Ruminal Degradation Characteristics of Conventional and Unconventional Roughages in Dairy Cows: Postprint

Authors: Liu Yanfang, Ma Jian, In this paper, we propose a novel method to address this problem. This method is based on deep learning technology and can effectively process large-scale datasets. Experimental results demonstrate that our method achieves state-of-the-art performance on multiple benchmarks.

Specifically, our method comprises three main steps: first, we use a pre-trained convolutional neural network to extract features; second, we apply an attention mechanism to enhance important features; finally, we use a fully connected layer for classification. The entire process can be expressed as:

$$y = f_{\text{cls}}(A(f_{\text{cnn}}(x))) \tag{1}$$

where x is the input image, f_{cnn} is the convolutional neural network, A is the attention mechanism, and f_{cls} is the classifier.

We evaluated our method on the CIFAR-10, CIFAR-100, and ImageNet datasets. As shown in Table **??**, our method outperforms existing methods on all datasets. Particularly on the ImageNet dataset, our method achieves a top-1 accuracy of 78.5 %, which is 1.2 % higher than the previous best method.

Furthermore, we conducted ablation studies to validate the effectiveness of each component. The results, as shown in Figure **??**, indicate that removing the attention mechanism leads to a performance drop of 2.3 %, demonstrating that the attention mechanism is crucial for our method. For more details, please refer to Appendix **??**., Wang Yajing, Cao Zhijun, Li Shengli, Yu Xiong

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Abstract

This study aimed to investigate the ruminal degradation characteristics of ten roughage types, including alfalfa silage, whole-plant wheat silage, whole-plant corn silage, alfalfa hay, oat grass (two types), rice straw, peanut vine, millet straw, and wheat straw, in dairy cows to provide data reference for scientifically formulating dairy cow diets. The nylon bag method was employed to evaluate the 72-hour dynamic degradation rates and effective degradation rates

of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF). The results showed that alfalfa silage exhibited the highest DM effective degradation rate at 58.24%, while wheat straw had the lowest at 34.20%; alfalfa hay presented the highest CP effective degradation rate, which was significantly different ($P<0.05$) from whole-plant wheat silage, alfalfa silage, whole-plant corn silage, oat grass, rice straw, wheat straw, millet straw, and peanut vine in descending order; the NDF effective degradation rate of whole-plant wheat silage showed no significant difference ($P>0.05$) from whole-plant corn silage, alfalfa hay, and oat grass, but was significantly higher than other roughages ($P<0.05$); the ADF effective degradation rate of whole-plant wheat silage was significantly higher than that of other roughages ($P<0.05$). In summary, alfalfa hay and alfalfa silage demonstrated higher ruminal degradation rates and superior nutritional value, wheat straw and millet straw were of relatively poorer quality, and peanut vine offered certain advantages compared with the aforementioned straw feeds.

Full Text

Degradation Characteristics of Common and Unconventional Roughage in the Rumen of Dairy Cows

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Abstract: This study investigated the ruminal degradation characteristics of ten roughages—alfalfa silage, whole wheat silage, whole corn silage, alfalfa hay, oat hay (two types), rice straw, peanut vine, millet straw, and wheat straw—to provide data references for scientifically formulating dairy cow diets. The nylon bag technique was employed to evaluate the 72-hour dynamic degradation rates and effective degradability of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF). The results demonstrated that alfalfa silage exhibited the highest DM effective degradability at 58.24%, while wheat straw showed the lowest at 34.20%. Alfalfa hay achieved the highest CP effective degradability, which was significantly higher ($P<0.05$) than those of whole wheat silage, alfalfa silage, whole corn silage, oat hay, rice straw, wheat straw, millet straw, and peanut vine in descending order. The NDF effective degradability of whole wheat silage did not differ significantly from whole corn silage, alfalfa hay, and oat hay ($P>0.05$) but was significantly higher than other roughages ($P<0.05$). Whole wheat silage also showed significantly higher ADF effective degradability than all other roughages ($P<0.05$). In conclusion, alfalfa hay and alfalfa silage possess higher ruminal degradation rates and nutritional

value, wheat straw and millet straw exhibit relatively poor quality, and peanut vine offers certain advantages compared with the aforementioned straw feeds.

Keywords: dairy cow; roughage; rumen; effective degradability

Introduction

Affected by international market conditions, China' s raw milk purchase price averaged 3.47 yuan/kg from January to November 2016, representing only a 1.2% increase compared to the same period in 2015 (3.43 yuan/kg). This persistent low price in China' s raw milk market has placed higher demands on the country' s dairy farming industry. The development of animal husbandry has increased demand for high-quality roughage, consequently raising production costs. China' s high-quality roughage primarily relies on imports; from January to June 2017 alone, China imported 977,200 tons of hay, a year-on-year increase of 21.89%, including 834,500 tons of alfalfa hay (up 20.41%). Since different species and growth stages of herbivores have varying nutritional requirements, the rational use of medium- to low-quality roughage in diets can substantially reduce feed costs without compromising production performance. Therefore, the development and utilization of medium- and low-quality roughage merit serious attention.

Beyond proximate nutrient analysis, studying feed nutrient degradation characteristics in the rumen serves as a common method to reflect nutritional value. China possesses abundant feed resources; Ma et al. studied King Grass and found its ruminal degradation characteristics superior to those of Leymus chinensis. Li et al. evaluated six economic crop byproducts—soybean straw, sugarcane tops, rapeseed straw, ramie, peanut vine, and lotus leaves—and determined that lotus leaves had the highest nutritional value while rapeseed straw had the lowest. Internationally, De Andrade et al. investigated the effects of corn silage, fresh sugarcane, and three types of sugarcane silage on dairy cow performance and digestibility, concluding that fresh sugarcane and sugarcane silage could be applied in dairy production. To better assess roughage nutritional value, analysis of both nutritional composition and degradation rates is necessary. This study analyzed the conventional nutritional components of ten roughages and employed the nylon bag technique to investigate nutrient degradation patterns in the rumen, providing data references for rational feed resource utilization and supplementing China' s feed nutritional value database.

1.1 Experimental Materials

The ten roughages selected for this study included alfalfa silage, whole corn silage, whole wheat silage, alfalfa hay, oat hay (two types), rice straw, peanut vine, millet straw, and wheat straw. Detailed descriptions of the feeds are provided in Table 1 . Collected silage samples were dried to constant weight in a 65°C oven to calculate initial moisture content. All feed samples were ground, with a portion passing through a 1 mm sieve for conventional nutrient analysis

and another portion through a 2.5 mm sieve for rumen degradation trials.

1.2 Experimental Procedure

Nylon cloth with 40–60 m pore size was sewn into 8$×$12 cm bags. Exactly 4 g of air-dried feed sample was placed in each bag bottom. Four replicates were prepared per time point per cow, with every four bags secured to a 50 cm flexible plastic tube using rubber bands. The other end of the tube was tied to a sturdy nylon rope, which was fastened to an iron ring outside the fistula. All nylon bags were inserted into the rumen via the fistula 1 hour before morning feeding. Following the principle of "simultaneous insertion, sequential removal," bags were retrieved at 4, 8, 12, 24, 30, 36, 48, and 72 hours post-insertion. Retrieved bags were rinsed with tap water until the rinse water ran clear, then dried in a 65°C constant-temperature oven for 48 hours. After cooling, bags were weighed and recorded for subsequent analysis.

1.3 Experimental Animals and Management

Four healthy lactating Chinese Holstein cows in late lactation, with similar body condition, weight, parity, and milk yield, were fitted with permanent rumen fistulas. The trial was conducted at the Beijing Zhongdi Dairy Science and Technology Park. The basal diet was formulated according to *Nutrient Requirements and Feeding Standards for Dairy Cows*. Composition and nutrient levels of the basal diet are presented in Table 2 . Cows were fed twice daily with free access to water.

1.4 Measurement Indicators and Methods

Residual samples from nylon bags were ground through a 1 mm analytical sieve after drying. Dry matter (DM) was determined by oven-drying method, crude protein (CP) by Kjeldahl method, and neutral detergent fiber (NDF) and acid detergent fiber (ADF) by Van Soest method. Specific procedures followed *Feed Analysis and Feed Quality Detection Technology*.

1.5 Calculation Formulas

The real-time degradation rate of a nutrient in feed samples was calculated as: Degradation rate (%) = 100 × (nutrient content before degradation -nutrient content after degradation) / nutrient content before degradation.

Dynamic degradation model parameters and effective degradability (ED) were calculated using the model proposed by Ørskov et al.:

P = a + b(1 - e^(-ct))
Effective degradability = a + b × c / (k + c)

Where: t represents feed retention time in the rumen (h); P represents real-time degradation rate (%) of a nutrient at time t; a represents the rapidly degradable

fraction (%); b represents the slowly degradable fraction (%); c represents the degradation rate of the slowly degradable fraction (%/h); and k represents the rumen outflow rate (%/h) of the nutrient, which was set at 0.031%/h according to Gong et al.

1.6 Statistical Analysis

SAS 9.2 software was used to calculate a, b, and c values using a nonlinear exponential model, followed by ANOVA and Duncan' s multiple comparison tests for mean analysis. Results are expressed as mean ± standard deviation, with $P<0.05$ as the significance threshold.

Results and Analysis

2.1 Conventional Nutrient Composition of Ten Roughages

As shown in Table 3 , substantial differences existed in nutrient composition among the ten roughages. Among silages, alfalfa silage had the highest DM content, significantly higher than the other two silages ($P<0.05$), while hay DM content was approximately 90%. CP content ranged from 3.05% to 20.39%, with alfalfa silage showing the highest value. Both alfalfa silage and alfalfa hay had significantly higher CP content than other roughages ($P<0.05$), while wheat straw had the lowest CP content at only 3.05%. NDF content across all feeds ranged from 41.93% to 83.62%, with wheat straw showing the highest value (83.62%), significantly exceeding other roughages ($P<0.05$). Whole corn silage had significantly lower NDF content than whole wheat silage ($P<0.05$). Similar to NDF results, wheat straw also had the highest ADF content (54.03%), significantly higher than other roughages ($P<0.05$), while whole corn silage had the lowest ADF content.

2.2 DM Degradation Characteristics

Table 4 shows that alfalfa silage achieved a DM degradation rate of 40.14% at 4 hours. All three silages reached over 60% DM degradation by 36 hours. At 72 hours, alfalfa silage showed significantly higher DM degradation than whole corn silage ($P<0.05$) but did not differ significantly from whole wheat silage ($P>0.05$). Alfalfa hay exhibited significantly higher DM degradation rates at all time points compared to other hays ($P<0.05$), while the two oat hays showed no significant differences in degradation rates within 72 hours ($P>0.05$). Peanut vine demonstrated significantly higher DM degradation at 72 hours than millet straw ($P<0.05$). Millet straw and wheat straw showed low degradation rates during the first 24 hours, with wheat straw' s DM degradation rate being lower than millet straw within 24 hours but accelerating thereafter, resulting in significantly higher DM degradation than millet straw at 72 hours ($P<0.05$).

As presented in Table 5 , DM degradation parameters varied considerably among roughages. Alfalfa silage had the highest rapidly degradable fraction (34.28%),

which did not differ significantly from whole corn silage (P>0.05) but was significantly higher than other roughages (P<0.05). Wheat straw had the lowest rapidly degradable fraction at only 0.72%. Wheat straw also showed the highest slowly degradable fraction, significantly exceeding other feeds (P<0.05). The effective degradability of alfalfa silage and alfalfa hay did not differ significantly (P>0.05) but was significantly higher than other roughages (P<0.05). The two oat hays showed similar effective degradability (P>0.05). Millet straw and wheat straw had relatively low effective degradability values of 34.74% and 34.20%, respectively.

2.3 CP Degradation Characteristics

Table 6 reveals that alfalfa hay reached a CP degradation rate of 58.85% by 8 hours and 82.79% by 72 hours, significantly higher than all other roughages (P<0.05). Alfalfa silage showed significantly lower CP degradation rates than whole wheat silage before 12 hours (P<0.05) but significantly higher rates at 72 hours (P<0.05). Except at 48 hours, the two oat hays showed no significant differences in CP degradation rates (P>0.05), with CP degradation slowing after 30 hours. Peanut vine exhibited significantly lower CP degradation than rice straw at 12 hours (P<0.05), though the difference was not significant at 72 hours (P>0.05). Peanut vine showed low CP degradation at 4 hours, with degradation slowing after 24 hours, indicating that CP degradation in peanut vine primarily occurred between 12 and 24 hours.

As shown in Table 7 , whole wheat silage had the highest rapidly degradable CP fraction, significantly exceeding other roughages (P<0.05), followed by alfalfa silage and whole corn silage, which did not differ significantly (P>0.05). Peanut vine had the lowest rapidly degradable CP fraction at only 1.55%. Conversely, peanut vine showed the highest slowly degradable CP fraction, significantly higher than other roughages (P<0.05). Alfalfa hay achieved the highest effective degradability, while peanut vine had the lowest, which did not differ significantly from millet straw and wheat straw (P>0.05). These three were significantly lower than other roughages (P<0.05).

2.4 NDF Degradation Characteristics

Table 8 shows that whole wheat silage achieved the highest NDF degradation rate at 72 hours, which did not differ significantly from whole corn silage (P>0.05) but was significantly higher than all other feeds (P<0.05). Alfalfa hay and alfalfa silage exhibited rapid NDF degradation before 24 hours, after which the rate slowed. At 4 hours, all hays except alfalfa hay had NDF degradation rates below 10%. Wheat straw showed the lowest 72-hour NDF degradation rate, significantly lower than other roughages (P<0.05).

As presented in Table 9 , all roughages had low rapidly degradable NDF fractions with no significant differences among them (P>0.05). The highest value was observed in alfalfa hay at only 2.28%. Whole wheat silage had the highest

slowly degradable NDF fraction, which did not differ significantly from whole corn silage and peanut vine (P>0.05) but was significantly higher than other roughages (P<0.05). The two oat hays showed no significant difference in NDF effective degradability (P>0.05). Wheat straw exhibited the lowest NDF effective degradability among all roughages.

2.5 ADF Degradation Characteristics

Table 10 indicates that at 4 hours, whole wheat silage had the highest ADF degradation rate (11.79%), while wheat straw had the lowest (4.18%). At 72 hours, wheat straw's ADF degradation rate was significantly lower than all other roughages (P<0.05), whereas peanut vine' s ADF degradation rate exceeded 50%.

As shown in Table 11 , rice straw had the highest rapidly degradable ADF fraction, while the two oat hays had lower values. The slowly degradable ADF fraction varied considerably, ranging from 43.60% to 79.39%, with peanut vine showing the highest value, significantly exceeding other roughages (P<0.05). Whole wheat silage achieved the highest effective degradability, while wheat straw had the lowest effective degradability among all roughages.

Discussion

3.1 Conventional Nutrient Composition of Roughages

The nutritional value of roughage is influenced not only by species but also by harvest time, growing environment, and processing methods. In this study, alfalfa silage had significantly higher DM content than the other two silages, and its CP content was significantly higher than whole wheat and whole corn silage. Zhang reported that alfalfa silage has high CP content, consistent with our findings. In this trial, hay and straw feeds showed similar DM content but differed substantially in CP and NDF content, aligning with previous research. Alfalfa hay had the highest CP content, befitting its title as the "king of forages." The two oat hays showed no significant differences in NDF and ADF content, but oat hay 2 had 43.55% higher CP than oat hay 1, attributable to species differences. Qiu reported wheat straw CP content of 3.60% and NDF content of 74.94%; our CP value was lower and NDF higher, possibly due to harvest stage differences. Peanut vine showed higher CP content and relatively lower NDF and ADF content compared to rice straw and other straws, indicating superior nutritional quality and confirming results from Li et al.

3.2 DM Degradation Characteristics of Different Roughages

DM degradation rate is a crucial factor affecting dry matter intake (DMI) in dairy cows, with higher degradation rates leading to greater DMI. This study revealed that different roughages showed varying increasing trends in DM degradation rate over time. The 72-hour DM degradation rate of whole corn silage

in this trial was lower than that reported by Xia et al., possibly due to differences in experimental animals. Alfalfa silage showed slightly higher effective degradability than alfalfa hay, suggesting that ensiling not only preserves nutrients but also improves digestibility. The two oat hays showed similar effective degradability and dynamic degradation patterns, indicating comparable DMI potential.

Among crop residues, peanut vine exhibited significantly higher DM effective degradability than rice straw, millet straw, and wheat straw, indicating easier digestibility. Peanut vine reached 47.81% DM degradation by 24 hours, with stable increases thereafter, suggesting degradation primarily occurs within 24 hours, similar to alfalfa. Compared to peanut vine, millet straw and wheat straw had higher plant maturity, increased cell content, and decreased cell wall content, resulting in lower DM degradation rates. Our peanut vine DM degradation results are consistent with Zheng et al., suggesting that peanut vine can be better utilized by dairy cows compared to millet and wheat straw.

3.3 CP Degradation Characteristics of Different Roughages

CP degradation rate is primarily influenced by feed protein content, composition, and rumen retention time. In this study, the effective degradability of alfalfa hay and whole corn silage was 69.85% and 63.63%, respectively, similar to previous findings. Although whole wheat silage had lower CP content than alfalfa silage, its effective degradability was slightly higher, possibly due to protein composition differences requiring further investigation. The CP degradation rates of all three silages exceeded 60% at 24 hours, indicating that CP degradation in silages occurs mainly before 24 hours, consistent with Yao' s findings.

Larry noted that CP degradation rate is greatly affected by feed properties, with varying proportions of rapidly degradable, slowly degradable, and undegradable fractions among feeds. In this trial, peanut vine showed higher 72-hour CP degradation than millet and wheat straw, but its effective degradability was slightly lower due to its extremely low rapidly degradable fraction. Considering CP content across different feeds, the ranking of CP content did not completely match the ranking of ruminal degradation rates, demonstrating that chemical analysis alone cannot fully determine roughage nutritional value and must be combined with assessments of utilization after ingestion or rumen fluid contact.

3.4 NDF and ADF Degradation Characteristics of Different Roughages

Ruminal degradation rates of NDF and ADF are important indicators of roughage quality, reflecting feed digestibility. Crude fiber comprises lignin, cellulose, and hemicellulose, with lignin being unavailable to microorganisms; thus, fiber digestion in the rumen is primarily limited by lignin content. Qiu noted that different roughages have varying NDF and ADF contents, resulting

in different rumen effective degradability rates. Xia et al. reported that ensiling improves feed degradability, but our study found no significant difference in NDF degradation between alfalfa silage and alfalfa hay, possibly due to feed variety differences. Dynamic trends showed that NDF and ADF degradation rates in the three silages were generally low before 12 hours but high at 72 hours, indicating that NDF and ADF degradation in silage feeds occurs mainly after 12 hours.

In this trial, wheat straw showed low NDF effective degradability due to reduced digestible components with plant maturity. Our results indicated that alfalfa hay had lower ADF effective degradability than oat hay, contradicting previous research but consistent with Hou et al., possibly related to feed sources and experimental animals. Jung et al. reported that grasses have higher potentially degradable fiber fractions than legumes but lower degradation rates, which aligns with our findings. Legume forages exhibit fast degradation of the slowly degradable NDF fraction but also contain more indigestible portions, resulting in NDF degradation rates similar to grasses, consistent with Hoffman et al.

ADF represents the most indigestible portion of roughage, resulting in generally low ruminal degradation rates.

Conclusion

1. The degradation rates of DM, CP, NDF, and ADF in different roughages showed varying degrees of increase with prolonged incubation time in the rumen.
2. Alfalfa hay and alfalfa silage demonstrated higher ruminal degradation rates and nutritional value, while wheat straw and millet straw exhibited relatively poor quality. Peanut vine offers certain advantages compared with the aforementioned straw feeds.

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Note: Figure translations are in progress. See original paper for figures.