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

Authors: Liu Yanfang, Ma Jian, full text, Wang Yajing, Cao Zhijun, Li Shengli, Yu Xiong

Date: 2018-12-24T00:00:00+00:00

Abstract

This study aimed to investigate the ruminal degradation characteristics of ten roughages, including alfalfa silage, whole-plant wheat silage, whole-plant corn silage, alfalfa hay, oat hay (two types), rice straw, peanut vine, millet straw, and wheat straw, in dairy cows to provide reference data for scientific formulation of dairy cow diets. The nylon bag technique 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 indicated that alfalfa silage had the highest DM effective degradation rate at 58.24%, while wheat straw had the lowest at 34.20%; alfalfa hay exhibited 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 hay, rice straw, wheat straw, millet straw, and peanut vine in descending order; the NDF effective degradation rate of whole-plant wheat silage was not significantly different ($P>0.05$) from that of whole-plant corn silage, alfalfa hay, and oat hay, 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 rumen degradation rates and nutritional value, wheat straw and millet straw were of relatively poorer quality, and peanut vine possessed certain advantages compared with the aforementioned straw feeds.

Full Text

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

LIU Yanfang[1,2], **MA Jian**[1*], **DU Wen**[2], **WANG Yajing**[2], **CAO Zhijun**[2], **LI Shengli**[2], YU Xiong[1]

(1. College of Animal Science and Technology, Xinjiang Agricultural University, Urumqi 830052, China;
2. State Key Laboratory of Animal Nutrition, Beijing Engineering Technology Research Center of Raw Milk Quality and Safety Control, College of Animal Science and Technology, China Agricultural University, Beijing 100193, China)

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 dynamic degradation rates and effective degradability of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) over 72 hours. 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 had the highest CP effective degradability, which was significantly higher than that of whole wheat silage, alfalfa silage, whole corn silage, oat hay, rice straw, wheat straw, millet straw, and peanut vine in descending order ($P<0.05$). The NDF effective degradability of whole wheat silage did not differ significantly from that of whole corn silage, alfalfa hay, and oat hay ($P>0.05$), but was significantly higher than other roughages ($P<0.05$). The ADF effective degradability of whole wheat silage was significantly higher than all other roughages ($P<0.05$). In conclusion, alfalfa hay and alfalfa silage demonstrate higher ruminal degradation rates and nutritional value, while wheat straw and millet straw exhibit relatively poor quality; peanut vine offers certain advantages compared with the aforementioned straw feeds.

Keywords: dairy cow; roughage; rumen; effective degradability

Introduction

Influenced by international markets, 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) [1]. The prolonged depression in domestic raw milk prices has imposed higher demands on China' s dairy farming industry. The development of animal husbandry has increased demand for high-quality roughage, consequently raising production costs [2]. China primarily relies on imports for quality roughage; from January to June 2017, the country imported 977,200 tons of hay, a year-on-year increase of 21.89%, in-

cluding 834,500 tons of alfalfa hay, up 20.41% year-on-year. Different herbivore species and growth stages have varying nutritional requirements, and rational utilization 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 warrant 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. [3] investigated the ruminal degradation characteristics of *Pennisetum* hybrid and found its degradation properties superior to those of *Leymus chinensis*. Li et al. [4] evaluated six economic crop by-products—soybean straw, sugarcane tops, rapeseed straw, ramie, peanut vine, and lotus leaf—and determined that lotus leaf had the highest nutritional value while rapeseed straw had the lowest. Internationally, De Andrade et al. [5] examined 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.

Materials and Methods

1.1 Experimental Materials

The ten roughages selected for this experiment 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; one portion was passed through a 1 mm sieve for conventional nutritional index determination, while another portion was passed through a 2.5 mm sieve for ruminal degradation trials.

1.2 Experimental Procedure

Nylon cloth with 40–60 m pore size was sewn into 8×12 cm bags. Accurately weighed 4 g air-dried samples were placed at the bottom of each nylon bag. Four replicates were prepared per time point per cow, with four bags secured together using a rubber band attached to a 50 cm flexible plastic tube. The other end of the tube was tied to a sturdy nylon rope, which was fixed to an iron ring outside the fistula. All nylon bags were inserted into the rumen via the fistula one 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, weighed after cooling, and stored for analysis.

1.3 Experimental Animals and Management

Four healthy lactating Chinese Holstein dairy 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 Livestock Dairy Science and Technology Park. The basal diet was formulated according to *Nutrient Requirements and Feeding Standards for Dairy Cows*. The 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

Residuals in nylon bags were ground using a mill and passed through a 1 mm analytical sieve. 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* [7].

1.5 Calculation Formulas

The real-time degradation rate of a nutrient in feed samples (%) was calculated as:
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. [8]:

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

$$ED = a + b \times c/(k + c)$$

Where:
- t = retention time of feed in the rumen (h)
- P = real-time degradation rate of a nutrient at time t (%)
- a = rapidly degradable fraction of the nutrient (%)
- b = slowly degradable fraction (%)
- c = degradation rate of the slowly degradable fraction (%/h)
- k = ruminal outflow rate of the nutrient (%/h); following Gong et al. [9], k was set at 0.031%/h

1.6 Statistical Analysis

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

Results

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%; alfalfa silage had the highest CP content, with both alfalfa silage and hay showing significantly higher CP than other roughages ($P < 0.05$). Wheat straw had the lowest CP content at only 3.05%. NDF content across all feeds ranged from 41.93% to 83.62%; wheat straw had the highest NDF content at 83.62%, significantly higher than other roughages ($P < 0.05$), while whole corn silage had significantly lower NDF content than whole wheat silage ($P < 0.05$). Similar to NDF results, wheat straw had the highest ADF content at 54.03%, significantly higher than other roughages ($P < 0.05$), with whole corn silage showing the lowest ADF content.

2.2 DM Degradation Characteristics

Table 4 shows that alfalfa silage had a DM degradation rate of 40.14% at 4 hours. All three silages reached DM degradation rates above 60% by 36 hours. At 72 hours, alfalfa silage' s DM degradation rate was significantly higher than that of 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' s DM degradation rate at 72 hours was significantly higher than that of millet straw ($P < 0.05$). Millet straw and wheat straw had low degradation rates during the first 24 hours; wheat straw' s DM degradation rate was lower than millet straw within 24 hours but accelerated thereafter, becoming significantly higher than millet straw at 72 hours ($P < 0.05$).

As shown in Table 5 , DM degradation parameters varied considerably among roughages. Alfalfa silage had the highest rapidly degradable fraction at 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 had the highest slowly degradable fraction, significantly higher than other feeds ($P < 0.05$). The effective degradability of alfalfa silage and alfalfa hay did not differ signifi-

cantly ($P > 0.05$) but was significantly higher than other roughages ($P < 0.05$). The two oat hays showed no significant difference in effective degradability ($P > 0.05$). Millet straw and wheat straw had relatively low effective degradability at 34.74% and 34.20%, respectively.

2.3 CP Degradation Characteristics

Table 6 indicates that alfalfa hay reached a CP degradation rate of 58.85% at 8 hours and 82.79% at 72 hours, significantly higher than all other roughages ($P < 0.05$). Alfalfa silage' s CP degradation rate was significantly lower than whole wheat silage before 12 hours ($P < 0.05$) but significantly higher 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' s CP degradation rate at 12 hours was significantly lower than rice straw' s ($P < 0.05$), but the difference was not significant at 72 hours ($P > 0.05$). Peanut vine had a low CP degradation rate at 4 hours, with degradation slowing after 24 hours, indicating that CP degradation in peanut vine primarily occurred between 12-24 hours.

As shown in Table 7 , whole wheat silage had the highest rapidly degradable CP fraction, significantly higher than 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' s slowly degradable CP fraction was significantly higher than other roughages ($P < 0.05$). Alfalfa hay had 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 had 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 other feeds ($P < 0.05$). Alfalfa hay and alfalfa silage exhibited rapid NDF degradation before 24 hours, after which the rate slowed. Except for alfalfa hay, all other hays had NDF degradation rates below 10% at 4 hours. Wheat straw had the lowest NDF degradation rate at 72 hours, significantly lower than other roughages ($P < 0.05$).

As shown in Table 9 , all roughages had low rapidly degradable NDF fractions with no significant differences among them ($P > 0.05$); the highest was 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 had 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 at 11.79%, while wheat straw had the lowest at 4.18%. At 72 hours, wheat straw' s ADF degradation rate was significantly lower than all other roughages ($P < 0.05$), while peanut vine's ADF degradation rate exceeded 50%.

As shown in Table 11 , rice straw had the highest rapidly degradable ADF fraction, while oat hay 1 and oat hay 2 had lower values. The slowly degradable ADF fraction varied considerably, ranging from 43.60% to 79.39%; peanut vine' s slowly degradable fraction was significantly higher than other roughages ($P < 0.05$). Whole wheat silage had the highest effective degradability, while wheat straw had the lowest effective degradability among all roughages.

Discussion

3.1 Conventional Nutrient Composition of Roughages

Roughage nutritional value is influenced not only by species but also by harvest time, growing conditions, 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 that of whole wheat and whole corn silage. Zhang [10] reported that alfalfa silage has high CP content, consistent with our findings. In this experiment, hay and straw feeds showed similar DM content but differed considerably in CP and NDF content, aligning with previous research [11]. Alfalfa hay had the highest CP content, consistent with its reputation 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 [12] reported wheat straw CP content of 3.60% and NDF content of 74.94%. Our results showed lower CP and higher NDF content, possibly due to harvest stage differences. Peanut vine had higher CP content and relatively lower NDF and ADF content compared to rice straw and other straws, indicating superior nutritional quality, consistent with Li et al. [2].

3.2 DM Degradation Characteristics of Different Roughages

DM degradation rate is a crucial factor affecting dry matter intake (DMI) in dairy cows; higher DM degradation rates correspond to greater DMI. Our results demonstrate that different roughages exhibited varying rates of increase in DM degradation over time. The 72-hour DM degradation rate of whole corn silage in this study was lower than that measured by Xia et al. [13], possibly due to differences in experimental animals. The effective degradability of alfalfa silage was slightly higher than that of 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, suggesting

comparable DMI.

Among crop residues, peanut vine' s DM effective degradability was significantly higher than that of rice straw, millet straw, and wheat straw, indicating easier digestibility. Peanut vine's DM degradation rate reached 47.81% at 24 hours and continued to increase steadily, suggesting that like alfalfa, degradation primarily occurs within 24 hours. Compared to peanut vine, millet straw and wheat straw have higher plant maturity, increased cell content, and decreased cell wall content, resulting in lower DM degradation rates. Our peanut vine DM degradation results are essentially consistent with Zheng et al. [14], suggesting that peanut vine can be better digested and utilized by dairy cows compared to millet straw and wheat straw.

3.3 CP Degradation Characteristics of Different Roughages

CP degradation rate is primarily influenced by feed protein content, composition, and retention time in the rumen [15]. In this study, the effective degradability of alfalfa hay and whole corn silage was 69.85% and 63.63%, respectively, similar to previous findings [13]. 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 [16].

Larry [17] noted that CP degradation rate is greatly affected by feed properties, with varying proportions of rapidly degradable, slowly degradable, and undegradable fractions among different feeds. In this study, although peanut vine' s CP degradation rate at 72 hours was higher than that of millet straw and wheat straw, its effective degradability was slightly lower due to its very 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; assessment of utilization after ingestion or rumen fluid contact is also required.

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; lignin is not utilized by microorganisms, so fiber digestion is primarily limited by lignin content. Qiu [12] noted that different roughages have varying NDF and ADF contents, resulting in different ruminal effective degradability rates. Xia et al. [13] reported that ensiling improves feed degradability, but in this study, no significant difference in NDF degradation rate was observed between alfalfa silage and alfalfa hay, possibly due to feed species differences. Dynamic trends showed that NDF and ADF degradation

rates of 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 experiment, wheat straw had low NDF effective degradability because plant maturity reduces digestible components. The results showed that alfalfa hay' s ADF effective degradability was lower than that of oat hay, inconsistent with previous research [12] but similar to Hou et al. [18], possibly due to feed sources and experimental animals. Jung et al. [19] reported that grasses have higher potentially degradable fiber fractions than legumes but lower degradation rates, consistent with our findings. Legume forages have fast degradation rates for the slowly degradable NDF fraction but also more undegradable fractions, resulting in NDF degradation rates similar to grasses, consistent with Hoffman et al. [20]. ADF is the most difficult component to digest in 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 exhibited higher ruminal degradation rates and nutritional value, while wheat straw and millet straw showed relatively poor quality; peanut vine offers certain advantages compared with the aforementioned straw feeds.

References

[1] LI Shengli, YAO Kun, CAO Zhijun, et al. 2016 Annual Report on Dairy Industry Technology Development [J]. Chinese Journal of Animal Science, 2017, 53(1): 156-164.

[2] LI Yang, DOU Xiujing, ZHANG Xingyi, et al. Comparative Study on Grading Index and Relative Value of Unconventional Roughage [J]. Journal of Northeast Agricultural University, 2016, 47(2): 54-60.

[3] MA Jian, LIU Yanfang, DU Yun, et al. Comparative Study on Rumen Degradation Characteristics of *Pennisetum* Hybrid and Common Roughages for Dairy Cows [J]. Chinese Journal of Animal Nutrition, 2016, 28(3): 816-825.

[4] LI Lizhi, PAN Ke, OUYANG Kehui, et al. Nutritional Value Evaluation of Six Economic Crop By-products [J]. Heilongjiang Animal Science and Veterinary Medicine, 2016(8): 151-153.

[5] DE ANDRADE F L, RODRIGUES J P P, DETMANN E, et al. Nutritional and Productive Performance of Dairy Cows Fed Corn Silage or Sugarcane Silage with or without Additives [J]. Tropical Animal Health and Production, 2016, 48(4): 747-753.

[6] FENG Yanglian, ZHOU Jianmin, ZHANG Xiaoming, et al. Study on Calculation Method of Net Energy for Lactation of Dairy Feed in China [J]. Chinese Journal of Animal Science, 1987(1): 8-11.

[7] ZHANG Liying. Feed Analysis and Feed Quality Detection Technology [M]. 2nd ed. Beijing: China Agricultural University Press, 2003.

[8] 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.

[9] GONG Fuchen, HAN Meilin, YANG Qiong, et al. Comparative Study on Rumen Degradation Characteristics of Spent Mushroom Substrate and Common Roughages for Dairy Cows [J]. Chinese Journal of Animal Nutrition, 2013, 25(6): 1366-1374.

[10] ZHANG Xiaona. Effects of Cutting Stage, Variety and Ensiling Method on Alfalfa Quality [D]. Master' s Thesis. Yangling: Northwest A&F University, 2016.

[11] CHEN Xiaolin. Study on Nutritional Value and Rumen Degradation Characteristics of Common Roughages for Mutton Sheep [D]. Master' s Thesis. Qingdao: Qingdao Agricultural University, 2014.

[12] QIU Yan. Nutritional Components, Rumen Degradation Rates, and in vitro Fermentation Characteristics of Common Roughages for Dairy Cows [D]. Master' s Thesis. Beijing: China Agricultural University, 2013.

[13] XIA Ke, YAO Qing, LI Fuguo, et al. Rumen Degradation Patterns of Common Roughages for Dairy Cows [J]. Chinese Journal of Animal Nutrition, 2012, 24(4): 769-777.

[14] ZHENG Xiangli, WANG Junhong, XU Guozhong, et al. Degradation Characteristics of Four Types of Peanut Straw in the Rumen of Dairy Cows [J]. Acta Prataculturae Sinica, 2016, 25(5): 149-155.

[15] FENG Yanglian. Ruminant Nutrition [M]. Beijing: Science Press, 2004.

[16] YAO Qing. Nutritional Value Evaluation of Corn Stover Fermented with Alcohol Wastewater and Its Effects on Dairy Cow Performance [D]. Master' s Thesis. Harbin: Northeast Agricultural University, 2013.

[17] LARRY D S. Protein Supply from Undegraded Dietary Protein [J]. Journal of Dairy Science, 1986, 69(10): 2734-2749.

[18] HOU Yujie, XU Jun, WU Chunhua, et al. Study on Degradation Characteristics of Five Different Forages in the Rumen of Dairy Cows [J]. China Dairy Cattle, 2013(16): 4-8.

[19] JUNG H G, ALLEN M S. Characteristics of Plant Cell Walls Affecting Intake and Digestibility of Forages by Ruminants [J]. Journal of Animal Science, 1995, 73(9): 2774-2790.

[20] HOFFMAN P C, SIEVERT S J, SHAVER R D, et al. In Situ Dry Matter, Protein, and Fiber Degradation of Perennial Forages [J]. Journal of Dairy Science, 1993, 76(9): 2632-2643.

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