from two different harvest periods by measuring nutrient composition and ruminal degradation rates to evaluate the effectiveness of kneading and provide a new approach for the feed utilization of rice straw.

Materials and Methods

1.1 Experimental Materials

Rice straw was collected on-site from Dadongchuandong Farm in Yancheng City, Jiangsu Province. After grain harvest, the remaining rice straw was harvested using self-propelled machinery with simultaneous kneading treatment. Untreated rice straw was also collected as a control. Sampling was conducted in late September (seed rice harvest) and early November (grain rice harvest), yielding four sample groups: rice straw from late September, kneaded rice straw from late September, rice straw from early November, and kneaded rice straw from early November. After collection, rice straw samples were dried at 65°C, ground through a 2.5 mm sieve, and stored at room temperature for later use.

1.2 Experimental Animals and Management

Three healthy Holstein dairy cows in mid-to-late lactation, with similar body condition and body weight [(500±25) kg], fitted with permanent rumen fistulas were selected as experimental animals. The cows were fed twice daily at 06:00 and 17:30 with free access to water. The composition and nutrient levels of the basal diet are shown in Table 1 .

Table 1 Composition and nutrient levels of the basal diet (DM basis)

Items	Content
Ingredients	
Corn	
Barley	
Soybean meal	
Cottonseed meal	
Beet pulp	
Alfalfa hay	

Items	Content
Oat hay	
Whole cottonseed	
Barley straw silage	
CaHPO4	
NaCl	
Premix1)	
Total	
Nutrient levels2)	
NEL/(MJ/kg)	
CP	
EE	
NDF	
ADF	

1) One kg of premix contained the following: VA 500,000 IU, VD3 80,000 IU, VE 2,100 IU, nicotinic acid 710 mg, Cu 1,250 mg, Mn 1,800 mg, Zn 4,850 mg, I 50 mg, Se 50 mg, Co 20 mg.

2) NEL was a calculated value, while other nutrient levels were measured values.

1.3 Nylon Bag Trial

The experiment was conducted at Guangming Xinghuo Second Factory in Fengxian District, Shanghai, from November 15 to 21, 2017. Following the method described in reference [12], 300-mesh (50 m) nylon bags (12 cm × 8 cm) were prepared using fine polyester thread with double stitching. Thread ends were burned off before use, and bags were soaked in water, dried at 65°C, and weighed. Four grams of sample were weighed into each nylon bag. Following the principle of "simultaneous insertion, sequential removal," bags containing test samples were placed in the rumen before feeding, attached to a semi-soft plastic tube tied with nylon thread, which was then fixed to the fistula cap. Bags were removed after 0, 2, 6, 12, 24, 36, 48, and 72 h of incubation, washed, dried, and weighed, then stored in ziplock bags. Each group had two replicates per time point and three repetitions. The real-time degradation rates of DM, CP, NDF, and ADF were determined and calculated at different time points.

The degradation rate of a nutrient at a specific time point was calculated using the following formula:

Degradation rate at a time point (%) = 100 × (nutrient content in bag before degradation - nutrient content in bag after degradation at that time point) / nutrient content in bag before degradation.

The rumen kinetic mathematical exponential model used in the experiment followed Ørskov et al. [13]. The real-time ruminal degradation rate of a feed nutrient conforms to the exponential curve:

$$P = a + b(1 - e^{-ct})$$

Where: t is the retention time of feed in the rumen (h); P is the degradation rate of a feed nutrient after retention time t in the rumen (%); a is the rapidly degradable fraction (%); b is the slowly degradable fraction (%); c is the degradation rate of the b fraction (%/h).

The ruminal effective degradability (ED) of dietary nutrients was calculated using the following formula:

$$ED = a + \frac{bc}{c + k}$$

Where: ED is effective degradability (%); k is the rumen outflow rate of a nutrient, with a value of 0.0253 [14].

DM content was determined using the constant temperature drying method; CP content was determined using the Kjeldahl method with a FOSS automatic Kjeldahl nitrogen analyzer; NDF and ADF contents were determined using an ANKOM-2000I automatic fiber analyzer; crude ash content was determined using the incineration method.

1.4 Data Processing and Analysis

Original data were compiled and organized using Excel 2007 software. The degradation constants a, b, and c were determined using the NLIN procedure in SAS 9.4 software. Duncan' s multiple comparison method in SPSS 22.0 software was used for statistical analysis, with $P<0.05$ considered statistically significant.

Results

2.1 Nutrient Composition of Rice Straw and Kneaded Rice Straw

As shown in Table 2 , the DM content of early November rice straw was slightly higher than that of late September rice straw. The CP content of late September rice straw was higher than that of early November rice straw. The NDF and ADF contents of rice straw from both harvest periods were relatively high, not meeting the requirements for sole feeding. The crude ash content of early November rice straw was higher than that of late September rice straw. Kneading treatment reduced the crude ash content and increased the CP content of rice straw, while having no obvious effect on NDF and ADF contents.

Table 2 Nutrient composition of rice straw and kneaded rice straw (DM basis)

Items	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
DM				
CP				
NDF				
ADF				
Ash				

2.2 Rumen Degradation Characteristics of DM in Rice Straw and Kneaded Rice Straw

As shown in Table 3 , the DM degradation rate of late September rice straw was significantly higher than that of late September kneaded rice straw during the first 24 h (P<0.05), but no significant difference was observed at 72 h (P>0.05). Compared with early November rice straw, the DM degradation rate of early November kneaded rice straw was significantly higher overall (P<0.05), except at 2 and 48 h where no significant differences were found (P>0.05). Although the DM degradation rates of rice straw from the two harvest periods fluctuated during the early stage, no significant differences were observed at 2, 24, 36, and 72 h (P>0.05). The DM degradation rates of kneaded rice straw from the two harvest periods showed distinct differences, with early November kneaded rice straw having significantly higher DM degradation rates at all time points than late September kneaded rice straw (P<0.05).

Table 3 DM degradation rate of rice straw and kneaded rice straw in rumen at different time points (%)

Time (h)	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
0				
2				
6				
12				
24				
36				
48				
72				

Values in the same row with different letter superscripts indicate significant differences (P<0.05), while the same or no letter superscripts indicate no significant difference (P>0.05). The same applies below.

As shown in Table 4 , the *a* value of early November kneaded rice straw was the highest, significantly higher than that of early November rice straw (P<0.05). Although the *a* value of late September rice straw was higher than that of late September kneaded rice straw, the difference was not significant (P>0.05). The *b* values differed considerably among groups, while no significant differences were found in *c* values among groups (P>0.05). The ED of DM for kneaded rice straw from both harvest periods was higher than that of untreated rice straw, with early November kneaded rice straw showing significantly higher ED than early November rice straw (P<0.05). Late September kneaded rice straw had higher ED than late September rice straw, but the difference was not significant (P>0.05).

Table 4 Parameters of DM dynamic degradation model of rice straw and kneaded rice straw

Items	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
a				
b				
c (%/h)				
ED				

a = rapidly degraded fraction; *b* = slowly degraded fraction; *c* = degradation rate of *b* fraction; ED = effective degradability. The same as Table 6 , Table 8 , and Table 10 .

2.3 Rumen Degradation Characteristics of CP in Rice Straw and Kneaded Rice Straw

As shown in Table 5 , the CP degradation rates of the four rice straw groups showed consistent differences during the first 12 h, with kneaded rice straw from both harvest periods having significantly higher CP degradation rates than rice straw (P<0.05). However, at 72 h, the CP degradation rate of late September kneaded rice straw showed no significant difference compared with late September rice straw (P>0.05), while the CP degradation rate of early November kneaded rice straw remained significantly higher than that of early November rice straw (P<0.05). The CP degradation rate of late September rice straw was significantly higher than that of early November rice straw (P<0.05). Kneading treatment increased CP degradation rates, with early November kneaded rice straw showing notable improvement, reaching 57.91% at 72 h, which was significantly higher than early November rice straw (P<0.05).

Table 5 CP degradation rate of rice straw and kneaded rice straw in rumen at different time points (%)

Time (h)	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
0				
2				
6				
12				
24				
36				
48				
72				

As shown in Table 6 , the *a* values of CP for kneaded rice straw from both harvest periods were significantly higher than those of rice straw (P<0.05). The *b* values showed the opposite pattern, with rice straw having higher values than kneaded rice straw, and early November rice straw being significantly higher than early November kneaded rice straw (P<0.05). The *c* value of early November rice straw was significantly lower than those of other rice straw treatments (P<0.05). The ED of CP for kneaded rice straw from both harvest periods was higher than that of rice straw, with early November kneaded rice straw being significantly higher than early November rice straw (P<0.05).

Table 6 Parameters of CP dynamic degradation model of rice straw and kneaded rice straw

Items	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
a				
b				
c (%/h)				
ED				

2.4 Rumen Degradation Characteristics of NDF in Rice Straw and Kneaded Rice Straw

As shown in Table 7 , the NDF degradation rate of late September rice straw was significantly higher than that of late September kneaded rice straw (P<0.05), though no significant differences were observed at 36 and 48 h (P>0.05). The NDF degradation rate of early November kneaded rice straw was significantly lower than that of early November rice straw during the first 6 h (P<0.05), but significantly higher at 24, 48, and 72 h (P<0.05). The NDF degradation rate of late September rice straw was significantly higher than that of early November rice straw (P<0.05), with no significant differences at 36 and 48 h (P>0.05). The NDF degradation rate of early November kneaded rice straw was higher than that of late September kneaded rice straw, showing significant differences at 24 and 72 h (P<0.05).

Table 7 NDF degradation rate of rice straw and kneaded rice straw in rumen at different time points (%)

Time (h)	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
0				
2				
6				
12				
24				
36				
48				
72				

As shown in Table 8 , the *a* values of kneaded rice straw from both harvest periods were significantly lower than those of rice straw (P<0.05). Kneading treatment had little effect on *b* values, but late September rice straw and kneaded rice straw were significantly lower than early November rice straw and kneaded rice straw (P<0.05). Although *c* values fluctuated, no significant differences were observed among groups (P>0.05). The ED values were generally low, with late September kneaded rice straw being significantly lower than other groups (P<0.05).

Table 8 Parameters of NDF dynamic degradation model of rice straw and kneaded rice straw

Items	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
a				
b				

Items	Late September	Early November
c (%/h)		
ED		

2.5 Rumen Degradation Characteristics of ADF in Rice Straw and Kneaded Rice Straw

As shown in Table 9 , compared with late September rice straw, the ADF degradation rate of late September kneaded rice straw showed no significant differences except at 6 h (P>0.05). The ADF degradation rate of early November kneaded rice straw was significantly higher than that of early November rice straw at all time points (P<0.05). Late September rice straw had significantly higher ADF degradation rates than early November rice straw at all time points (P<0.05). The kneading treatment effect was better for early November rice straw than for late September rice straw.

Table 9 ADF degradation rate of rice straw and kneaded rice straw in rumen at different time points (%)

Time (h)	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
0				
2				
6				
12				
24				
36				
48				
72				

As shown in Table 10 , the *a* value of early November rice straw was significantly lower than that of late September rice straw (P<0.05). The *a* value of late September kneaded rice straw was significantly lower than that of late September rice straw (P<0.05), while the *a* value of early November kneaded rice straw was significantly higher than that of early November rice straw (P<0.05). No significant difference in *b* values was observed between late September kneaded rice straw and late September rice straw (P>0.05), but a significant difference was found between early November kneaded rice straw and early November rice straw (P<0.05). The *c* values showed little fluctuation, with no significant differences among groups (P>0.05). The ED of ADF for late September rice straw was significantly higher than that for early November rice straw (P<0.05). Although the ED of late September kneaded rice straw was lower than that of late September rice straw, the difference was not significant (P>0.05), while early November kneaded rice straw was significantly higher than early November rice straw (P<0.05).

Table 10 Parameters of ADF dynamic degradation model of rice straw and kneaded rice straw

Items	Late September		Early November	
	Rice straw	Kneaded rice straw	Rice straw	Kneaded rice straw
a				
b				
c (%/h)				
ED				

Discussion

3.1 Nutritional Evaluation of Rice Straw and Kneaded Rice Straw at Different Harvest Periods

As sampling time progressed, differences in nutrient composition were observed between the two types of rice straw, primarily in CP and crude ash content. The CP content of late September rice straw reached 9.72%, while early November straw contained only 5.31%, which may be related to different harvest purposes. Late September represents the local harvest period for rice seeds, while early November is for grain rice harvest. As rice matures and fills, nutrients in the straw are transported and accumulated in the panicle, creating this difference. However, previous studies by Hua Jinling et al. [15] and Wang Ying et al. [16] reported rice straw CP contents of only 3%~5%, possibly due to different harvesting methods. Previous research often used open-air sun-dried rice straw, whereas this study used fresh green rice straw from the field that was dried after enzyme deactivation, preventing nutrient loss. The difference may also be related to CP determination methods, as traditional methods used classic Kjeldahl distillation apparatus where human titration differences and digestion time could affect CP content. This experiment used a FOSS automatic nitrogen analyzer, reducing human-induced errors. Crude ash content showed opposite results, possibly because crude ash consists mainly of mineral elements that accumulate over time, and because nutrient transport to the panicle relatively increased mineral content. Rice is a silicon-rich plant, typically containing 10%~20% silicon in rice straw ash [17], resulting in higher crude ash content than other crops. The measured crude ash values in this experiment reached 13.10% and 17.02% for the two harvest periods, consistent with previous reports.

Notably, whether the high silicon content in rice straw affects dairy cow performance has not been reported and warrants further investigation. Kneading treatment using a harvester reduced crude ash content, potentially improving rice straw intake and palatability. No previous studies on kneading treatment of rice straw have been reported, but Wang Qingqing [18] proposed that kneading could improve palatability and intake in dairy cows when studying corn straw, and investigated the effects of kneading and micro-silage of corn straw, providing new possibilities for post-treatment of kneaded rice straw. Notably, kneading treatment increased rice straw CP content, though the mechanism requires further study. NDF is currently the most effective indicator for reflecting fiber quality in feed and is also important for reflecting the concentrate-to-forage ratio in ruminants, while ADF reflects the digestibility and utilization of roughage. This experiment found that kneading treatment had no obvious effect on NDF and ADF contents compared with untreated rice straw, indicating that mechanical kneading alone had limited apparent effect.

3.2 Rumen Degradation Patterns of Rice Straw and Kneaded Rice Straw at Different Harvest Periods

The nylon bag technique used in this study is an in situ method that is currently widely used to determine nutrient degradation patterns in feed. DM serves as the basis for comparing feed nutritional value, determining dry matter intake (DMI) of various feeds for ruminants and the level of other nutrients. As DMI increases, nutrient intake by ruminants increases, improving milk production [19]. This experiment showed that DM degradation rates of rice straw from different harvest periods increased to varying degrees with extended incubation time, with ED of DM around 25%, similar to results reported by Li Yang et al. [20]. The study also found that among various straw feeds, rice straw had the lowest ED. This experiment demonstrated that simple kneading treatment could improve ED, possibly because kneading disrupts straw fiber structure, enhancing the effect of rumen microorganisms when consumed by cows. The *a* values were lower compared with conventional roughage, while *b* values were higher, and the degradation rate of the *b* fraction was significantly lower than that of conventional roughage [21]. Therefore, for rice straw to become an alternative to conventional roughage, physical or chemical treatment is needed to compensate for deficiencies in palatability, fiber length, and nutritional structure. Kneading affected the *a*, *b* values and ED of rice straw, particularly for early November rice straw harvested for grain, significantly improving DM ED by 4.26%.

Feed protein degradation rate depends primarily on fermentation retention time and fermentation difficulty in the rumen [22]. After 72 h of rumen incubation, the CP degradation rate of early November rice straw, which had longer growth duration, was significantly lower than that of late September rice straw, consistent with CP content differences between the two harvest periods. Liu Kaiyu [23] also measured the degradation rate of dried rice straw at 72 h (around 50%), similar to this study' s results. Kneading treatment affected rice straw

CP degradation rate by increasing it at all time points and raising the 72 h CP degradation rate to 57.91%. The *a* value of CP increased significantly after kneading treatment, while the *b* value decreased. Numerically, there were large differences from the *a* value of rice straw (8.67%) reported by Li Yang et al. [20], but it was 6% higher than the *a* value for dried rice straw reported by Liu Kaiyu [23], while this study' s *a* value reached 18.91% with little difference in *b* values, indicating large variations in CP degradation parameters. Comparing different crop straws, corn straw had an *a* value of 21.37% [21], while rapeseed straw had only 9.86% [8], but no studies have reported degradation parameters for kneaded rice straw. The ED of rice straw CP increased after kneading treatment, similar to the goals of silage or ammoniation, which aim to improve nutrient ED so dairy cows can obtain more nutrients from straw feeds. Previous studies typically measured rice straw after grain harvest, with ED during this period being 30.45% in this study, consistent with the 29.59% reported by Li Yang et al. [19]. This study also found that straw from late September harvested for seed had higher ED, reaching 40.96%, though kneading treatment had no obvious effect on rice straw at this time, requiring further investigation.

The 72 h NDF degradation of rice straw measured in this study was significantly lower than that of commonly used roughage for dairy cows, such as corn leaves and yellow-stored straw, which can exceed 60%, while rice straw is less than 30% [19], consistent with this study' s results. This may be because untreated rice straw has high fiber content and high lignification, making it difficult for rumen microorganisms to degrade. The *a* values of NDF were not high, but previous studies also showed low *a* values for commonly used roughage, with alfalfa at only about 10%, Leymus chinensis at 1.19% [21], and corn silage at about 7% [24]. Kneading treatment reduced *a* values, though the mechanism requires further study. Previous studies reported generally high *b* values for NDF that determine ED magnitude. Kneading treatment had little effect on *b* values, which were generally lower than other roughage at 30%~40%, similar to results reported by Hua Jinling et al. [15]. The ED of NDF measured in this study was low at only 17.38%~19.85%, while Li Yang et al. [20] reported 33% and Hua Jinling et al. [15] reported 28.52%, possibly due to differences in rice variety and harvest methods.

ADF consists mainly of cellulose and lignin, so differences arise from variations in their composition and ratio. The 72 h ADF degradation rate of rice straw measured in this study was less than 30%, with ED less than 20%, consistent with results reported by Li Yang et al. [20]. Overall, kneading treatment had little effect on the ED of NDF and ADF in rice straw. According to various previous studies, factors affecting these parameters include animal species and condition, dietary nutrient levels, and the nature, collection method, and treatment method of samples used in bag trials, all of which require further integrated investigation.

Conclusion

1. Rice straw harvested in late September is more suitable as a roughage for feeding animals compared to rice straw harvested in early November.
2. Kneading treatment of rice straw harvested in early November can improve its nutritional value and ruminal degradation rate.

References

[1] ZHAO L, ZHAO C F, ZHOU L H, et al. Current status and development trends of rice production in China[J]. Jiangsu Agricultural Sciences, 2015, 43(10): 105-107.

[2] WANG Y J, BI Y Y, GAO C Y. Collectable and utilizable amounts of straw resources and their suitability evaluation in China[J]. Scientia Agricultura Sinica, 2010, 43(9): 1852-1859.

[3] HAN L J, YAN Q J, LIU X Y, et al. Crop straw resources and their utilization status in China[J]. Transactions of the Chinese Society of Agricultural Engineering, 2002, 18(3): 87-91.

[4] LI B, GAO X, LIU Y T, et al. Research on feed utilization technology of rice straw resources in Jiangsu Province[J]. Journal of Chinese Agricultural Mechanization, 2017, 38(5): 100-104, 134.

[5] LIU Y Q. Investigation on large-scale comprehensive utilization and technology of crop straw in Jiangsu Province[J]. Science and Technology Information, 2011(26): 162.

[6] GUO X S, CUI W X. Research progress on improving straw feed utilization and nutritional value[J]. Journal of Ningxia Agricultural College, 2002, 23(3): 56-60.

[7] LIANG H, QU M R. Research progress on rice straw silage processing and its application in animals[J]. Prataculture and Animal Husbandry, 2016(5): 1-7.

[8] MENG C H, QIAO Y H, QIAN Y, et al. Effects of ammoniation on nutrient composition and rumen degradation characteristics of rapeseed straw in goats[J]. Chinese Journal of Animal Nutrition, 2016, 28(6): 1796-1803.

[9] WANG J K. Study on ultrastructure and physicochemical properties of rice straw after pretreatment[D]. PhD Thesis. Hangzhou: Zhejiang University, 2006: 31-35.

[10] LI B, CHEN K J, GAO X, et al. Influence of steam explosion on rice straw fiber content[J]. Journal of Biobased Materials and Bioenergy, 2015, 9(6): 596-608.

[11] LI B, CHEN K J, GAO X, et al. The use of steam explosion to increase the nutrition available from rice straw[J]. Biotechnology and Applied Biochemistry,

2015, 62(6): 823-832.

[12] WANG J Q. Research methods in ruminant nutrition[M]. Beijing: Modern Education Press, 2011: 133-136.

[13] ØRSKOV E R, MCDONALD I. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage[J]. The Journal of Agricultural Science, 1979, 92(2): 499-503.

[14] ZHAO L S, NIU J L, XU Y J, et al. Rumen degradation characteristics and small intestinal digestibility of rumen undegraded protein of six feed ingredients[J]. Chinese Journal of Animal Nutrition, 2017, 29(6): 2038-2046.

[15] HUA J L, WANG L K, DAI S F, et al. Effects of different treatment methods on rumen degradation rate of rice straw[J]. Anhui Agricultural Science Bulletin, 2013, 19(13): 28-31.

[16] WANG Y, ZHANG Y P, LIU T Y, et al. Study on nutritional value and degradation characteristics of straw roughage using in vitro fermentation technology[J]. Animal Husbandry and Veterinary Medicine, 2016, 48(12): 24-29.

[17] ZHENG A Z, REN X P. Role of silicon in rice physiology[J]. Agriculture and Technology, 2004, 24(1): 50-52.

[18] WANG Q Q. Study on production and feeding effect of kneaded and microsilage corn straw feed[D]. Master' s Thesis. Luoyang: Henan University of Science and Technology, 2013: 7-16.

[19] LI C L. Evaluation of nutritional value of commonly used roughage for dairy cows[D]. Master' s Thesis. Harbin: Northeast Agricultural University, 2014: 19-30.

[20] LI Y, XIN H S, LI C L, et al. Evaluation of nutritional value of commonly used straw feeds for dairy cows[J]. Journal of Northeast Agricultural University, 2015, 46(4): 76-82.

[21] JIA H J. Study on rumen degradation patterns of commonly used forages for dairy cows[D]. Master' s Thesis. Baoding: Hebei Agricultural University, 2010: 13-29.

[22] DIAO Q Y, TU Y. Rumen degradation parameters of protein in commonly used feeds for dairy cows[J]. Dairy Science and Technology, 2005, 27(2): 70-74.

[23] LIU K Y. Effects of different rice straw treatments on rumen degradation and in vitro methane production[D]. Master' s Thesis. Harbin: Northeast Agricultural University, 2014: 19-20.

[24] MIAO S J, QU Y L, YANG L, et al. Study on rumen degradation rate of nutrients in corn silage harvested at different periods in dairy cows[J]. Chinese Journal of Animal Nutrition, 2007, 19(2): 172-176.

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