Effects of Ammoniation on Nutritional Composition and Rumen Degradation Characteristics of Rapeseed Straw in Goats (Postprint)

Authors: Meng Chunhua, Qiao Yonghao, Qian Yong, Wang Ziyu, Wang Huili, Cao Xianxian

Date: 2017-10-23T00:00:00+00:00

Abstract

This experiment aimed to investigate the effects of ammonia treatment on the nutritional components and rumen degradation characteristics of rapeseed straw in goats. Ground rapeseed straw was treated with 30% water and different proportions of ammonium bicarbonate (10%, 15%, 20%) for ammoniation, and samples were collected at 7, 14, and 21 days post-treatment. Simultaneously, nutritional composition analysis was conducted on both ammonia-treated and untreated rapeseed straw (control). The nylon bag technique was then employed to determine the rumen degradation rates of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) in ammonia-treated and untreated rapeseed straw. The results demonstrated that ammonia treatment increased the CP content of rapeseed straw, while decreasing the ether extract (EE), NDF, and ADF contents; DM and crude ash contents remained essentially unchanged. The effective degradation rates of DM and CP in ammonia-treated rapeseed straw were significantly higher than those in the control group ($P<0.05$). The effective degradation rates of ADF in rapeseed straw treated with 15% and 20% ammonium bicarbonate were significantly higher than that in the control group ($P<0.05$). In conclusion, ammoniation with 15% and 20% ammonium bicarbonate can significantly improve the rumen degradation rates of DM, CP, and ADF in rapeseed straw in goats, with the optimal and most economical treatment being 15% ammonium bicarbonate under 30% moisture conditions.

Full Text

Preamble

Ammonification of Rape Straw: Effects on Nutrient Composition and Rumen Degradation Characteristics in Goats

MENG Chunhua[1,2], QIAO Yonghao[1,3], QIAN Yong[1,2], WANG Ziyu[3], WANG Huili[1,2], CAO Shaoxian[1,2*]

[1]Institute of Animal Science, Jiangsu Academy of Agricultural Sciences, Nanjing 210014, China
[2]Key Laboratory of Animal Breeding and Reproduction, Jiangsu Academy of Agricultural Sciences, Nanjing 210014, China
[3]College of Animal Science, Nanjing Agricultural University, Nanjing 210095, China

Abstract: This study investigated the effects of ammonification on the nutrient composition and rumen degradation characteristics of rape straw in goats. Crushed rape straw was treated with 30% water and varying proportions of ammonium bicarbonate (10%, 15%, and 20%) for 7, 14, and 21 days. Samples of both ammonified and untreated rape straw (control) were collected for nutrient composition analysis. The rumen degradation rates of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) were determined using the nylon bag technique. The results demonstrated that ammonification increased CP content while decreasing ether extract (EE), NDF, and ADF contents; DM and ash contents remained essentially unchanged. The effective degradability of DM and CP in ammonified groups was significantly higher than in the control group ($P<0.05$). The effective degradability of ADF in the 15% and 20% ammonium bicarbonate groups was also significantly higher than in the control group ($P<0.05$). In conclusion, ammonification with 15% and 20% ammonium bicarbonate significantly improved the rumen degradability of DM, CP, and ADF in rape straw for goats, with treatment using 15% ammonium bicarbonate and 30% water representing the optimal and most economical condition.

Keywords: rape straw; ammonification; rumen degradation; goat

---

Introduction

China generates approximately 600 million tons of crop residues annually, the highest in the world. Southern agricultural regions are particularly rich in straw resources, yet comprehensive utilization efforts remain underdeveloped. Open burning of straw, despite being prohibited, persists as a social problem causing severe air pollution [1]. Rapeseed is China' s largest oil crop, predominantly cultivated in the southern Yangtze River basin, with an annual planting area of about 6.7 million hectares and rape straw production of approximately 20

million tons. The conversion and utilization of this resource represent an urgent challenge [1-4].

Furthermore, southern agricultural regions face shortages of roughage resources, which constrain the development of herbivorous livestock production. Rape straw contains relatively high levels of crude protein (CP) and crude fiber, making it a potential partial substitute for conventional roughage [4-5]. However, direct feeding of rape straw is limited by poor palatability, low intake rates, large volume, susceptibility to mold, and inconvenient transportation, storage, and feeding, resulting in very low feed utilization efficiency [4].

Ammonification is a straw treatment method that enhances feeding value by spraying ammonia sources (liquid ammonia, ammonia water, urea solution, or ammonium bicarbonate solution) onto straw under sealed conditions, allowing chemical reactions to occur at suitable temperatures over a specified period. This process can improve palatability and digestibility, increase CP content, and extend storage time to meet the feeding requirements of ruminants. This study compared the effects of different ammonium bicarbonate addition levels on rape straw ammonification, determining optimal treatment methods through nutrient composition analysis and rumen degradation measurements to provide a scientific basis for the feed utilization of rape straw.

Materials and Methods

1.1 Experimental Materials and Animals

Rape straw was collected from the experimental base of the Industrial Crops Institute at the Jiangsu Academy of Agricultural Sciences. Three Boer crossbred goats fitted with permanent rumen fistulas served as experimental animals. The trial was conducted at the Liuhe Animal Science Base of the Jiangsu Academy of Agricultural Sciences.

1.2 Experimental Methods

After collection, rape straw was sun-dried (moisture content 9.31%) and crushed into 0.3–3.0 cm pieces. The material was divided into four groups: one control group of untreated rape straw (air-dried) and three ammonification groups treated with 30% water and different proportions of ammonium bicarbonate (10%, 15%, and 20%). The mixtures were packed in plastic bags, vacuum-sealed, and stored at room temperature. Each treatment had three replicates, and samples were collected at 7, 14, and 21 days post-ammonification for analysis.

1.3 Nutrient Composition Analysis

Crude protein content was determined by the Kjeldahl method, ether extract (EE) by Soxhlet extraction, and neutral detergent fiber (NDF) and acid detergent fiber (ADF) by the Van Soest method. Dry matter (DM) was measured by oven drying, ash content by incineration, and calcium (Ca) and phosphorus

(P) by colorimetry, following the procedures detailed in *Feed Analysis and Feed Quality Detection Technology* edited by Zhang Liying.

1.4 Rumen Degradation Experiment and Sample Collection

Three 2-year-old Boer crossbred does fitted with rumen fistulas were used. The basal diet consisted of corn silage as roughage and a concentrate mixture containing corn, soybean meal, and other ingredients. Diet composition and nutrient levels are presented in Table 1 . Animals were housed individually and fed twice daily.

Samples from control and treatment groups (approximately 2 g each) were placed in nylon bags (12 cm × 8 cm, made from 50 m pore size nylon cloth and double-stitched with polyester thread). Bags were pre-incubated in the rumen for 72 h, then removed, washed, and dried at 65°C before use. Sample bags were incubated in the rumen of each fistulated goat for 3, 6, 12, 24, 36, 48, and 72 h, with two replicates per time point per goat. After incubation, bags were removed, washed, dried, and used to calculate the real-time rumen degradation rates of DM, CP, NDF, and ADF at each time point.

1.5 Data Processing and Analysis

Rumen degradation kinetics were calculated using the exponential model proposed by Ørskov et al. [6]:

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

where:
a = rapidly degradable fraction (%)
b = slowly degradable fraction (%)
c = degradation rate of fraction b (%/h)
dp = real-time rumen degradation rate of a nutrient at time t (%)
t = feed retention time in the rumen (h)

The effective degradability (ED) of dietary nutrients was calculated as:

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

where:
ED = effective degradability (%)
k = rumen outflow rate of the nutrient, set at 0.031 [7]

Data were analyzed using SPSS 18.0 software. One-way ANOVA was used to test for significant differences, with results expressed as mean ± standard error.

Results

2.1 Sensory and Nutrient Composition Changes in Ammonified Rape Straw

Compared with the control group, all ammonified groups exhibited yellowish coloration, moderate moisture, soft texture, and strong ammonia odor after 21 days. Releasing the ammonia odor by opening the sealed packages before feeding and mixing with concentrate in total mixed ration (TMR) form did not affect intake. As shown in Table 2 , CP content in ammonified groups increased more than twofold after 21 days, while NDF and ADF contents decreased by over 10%. EE content gradually declined with ammonification duration, decreasing by approximately 70% after 21 days. DM and ash contents remained essentially unchanged during the ammonification process.

2.2 DM Degradation Rate and Dynamic Degradation Model of Ammonified Rape Straw

Table 3 shows that DM degradation rates at 48 and 72 h were significantly higher in all ammonified groups compared with the control ($P<0.05$). The 15% and 20% ammonification groups also exhibited significantly higher DM degradation rates at 24 and 36 h ($P<0.05$). Degradation rates at 24, 36, 48, and 72 h tended to increase with higher ammonium bicarbonate addition levels. Comparisons across time points revealed that DM degradation rates increased rapidly during the first 24 h, with slower growth thereafter.

As shown in Table 4 , the effective degradability of DM in all ammonified groups was significantly higher than in the control group ($P<0.05$), with the 15% ammonification group showing the highest value, significantly exceeding other ammonified groups ($P<0.05$).

2.3 CP Degradation Rate and Dynamic Degradation Model of Ammonified Rape Straw

All ammonified groups demonstrated significantly higher CP degradation rates at all time points compared with the control group ($P<0.05$), with a tendency for CP degradation rates to increase with higher ammonium bicarbonate addition levels (Table 5).

Table 6 reveals that the rapidly degradable fraction of CP in the control group was significantly lower than in ammonified groups ($P<0.05$), while the slowly degradable fraction in the 10% and 20% ammonification groups was significantly higher than in the control ($P<0.05$). The effective degradability (ED) of CP in all ammonified groups was significantly higher than in the control group ($P<0.05$).

2.4 NDF Degradation Rate and Dynamic Degradation Model of Ammonified Rape Straw

Rape straw exhibited generally low NDF degradation rates, with 72 h degradation rates around 20%. NDF degradation rates tended to increase with higher ammonium bicarbonate addition levels, with the 15% and 20% ammonification groups showing significantly higher degradation rates at 36, 48, and 72 h compared with the control ($P<0.05$) (Table 7).

As shown in Table 8 , the effective degradability of NDF for all straw samples was below 20%. The rapidly degradable fraction of NDF tended to decrease, while the slowly degradable fraction increased with higher ammonium bicarbonate addition levels. The 20% ammonification group exhibited the highest NDF effective degradability ($P<0.05$), which increased progressively with ammonium bicarbonate proportion.

2.5 ADF Degradation Rate and Dynamic Degradation Model of Ammonified Rape Straw

All ammonified groups showed significantly higher ADF degradation rates at 72 h compared with the control group ($P<0.05$), with a tendency for 72 h ADF degradation rates to increase with higher ammonium bicarbonate proportions (Table 9).

Table 10 indicates that the rapidly degradable fraction of ADF decreased in all ammonified groups, with significant reductions in the 15% and 20% ammonification groups compared with the control ($P<0.05$). The slowly degradable fraction was significantly higher in all ammonified groups than in the control ($P<0.05$). ADF effective degradability increased with ammonium bicarbonate addition level, with both 15% and 20% ammonification groups showing significantly higher values than the control ($P<0.05$).

Discussion

3.1 Evaluation of Different Ammonium Bicarbonate Ratios for Rape Straw Ammonification

Ammonification duration is strongly influenced by ambient temperature, with higher temperatures requiring shorter treatment times and yielding better results [8]. This study was conducted during summer when rapeseed matures, with temperatures above 25°C, which likely contributed to rapid ammonification. Different nitrogen sources produce varying effects; ammonium bicarbonate used in this trial decomposes more readily than urea and is safer and more convenient than ammonia water, representing a widely available, low-cost, and effective nitrogen source [9]. Ammonium bicarbonate contains approximately 17% ammonia; the 10%, 15%, and 20% addition levels in this study correspond to ammonia additions of 1.7%, 2.6%, and 3.4%, respectively. Moisture content significantly affects ammonification efficacy; Huang [10] reported that 30% water

and 3.5% ammonia from urea produced optimal results, similar to our findings using 30% water and 3.4% ammonia from ammonium bicarbonate. While both 15% and 20% ammonium bicarbonate produced satisfactory ammonification results, the 15% level is recommended as most economical.

3.2 Nutrient Composition Changes in Ammonified Rape Straw with Different Ammonium Bicarbonate Ratios

Direct feeding of rape straw is limited by poor palatability and low intake rates, compounded by its bulky nature and susceptibility to mold, which hinder transportation, storage, and feeding. Consequently, only 2% of rape straw is currently utilized as feed, indicating substantial potential for feed utilization [4,11]. Rape straw offers superior nutritional value compared to rice or wheat straw, and ammonification can increase CP content while reducing NDF and ADF contents, thereby improving palatability [12]. Ammonification with ammonium bicarbonate provides a simple method for feed utilization of rape straw, enabling full utilization of this valuable resource, reducing environmental pollution, and alleviating roughage shortages for ruminants in southern agricultural regions [4,11]. The control group in this study contained 3.37% CP, which may vary with rape cultivar. Ammonification increased CP content from 3.37% to over 7%, consistent with Huang' s findings [10]. After 21 days of ammonification, NDF and ADF contents decreased by more than 10%, while effective degradability increased significantly, likely because ammonification disrupted the internal fiber structure, weakened hydrogen bonding between fibers, and broke ester bonds between lignin and cellulose/hemicellulose, releasing starch and other nutrients and enhancing nutritional value [10]. The treated straw became more porous with increased surface area for cellulase adsorption, facilitating enzymatic hydrolysis [13]. Ammonium salts formed during the process could serve as a nitrogen source, promoting rumen microbial growth and proliferation.

3.3 Rumen Degradation Characteristics of Nutrients in Ammonified Rape Straw

This study employed the nylon bag technique to determine rumen degradation rates of ammonified rape straw. This semi-in vivo method is widely used for evaluating the nutritional value of roughages [12]. The effective degradability of DM, a primary factor affecting dry matter intake (DMI) in ruminants, varies with feed type, with degradation rates increasing over incubation time to different extents. Our results demonstrate that ammonification effectively improved the effective degradability of DM, CP, NDF, and ADF in rape straw. After 72 h of rumen incubation in goats, DM degradation rates for both control and ammonified groups were around 30%, substantially lower than the 69.09% observed for corn silage [14] but similar to soybean straw and higher than wheat straw (25.38%) [14]. Ammonification significantly increased both CP degradation rates and effective degradability parameters, confirming it as an effective method for improving straw nutritional value [9]. The significantly increased

rapidly degradable fraction and decreased slowly degradable fraction of CP in ammonified straw indicate that CP degradation in goats occurs primarily during early incubation. NDF and ADF degradation rates are important indicators of roughage nutritional value, influenced by feed composition [13]. Ammonification improved NDF and ADF rumen degradation rates, with degradation occurring mainly in the slowly degradable fraction, as the rapidly degradable fraction was lower than in the control. This suggests that rape straw is relatively resistant to degradation, possibly due to chemical bonds (e.g., ether bonds) between cellulose, hemicellulose, and lignin that cannot be broken by enzymes produced by anaerobic rumen microorganisms [13]. Ruminants utilize cellulose through bacteria, fungi, and protozoa that secrete cellulase [15]. Ammonification disrupts the strong ester bonds between lignin and hemicellulose, facilitating rumen microbial digestion and thereby increasing the rumen degradation rates of CP, NDF, and ADF in rape straw.

Conclusion

Ammonification with ammonium bicarbonate increased CP content and decreased NDF and ADF contents in rape straw without affecting dry matter content. The process improved rumen degradation rates of DM, CP, NDF, and ADF. Treatment with 15% ammonium bicarbonate and 30% water provided the optimal and most economical ammonification condition for rape straw.

References

[1] HE M, WANG X R, HAN L, et al. Emission inventory of crop residues field burning and its temporal spatial distribution Sichuan Province[J]. Environmental Science, 2015, 36(4):1208-1216.
[2] SHEN Jinxiong, FU Tingdong. Rapeseed production, improvement and edible oil supply security in China[J]. Journal of Agricultural Science and Technology, 2011, 13(1):1-8.
[3] HU Hongxiang, CHENG Yan, MA Youhua, et al. Decomposition characteristics of returned rapeseed straw in soil and its effect on soil fertility improvement[J]. Chinese Journal of Eco-Agriculture, 2012, 20(3):297-302.
[4] QU Mingren. Current status and problems of production and feed utilization of by-products from economic crops in southern China[J]. Feed Industry, 2013, 34(23):1-6.
[5] CHEN Liyuan, XIA Lunzhi, WU Dong. Study on pollution-free treatment of rapeseed straw[J]. China Herbivores, 2010, 30(4):36-38.
[6] 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.
[7] CHEN Xiaolin, SUN Juan, CHEN Dandan, et al. Rumen outflow rate of five common roughages in mutton sheep[J]. Chinese Journal of Animal Nutrition, 2014, 26(7):1981-1987.
[8] SUNDSTØL F, OWEN E. Straw and other fibrous by-products as feed[J].

Livestock Production Science, 1988, 19(1/2):137–158.
[9] DIAO Qiyu, TU Yan, CHEN Qun. Handbook of crop straw feeding for cattle[M]. Beijing: Chemical Industry Press, 2013:120–122.
[10] HUANG Ruipeng. Study on the effect of crushing and ammoniating rapeseed straw on feeding Weining cattle[D]. Master' s thesis. Nanchang: Jiangxi Agricultural University, 2013:19–26.
[11] Wulan, MA Weijie, Yirugeletu, et al. Analysis of feeding value of rapeseed straw and its development and utilization[J]. Animal Husbandry and Feed Science, 2010, 31(6/7):421–422.
[12] CHEN Xiaolin. Study on nutritional value and rumen degradation characteristics of common roughages for mutton sheep[D]. Master' s thesis. Qingdao: Qingdao Agricultural University, 2014:24–31.
[13] YANG You. Study on ammoniation mechanism and parameter optimization of rice straw[D]. Master' s thesis. Chongqing: Southwest Agricultural University, 2004:33–39.
[14] 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.
[15] ZHANG Jie, CHEN Xuwei, XU Aiqiu, et al. Digestion and metabolism of dietary carbohydrates by rumen microorganisms[J]. China Dairy Cattle, 2008(2):17–20.

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