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Research Article

Nutrient Digestibility and Greenhouse Gas Emission in Castrated Goats (*Capra hircus*) Fed Various Roughage Sources

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조사료원 종류가 거세 염소(*Capra hircus*)의 영양소 소화율 및 온실가스 발생량에 미치는 영향

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ABSTRACT

The objective of this study was to determine the effect of various roughage sources on nutrient digestibility and enteric methane (CH_4), and carbon dioxide (CO_2) production in goats. Four castrated black goats (48.5 ± 0.6 kg) were individually housed in environmentally controlled respiration-metabolism chambers. The experiment design was a 4 × 4 balanced Latin square design with 4 roughage types and 4 periods. Alfalfa, tall fescue, rice straw, and corn silage was used as representative of legume, grass, straw, and silage, respectively. Dry matter digestibility was higher ($p < 0.001$) in corn silage than in alfalfa hay. Dry matter digestibility of alfalfa hay was higher than those of tall fescue or rice straw ($p < 0.001$). Neutral detergent fiber digestibility of tall fescue was lower ($p < 0.001$) than those of alfalfa, rice straw, or corn silage. Daily enteric CH4 production and the daily enteric CH_4 production per kilogram of $BW^{0.75}$, dry matter intake (DMI), organic matter intake (OMI), digested DMI, and digested OMI of rice straw did not differ from those of tall fescue but were higher ($p < 0.001$) than those of alfalfa or corn silage. Roughage type had no effect on enteric CO_2 emission in goats. Straw appeared to generate more enteric CH_4 production than legume or silage, but similar to grass.
(**Key words** : *Capra hircus*, Roughage, Goats, Methane)

Ⅰ. INTRODUCTION

Enteric methane (CH_4) and carbon dioxide (CO_2) productions from the ruminant are recognized as the major sources of greenhouse gas (GHG) worldwide. In addition, enteric CH_4 represents an energy loss of animals ranging from 2 to 12% of gross energy intake (Johnson and Johnson, 1995). Although cattle and buffalo are the main generators of GHG emission, about 4.4% of the total GHG from livestock was produced from the goats (Food and Agricultural Organization of the United Nations). Roughages are the primary feeds for all ruminant animals. In general, enteric CH_4 emission is affected by roughage maturity (Benchaar et al., 2001), quality (Westberg et al., 2001), proportion (Blaxter and Wainman, 1964; Harper et al., 1999; Hales et al., 2014), carbohydrate fraction (Dong and Zhao, 2013), and roughage type (Meale et al., 2012). Ruminant animals fed with legume usually produce lower enteric CH_4 production than those of grass feeding animals (McCaughey et al., 1999; Waghorn et al., 2002; Beauchemin et al., 2008). Ulyatt et al. (2002) have reported that subtropical C4 grasses yield greater CH_4 emission than those of temperate C3 grasses in the ruminant. A modeling study has shown that the CH_4 emission of animals with grass was greater than those with legume (Benchaar et al., 2001). Although there were some attempts to determine the effect of roughage type on enteric GHG production in cows and beef cattle, more *in vivo* work in goats is needed. Therefore, the objective of this study was to determine the effect of various roughage sources on nutrient digestibility and enteric CH_4 and CO_2 production in goats using whole-body respiration-metabolism chamber system.

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Ⅱ. MATERIALS AND METHODS

The protocols used in this study were approved by the Institutional Animal Care and Use Committee of Konkuk University (Approved number: KU13092).

1. Animals, diets, and experimental design

Four castrated black goats (*Capra hircus*) with an initial body weight of 48.5 ± 0.6 kg were individually housed in environmentally controlled (20.4 ± 2.0°C) respiration-metabolism chambers as described by Li et al. (2010). Animals were randomly allotted to a 4 × 4 balanced Latin square design with 4 roughage type and 4 periods (Kim and Stein, 2009). Each period consisted of a 10-d of diet adaptation period and a 4-d of data and sample collection period. Four experimental diets were prepared (Table 1). Alfalfa hay, tall fescue hay, rice straw, and corn silage were used to represent legume, grasses, straw, and silage, respectively. Experimental diets were fed to animals at 1.5% of the initial body weight (DM basis). They were offered once daily at 1100 h. Water and mineral blocks were available at all times. Orts were removed daily and weighted at 1000 h for DM intake calculation. Fecal samples were collected daily using a total collection method. They were dried immediately and stored at −20°C before chemical analysis.

2. Chemical analysis

All roughages and frozen fecal samples were dried at 60°C in a forced air oven for 48 h and ground to pass a 1-mm Wiley mill screen. All samples were analyzed in duplication for crude protein (CP), ether extract (EE), and ash contents using AOAC methods (AOAC International and Cunniff, 1995). Amylase-treated neutral detergent fiber (NDF) was determined with the method of Mertens (Mertens, 2002) using sodium sulfite and heat stable α-amylase (Sigma-Aldrich, Steinheim, Germany). Acid detergent fiber (ADF) was measured according to the methods of Van Soest et al. (Van Soest et al., 1991). Neutral detergent insoluble CP was determined according to the method of Licitra et al. (Licitra et al., 1996).

3. Gas production measurement

Gas concentrations of both CH_4 and CO_2 were measured using the respiration-metabolism chamber system (Li et al., 2010). Before each period, a recovery test was performed using standard CH_4 gas (1.67%, v/v). Inlet and outlet gas flow were measured with a flow meter (GFM57, Aalborg Instruments & Controls Inc., Orangeburg, NY, USA). A sample pump (Columbus Instruments, Columbus, OH, USA) was used to collect gas samples. The gas samples passed through desiccants $CaSO_4$, before the samples flew into the gas analyzer for dehumidification. Non-dispersive infrared gas analyzer (VA-3000, Horiba Stec Co., Kyoto, Japan) was used to analyze the concentration of CH_4 and CO_2.

4. Statistical analysis

Table 1. Chemical composition of roughages used in this study

Items[1]	Alfalfa	Tall fescue	Rice straw	Corn silage
DM (%)	93.7	93.7	89.5	37.1
OM (% DM)	89.2	94.5	87.7	95.1
CP (% DM)	17.3	7.7	5.8	7.8
EE (% DM)	1.3	1.1	1.2	2.3
NDF (% DM)	51.8	64.3	74.1	43.0
ADF (% DM)	36.5	41.8	56.6	24.4
NFC (% DM)	18.8	21.3	6.7	42.0
NDICP (% DM)	4.3	3.1	3.3	2.4
NDF:NFC	2.8	3.0	11.1	1.0

[1]DM: Dry matter, OM: Organic matter, CP: Crude protein, EE: Ether extract, NDF: Neutral detergent fiber, ADF: Acid detergent fiber, NFC: Non-fiber carbohydrate, NDICP: Neutral detergent insoluble crude protein.

Data were analyzed with SAS PROC MIXED (Version 9.3, SAS Institute Inc., USA). The model included roughage type as a fixed effect with animal and period as a random effect. Differences among least squares means were tested using the PDIFF option with Tukey's adjustment. The individual animal was the experimental unit. Treatment effects are considered as statistically significant at $p < 0.05$. Trends were considered at $0.05 \leq p < 0.10$.

Ⅲ. RESULTS AND DISCUSSION

Results of dry matter intake (DMI) and nutrient digestibility of goats are given in Table 2. Dry matter intake did not differ ($p = 0.105$) among treatments because experimental diets were restrictedly offered to animals in this study. In general, feed intake directly affects the enteric CH_4 emission in the ruminant. Therefore, in the current study, we restricted the level of feed intake to minimize the effect of feed intake difference on enteric CH_4 emission. Dry matter digestibility was higher ($p < 0.001$) in the group fed with corn silage than those fed of alfalfa. The DM digestibility in the group fed with alfalfa was higher than those fed with tall fescue and rice straw ($p < 0.001$). Neutral detergent fiber digestibility was lower ($p < 0.001$) in the group fed with tall fescue than those fed with alfalfa, rice straw, or corn silage. It seems that tall fescue has low NDF digestibility because it has more indigestible fiber contents (e.g. ADF) than alfalfa and corn silage. Nutrient digestibility values of roughages in goats in this study were in agreement with previously reported values (Antoniou and Hadjipanayiotou, 1985; Nishida et al., 2007; Puchala et al., 2012). The reduced DM digestibility in the group fed with tall fescue or rice straw compared to that fed with alfalfa or corn silage might be due to different cell wall contents in roughages. Due to the differences in chemical compositions of roughages, NDF and ADF intakes were lower in the group fed with alfalfa or corn silage than those in the group fed with tall fescue or rice straw. As structural carbohydrate is less digestible than non-structural carbohydrate, the concentration of NDF and ADF in roughages is inversely related to the DM digestibility.

Results of the enteric CH_4 and CO_2 productions expressed as the daily amount and per unit of nutrient intake and digested nutrient intake are given in Table 3. The daily enteric CH_4 or CH_4 production per kilogram of $BW^{0.75}$, DMI, OM intake (OMI), digested DMI, digested OMI (DOMI), and digested NDFI (DNDFI) of the rice straw feeding group were similar with tall fescue feeding group. The enteric CH_4 production per kg of NDF intake was similar ($p = 0.193$) among all treatments. The roughage type had no effect ($p = 0.128$) on enteric CO_2 emission in goats. In general, a diet containing high non-fiber carbohydrate can derive propionate production in the rumen, thereby inhibiting rumen methanogen growth (Van Kessel and Russell, 1996). In the current study, although grass (tall fescue) has high non-fiber carbohydrate (NFC) than legume (alfalfa), the NDF:NFC ratio was lower in alfalfa hay than in tall fescue. Previous studies reported that the enteric CH_4 production from ruminant consuming legume was lower compared to grass (Varga et al., 1985; Benchaar et

Table 2. Effect of roughage sources on dry matter intake and nutrient digestibility of goats

Items[1]	Alfalfa	Tall fescue	Rice straw	Corn silage	SEM	p-value
Body weight (kg)	48.5	48.3	48.5	47.5	2.6	0.337
Dry matter intake (g/d)	718.0	685.0	700.0	717.0	29.0	0.105
Digestibility (%)						
DM	69.0^b	50.5^c	52.5^c	79.5^a	0.03	<0.001
OM	83.8^b	79.0^{bc}	76.8^c	90.5^a	0.01	<0.001
CP	77.8^a	55.5^{bc}	53.3^c	66.0^{ab}	0.03	<0.001
NDF	71.3^a	45.8^c	61.3^a	70.8^a	3.24	<0.001
ADF	54.5^a	37.5^c	53.3^{ab}	64.8^a	0.04	<0.001

[1]DM: Dry matter, OM: Organic matter, CP: Crude protein, NDF: Neutral detergent fiber, ADF: Acid detergent fiber.

Table 3. Effect of various roughage sources on enteric methane and carbon dioxide emission in goats

Items[1]	Alfalfa	Tall fescue	Rice straw	Corn silage	SEM	*p*-value
CH_4 production						
L/d	30.6^{b}	40.2^{ab}	45.7^{a}	32.8^{b}	3.4	<0.001
L/kg of $BW^{0.75}$	1.7^{b}	2.2^{ab}	2.5^{a}	1.8^{ab}	0.2	0.041
L/kg of DMI	43.3^{b}	58.9^{ab}	68.5^{a}	45.8^{b}	5.5	0.022
L/kg of OMI	48.6^{b}	62.3^{ab}	78.1^{a}	48.2^{b}	6.2	0.017
L/kg of NDFI	83.5	91.6	92.5	106.7	8.4	0.193
L/kg of ADFI	126.6^{b}	150.3^{ab}	135.5^{b}	187.7^{a}	13.0	0.021
L/kg of DDMI	63.0^{b}	120.6^{a}	130.7^{a}	57.7^{b}	11.8	<0.001
L/kg of DOMI	58.1^{b}	79.0^{ab}	101.9^{a}	53.4^{b}	7.7	<0.001
L/kg of DNDFI	117.4^{b}	209.3^{a}	150.3^{ab}	151.4^{ab}	16.9	<0.001
L/kg of DADFI	234.5	465.2	256.7	292.3	60.1	0.061
CO_2 production						
L/d	460.7	498.8	428.4	466.0	40.7	0.128
L/kg of $BW^{0.75}$	25.4	27.3	23.4	25.9	2.5	0.142

[1]BW: Body weight, DMI: Dry matter intake, OMI: Organic matter intake, NDFI: Neutral detergent fiber intake, ADFI: Acid detergent fiber intake, DDMI: Digested dry matter intake, DOMI: Digested organic matter intake, DNDFI: Digested neutral detergent fiber intake, DADFI: Digested acid detergent fiber intake.

al., 2001), however, the enteric CH_4 production (L/d) in the current study was similar between alfalfa and tall fescue. On the other hands, the enteric CH_4 production per DDMI was greater ($p < 0.001$) in tall fescue or rice straw feeding group than in legume or corn silage feeding group. The straw feeding group had greater ($p < 0.001$) daily enteric CH_4 production and daily CH_4 production per unit of nutrient intake and digested nutrient intake than legume or silage feeding group. These results could be assumed that the high NDF:NFC ratio of straw increase the enteric CH_4 production for goats. Therefore, the straw feeding group produced more enteric CH_4 gas production than legume or silage feeding group, but it had a similar amount of enteric CH_4 production to the grasses group. Goats are an intermediate type ruminant, whereas cattle are grass and roughage eaters (Hofmann, 1989). Despite morphological and physiological differences, similar results have been found for CH_4 production in both goats and cattle.

Ⅳ. CONCLUSION

The objective of this study was to determine the effect of various roughage sources on nutrient digestibility and enteric CH_4 and CO_2 production in goats. In conclusion, rice straw which contains high NDF:NFC generated more enteric CH_4 gas emission than those of alfalfa hay or corn silage, but similar to grass. The roughage types had no effect on enteric CO_2 emission in goats.

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