Effect of Dietary Structural to Nonstructural Carbohydrate Ratio on Rumen Degradability and Digestibility of Fiber Fractions of Wheat Straw in Sheep

Z.-L. Tan*, D.-X. Lu[1], M. Hu[1], W.-Y. Niu[1], C.-Y. Han[1], X.-P. Ren[1], R. Na[1] and S.-L. Lin[1]
Changsha Institute of Agricultural Modernization, the Chinese Academy of Sciences, Changsha 410125, P. R. China

ABSTRACT : The effect of different dietary structural carbohydrate (SC) to nonstructural carbohydrate (NSC) ratios on fiber degradation, digestion, flow, apparent digestibility and rumen fluid characteristics was studied with a design using 18 wethers fitted with permanent rumen and duodenum cannulae. All sheep were divided into six groups randomly, receiving six diets with varying SC to NSC ratios. All diets contained the same proportion of wheat straw and concentrate. The dietary SC to NSC ratios were adjusted by adding cornstarch to the concentrate supplements. The duodenal and fecal flows of dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose (HC) and cellulose (CEL) were estimated using chromium-mordanted wheat straw as a flow marker. The degradation parameters of wheat straw DM, NDF, ADF, HC and CEL were determined by incubating the ground wheat straw in nylon bags in the rumen for different periods of time. There was no effect ($p>0.05$) of the different dietary SC to NSC ratios on rumen pH or NH_3-N, but acetate, propionate and butyrate concentrations were significantly affected ($p<0.05$ or $p<0.01$) by dietary SC to NSC ratios in the rumen fluid. When the dietary SC to NSC ratio was 2.86, the highest rumen degradability of wheat straw DM, NDF, ADF and CEL was found, but the highest apparent rumen digestibilities of DM, NDF, ADF, HC and CEL occurred at a 2.64 SC to NSC ratio. However, because of compensatory digestion in the hindgut, the apparent digestibilities of DM, NDF, ADF, HC and CEL were highest when the dietary SC to NSC ratio was 2.40. In conclusion, there is a optimal range of dietary SC to NSC ratios (between 2.86 and 2.40) that is beneficial to maximize wheat straw fiber degradation and apparent digestibility. ***(Asian-Aust. J. Anim. Sci. 2002. Vol 15, No. 11 : 1591-1598)***

Key Words : Carbohydrate, Fibre Degradation, Fibre Flow, Apparent Digestibility, Sheep

INTRODUCTION

Cereal straw offered as the only feed, even supplemented with minerals, vitamins and a source of non-protein nitrogen (NPN), does not satisfied ruminant maintenance requirements, because of its low digestibility and voluntary intake resulted from its many nutritional limiting factors (i.e. low protein contents and low digestible energy). This problem has been traditionally solved by chemical treatment of straw or processing treatment or supplementation with energy or protein sources (Tan et al., 2001).

When a higher level of production is required, it is necessary to include an energy supplement in the ruminant diet. Many studies indicate that rumen condition for fibrolysis may become adverse, when the level of energy supplement in the diet increases. The extent of this depression depends on the source of supplement (Fahmy et al., 1984), the quality of the basal roughage (Orr et al., 1985; Mould et al., 1983a) and the level of energy supplement (Henning et al., 1980). It is now well known that a specific amount of readily fermentable carbohydrate (non-structural carbohydrate, NSC) is needed to satisfy the activity of rumen microbes. Hence, it is very important to seek the optimum amount of NSC supplement, which minimizes the negative effects of supplements on roughage digestion and utilization in the ruminant rations.

In the past, some authors have discussed the effect of dietary different roughage-to-concentrate ratios on feed intake, rumen fermentation, rumen cell wall degradation, rumen fluids characteristics, and apparent digestibility in ruminants (Van der Linden et al., 1984; Forbes, 1986; Poore et al., 1990). There has been no evaluation of the concept of roughage-to-concentrate ratio among the different diets that comprised different sources of roughages and concentrates. However structural carbohydrate (SC) and non-structural carbohydrate (NSC) are two important chemical indices which are often used to evaluate the nutritional composition of roughages and concentrates. The dietary SC to NSC ratio is more rational and provides potential for a unifying hypothesis to explain effects of varying roughage to concentrate ratio in ruminant rations. In practice, there has been limited evaluation on effects of varying dietary SC to NSC ratio on fiber degradation and digestion in ruminant diets. The objectives of the present study were to investigate the effect of various dietary SC to NSC ratios on fiber rumen degradability and flow in the different digestive sites as well as apparent digestibility and rumen fluid parameters for sheep fed wheat straw. From these results, a suitable range of dietary SC to NSC ratios, which was beneficial to the fiber degradation and digestion, could be ascertained.

* Corresponding Author: Z.-L. Tan. Tel: +86-731-4615228, E-mail: zltan@ms.csiam.ac.cn
[b] Inner Mongolian Academy of Animal Science, Huhhot, 010030, P. R. China.
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MATERIALS AND METHODS

Animals and feeds

Eighteen growing Inner Mongolian wethers with an initial live weight of 28.9±1.0 kg fitted with permanent rumen and duodenal cannulae were penned individually, with free access to fresh water. The animals were randomly divided into six groups, 3 animals per group on the basis of their body weight. Each sheep was offered equal amounts (to 5% refusal) of chopped wheat straw (2 cm length) and concentrate (see Table 2) at 07:00 and 19:00 h daily to meet 1.1 times maintenance requirements of Inner Mongolian sheep (SIMA, 1992). Then each group of sheep was fed either 0, 20, 40, 60, 90 or 120 g cornstarch per day. The different dietary SC to NSC ratios were calculated by the total actual intake of wheat straw and concentrate and corn starch. The chemical composition of experimental feedstuffs and the ingredient composition of concentrates are shown in Table 1 and Table 2, respectively.

Experimental procedures

The experimental period lasted for 40 days. The adaptation period was from day 1 to 15, where each sheep was offered the equal amounts of wheat straw and concentrate according to treatments. The rate of disappearance of wheat straw dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose (HC) and cellulose (CEL) from nylon bags (70×100 mm, pore size: 45 μm) was determined as described by Ørskov and McDonald (1979) from day 16 to 20. The wheat straw was ground by a laboratory mill (DF-2, Changsha Instrument Factory, China) to pass through a 1mm screen. Duplicate bags containing approximately 2.5 g DM of the experimental wheat straw were incubated in the rumen of each sheep for periods of 1, 2, 3, 6, 12, 24, 36, 48, 72 and 96 h. After withdrawal from the rumen, the bags were washed with cold water in a washing machine until the water ran clear. The length of the washing procedure was 30 min, consisting of five rinsing cycles. A “0 h wash value” for the calculation of the lag time of DM, NDF, ADF, HC and CEL degradation was determined twice in three bags. After washing, all samples were dried at 105ºC for 24 h.

After a recovery period from day 21 to 23, on day 24 to 32, 40 g day^{-1} (4×10, i.e. four times infusion at 6 h intervals each day) of the particulate-phase digesta marker, which was chromium-mordanted wheat straw, was administered via the rumen cannula at 06:00, 12:00, 18:00 and 24:00 h respectively. The straw markers were prepared according to the method of Uden et al. (1980). From day 29 to 32, ruminal digesta, duodenal digesta and rectal fecal samples were taken at 6 h intervals over 4 days. Equal amounts of rumen digesta, duodenum digesta and feces, which were taken at each time interval, were mixed and dried at 105°C for 24 h, then ground in a laboratory mill (DF-2, Changsha Instrument Factory, China) through a 1mm screen and analyzed for DM, NDF, ADF, HC and CEL to determine the ruminal, duodenal and rectal flows, as described by Lu and Xie (1991) and measured their apparent digestibilities in the rumen and total gastrointestinal tract.

On day 33 to 35, the wheat straw marker infusion was terminated at 06:00 h on day 33 and ruminal digesta samples were taken from each sheep at 3 h intervals for 3 days to enable estimation of the mean retention time (MRT) of the wheat straw fiber in the reticulo-rumen (ReRu).

After recovery from day 36 to 38, on day 39 to 40, rumen fluid was sampled via cannula according to the following timetable:

Day 39-08:00, 09:00, 10:00, 11:00, 13:00, 16:00, 19:00, 23:00, 21:00, 22:00, 23:00 h
Day 40-01:00, 04:00, 07:00 h

The pH was measured immediately after obtaining the ruminal fluid sample that was subsequently filtered through a metal mesh (1 mm pore size). 20 ml of the filtrate was diluted 1:1 with 0.2M HCl and stored frozen until analysis of ammonia-N (NH_3-N). A second 10 ml subsample was centrifuged at 25,000×g for 20 min and mixed with 1ml formic acid to 25% H_3PO_4 (1:3, V/V) and kept frozen prior to analyses of volatile fatty acids (VFA) as described by Erwin et al. (1961).

Table 1. Chemical composition of experimental feedstuffs (% DM)*

Feedstuffs	CP	FAT	NDF	ADF	ASH	NDFCP	CHO	NSC	SC
Wheat straw	4.2	1.3	82.1	57.7	8.5	1.3	86.0	5.1	80.8
Corn	8.7	3.2	13.1	5.5	1.7	1.4	86.4	74.7	11.7
Wheat bran	16.2	3.1	27.4	11.9	4.1	2.3	76.6	51.5	25.1
Rapeseed cake	27.2	8.5	39.4	33.5	16.8	9.2	44.0	13.8	30.2
Soybean meal	39.7	5.6	18.4	15.8	9.0	6.4	45.7	33.7	12.0
Bone meal	-	1.5	-	-	65.1	-	-	-	-
Urea	281.0	-	-	-	-	-	-	-	-

* DM=dry matter, CP=crude protein, FAT=crude fat, NDF=neutral detergent fiber, ADF=acid detergent fiber, ASH=total crude ash, NDFCP= NDF bound CP, CHO=total carbohydrate, NSC=nonstructural carbohydrate, SC=structural carbohydrate.

Table 2. The ingredients (%) and composition (% of dry matter) of the concentrates used in the experimental diets

Corn	36.0
Rapeseed cake	20.0
Wheat bran	19.0
Soybean meal	17.6
Urea	4.0
Bone meal	0.8
Salt	1.6
Mineral-vitamin premix [1]	1.0
Dry matter	90.0
Crude protein	32.9
UDP[2]/CP[3]	19.5
RDP[4]/CP	80.5
UDP:RDP	0.24
Calcium	0.44
Phosphorus	0.58
Non-structural carbohydrate	42.0
Structural carbohydrate	17.4
Neutral detergent fiber	21.3
Acid detergent fiber	13.8
Hemicellulose	7.5
Cellulose	8.8

[1] The mineral-vitamin premix contained per kg: vitamin A 54,000,000 IU; vitamin D_3 10,800,000 IU; vitamin E 18,000 IU; vitamin K_3 5 g; vitamin B_1 2 g; vitamin B_2 15 g; vitamin B_{12} 0.03 g; vitamin B_5 35 g; pantothenic acid calcium 25 g; folic acid 0.5 g; anti-oxidant 0.2 g; $FeSO_4 \cdot 7H_2O$, 32.2 g; $CuSO_4 \cdot 5H_2O$, 1.5 g; $ZnSO_4 \cdot 7H_2O$, 17.5 g; $MnSO_4 \cdot 5H_2O$, 7.8 g; KI, 170 mg; $CoCl_2 \cdot 6H_2O$, 1.0 g. The remainder was made up of ground zeolite.
[2] Undegradable dietary crude protein in rumen.
[3] Crude protein.
[4] Degradable dietary crude protein in rumen.

Chemical analyses

All samples were analysed for DM, crude fat (FAT), total crude ash (ASH) and Kjeldahl nitrogen (N) content by the Association of Official Analytical Chemist (AOAC) methods (AOAC, 1980), and for NDF, ADF, HC, CEL and NDF bound CP (NDFCP) content by the procedure proposed by Van Soest et al. (1991). Rumen fluid samples were analysed for NH_3-N according to the method of Feng and Gao (1993). Estimation of VFA contents was performed by gas-liquid chromatography in a GC-7A (Shimadzu Co., Kyoto, Japan). Measurement of chromium (Cr) was performed according to the procedure of Gao and Feng (1993).

Calculations

The ruminal digesta passage rate (k) was fitted to the following equation as described by Lu and Xie (1991).

$$C=C_0 \times e^{-kt}$$

Where C is Cr concentration of ruminal digesta at time t after the wheat straw marker infusion was terminated. C_0 is Cr concentration of ruminal digesta at zero time when wheat straw marker infusion was just terminated. t is time. k is the ruminal digesta passage rate. The decline in the log of Cr concentrations over time was used to estimate the ruminal digesta passage rate.

The flow of DM, NDF, ADF, HC and CEL at the duodenum and rectum was calculated using the single-marker method as described by Lu and Xie (1991). The disappearance of DM, NDF, ADF, HC and CEL from nylon bags was fitted to the equations of McDonald (1981) and Dhanoa (1988).

$$P_1=a' \quad \text{for } t\leq t_0 \qquad (1)$$
$$P_2=a+b(1-e^{-ct}) \quad \text{for } t>t_0 \qquad (2)$$

Where a' represents the 0 h wash value, immediately degradable fraction disappearing during the washing procedure. P_2 is the proportionate amount of DM, NDF, ADF, HC and CEL disappearance from the nylon bags after time t ($t>t_0$), and a, b and c are degradation constants fitted by the NLIN Procedure of SAS (1985). In equation 2, a, b and c represent readily available fraction, degradable fraction of insoluble fraction and fractional degradation rate respectively. The lag time (L) before the start of component b degradation was calculated as described by Khalili and Huhtanen (1991).

$$L=1/c\times(\ln(b/(a+b-a'))) \qquad (3)$$

The apparent effective degradability (AED) was calculated as

$$AED=a+(b\times c/(c+k)) \qquad (4)$$

Where, k is the passage rate of digesta in the rumen. The dietary SC, NSC and total carbohydrate (CHO) were calculated according to the following equations, which were proposed by Van Soest et al. (1991).

$$SC=NDF-NDFCP \qquad (5)$$
$$NSC=100-(NDF+CP+FAT+ASH-NDFCP) \qquad (6)$$
$$CHO=100-CP-FAT-ASH \qquad (7)$$

Statistical analyses

All data regarding the degradation kinetic parameters, digestion and ruminal characteristics were analyzed using the General Linear Models procedure of SAS (1985). The results were subjected to the GLM procedure with treatment as a only main factor according to the following statistical model:

$$Y_{ij}=\mu+T_i+e_{ij}$$

where Y_{ij} is dependent variable, μ is overall mean, T_i is treatment (SC to NSC ratio), and e_{ij} is residual error.

Analysis of linear and quadratic group (SC to NSC ratio) effects was conducted using linear and quadratic contrasts of PROC GLM of SAS (1985). The P-values less than 0.05 were used to determine whether mean differences were different.

RESULTS

Voluntary intake

Results for intake of wheat straw, concentrate and cornstarch are shown in Table 3. The six dietary SC to NSC ratios were 3.52, 3.32, 2.86, 2.64, 2.40 and 1.88 respectively.

Digesta passage and fiber degradation

Results for fiber degradation of wheat straw are shown in Table 4. There were significant effects ($p<0.01$) on the rumen passage rate of particulate marker for the different SC to NSC ratios. The k values were lower ($p<0.05$ and $p<0.01$) for the 3.32 and 2.86 of SC to NSC ratios than those of 3.52, 2.64, 2.40 and 1.88 of SC to NSC ratios. The possible reason is that: when dietary NSC was deficient (SC:NSC=3.52), the ruminal microbe had to utilize the dietary fiber, so the k value was higher; when the limited NSC (SC:NSC=3.32 and 2.86) was supplied in the diets, there were the possibly competitive digestion on fiber and NSC, so the k values were lower; however, when there were the enough and suitable dietary NSC (SC:NSC=2.64, 2.40 and 1.88), the ruminal microbe obtained the satisfied energy requirement, it was advantageous to utilize fiber, so the k values were the highest. From 3.52 to 1.88, the ruminal passage rate increased (linear, $p<0.01$) with decreasing dietary SC to NSC ratios.

The apparent effective degradability (AED) of wheat straw DM was influenced significantly ($p<0.001$) by different dietary SC to NSC ratios. There were no significant differences for DM degradability within 3.52, 3.32 and 2.86 of SC to NSC ratios, but the AED of DM was higher ($p<0.01$; $p<0.05$) for these three higher ratios of SC to NSC than for the ratios of 2.64 or less. The readily available fraction (a), degradable fraction of insoluble fraction (b), fractional degradation rate (c), potential degradable fraction (a+b) and the degradation lag time (L) were not significantly affected ($P>0.05$) by the different dietary SC to NSC ratios. The AED of DM decreased (linear, $p<0.01$) with decreasing dietary SC to NSC ratios from 3.52 to 1.88.

Results for the degradation kinetic parameters of NDF and ADF reflected similar results with DM degradation parameters. Effect of different dietary SC to NSC ratios on AED of NDF and ADF was highly significant ($p<0.001$), but the a, b, c, a+b and L of NDF and ADF were not significantly ($p>0.05$) affected by the different dietary SC to NSC ratios. When dietary SC to NSC ratios were below 2.86, the AED of NDF and ADF significantly decreased respectively ($p<0.05$ and $p<0.01$). However, there were not significant differences ($p>0.05$) in AED of NDF among these 3.52, 3.32 and 2.86 of SC to NSC ratio diets. For AED of ADF, although there was not significant difference ($p>0.05$) between the 3.32 and 2.86 of SC to NSC ratio diets, the significant difference ($p<0.05$) was noticed between the 3.52 and 3.32 or 2.86 of SC to NSC ratio diets. In the meantime, from 3.52 to 1.88, the AED of NDF (quadratic, $p<0.05$) and ADF (quadratic, $p<0.01$) decreased with decreasing dietary SC to NSC ratios.

The degradation kinetic parameters of HC and CEL demonstrated that there were significant differences in AED of HC ($p<0.05$) and CEL ($p<0.001$) for different dietary SC to NSC ratios. In the meantime, it was investigated that there were not significant differences ($p>0.05$) in AED of HC among these 3.52, 3.32, 2.86 and 1.88 of SC to NSC ratio diets. Of these 3.32 and 2.86 of SC to NSC ratio diets, the AED of CEL are higher ($p<0.05$ or $p<0.01$) than those of 3.52, 2.64, 2.40 and 1.88 of SC to NSC ratio diets. a, b, c, a+b and L of HC were not significantly ($p>0.05$) influenced by the dietary SC to NSC ratios. However, a and L of CEL were very significantly ($p<0.001$ and $p<0.01$) affected by the dietary SC to NSC ratios. From 3.52 to 1.88, the AED of HC (quadratic, $p<0.05$) and CEL (quadratic, $p<0.05$) decreased with decreasing dietary SC to NSC ratios.

According to all above results, it may be concluded that there were no significant differences in AED of fiber at the range of 3.52 to 2.86 of SC to NSC ratios, but when the dietary SC to NSC ratios are below 2.86, the ruminal fiber degradation may be obviously inhibited. Meanwhile, the AED of NDF, ADF and CEL decreased (quadratic, $p<0.05$ or $p<0.01$) with decreasing SC to NSC ratios, and the highest apparent effective degradabilities of NDF, ADF and CEL occurred at 2.86 of SC to NSC ratio. Hence, the suitable SC to NSC ratio that is beneficial to improve the ruminal fiber degradation should be at 2.86.

Table 3. Mean sheep intakes (g/d) in the different groups

Items[a]	Groups					
	1	2	3	4	5	6
Wheat straw intake	483	531	507	535	565	492
Concentrate intake	210	210	210	210	210	210
Corn starch intake	0	20	40	60	90	120
NSC intake	110	129	144	163	190	211
SC intake	392	428	411	432	455	402
SC to NSC ratio	3.52	3.32	2.86	2.64	2.40	1.88

[a] NSC=nonstructural carbohydrate, SC=structural carbohydrate.

Fiber digestion

Results for DM, NDF, ADF, HC and CEL digestion are shown in Table 5. DM digestibilities were significantly ($p<0.05$ or $p<0.01$) affected by different dietary SC to NSC ratios. DM digestibilities in the rumen and in the total

Table 4. Effect of different structural carbohydrate to non-structural carbohydrate ratios on the degradation kinetic parameters of dry matter, neutral detergent fiber, acid detergent fiber, hemicellulose and cellulose in the sheep

Items[1]	Parameters[2]	Dietary structural carbohydrate to non-structural carbohydrate ratios						
		3.52	3.32	2.86	2.64	2.40	1.88	SEM
	k ($\%h^{-1}$)[E]	4.4[b]	2.9[c]	3.0[c]	5.6[a]	5.3[ab]	5.0[ab]	0.48
DM	a (%)	13.5	14.0	12.9	13.2	13.8	13.3	0.16
	b (%)	36.8	38.1	38.8	31.2	30.0	32.9	1.54
	c ($\%h^{-1}$)	2.4	2.1	2.3	2.0	1.8	2.3	0.10
	a+b (%)	50.3	52.1	51.7	44.4	43.8	46.3	1.53
	L (h)	2.3	2.6	3.8	3.8	4.1	3.4	0.29
	AED (%)[3]	26.7[ab]	29.6[a]	29.7[a]	21.6[c]	21.1[c]	23.4[bc]	1.57
NDF	a (%)	4.5	2.2	-0.3	-0.2	-0.3	-1.1	0.87
	b (%)	40.6	45.1	46.2	39.7	36.9	41.0	1.41
	c ($\%h^{-1}$)	2.3	1.9	2.8	2.5	2.2	2.6	0.12
	a+b (%)	45.1	47.2	45.9	39.4	36.6	39.9	1.75
	L (h)	-2.2	0.2	2.2	2.6	3.7	3.5	0.93
	AED (%)[3,4]	18.4[a]	19.7[a]	21.7[a]	11.8[b]	10.2[b]	12.8[b]	1.93
ADF	a (%)	-1.9	1.0	-0.1	2.1	-0.1	-0.9	0.58
	b (%)	46.6	45.2	46.6	36.0	35.8	41.0	2.06
	c ($\%h^{-1}$)	2.5	2.0	2.7	1.9	2.1	2.0	0.12
	a+b (%)	44.6	46.2	46.5	38.1	35.7	40.2	1.86
	L (h)	7.05	5.7	4.9	5.6	8.2	9.0	0.66
	AED (%)[3,5]	15.0[b]	19.4[a]	21.7[a]	11.2[c]	9.9[c]	10.8[c]	2.02
HC	a (%)	3.5	-2.7	-7.5	-3.3	-2.7	3.2	1.72
	b (%)	36.0	45.3	52.2	43.7	43.3	44.2	2.10
	c ($\%h^{-1}$)	3.8	2.8	3.1	3.1	2.7	3.3	0.15
	a+b (%)	39.5	42.6	44.7	40.4	40.6	47.4	1.24
	L (h)	-2.6	2.4	5.0	2.7	2.0	-2.4	1.25
	AED (%)[4]	20.0[a]	19.1[ab]	18.7[ab]	12.0[b]	12.1[b]	20.7[a]	1.61
CEL	a (%)	0.9[ab]	2.5[a]	2.6[a]	0.4[ab]	-0.6[b]	-3.7[c]	0.95
	b (%)	45.4	46.0	48.1	42.0	39.1	47.9	1.44
	c ($\%h^{-1}$)	2.3	2.2	2.6	2.2	1.8	2.5	0.11
	a+b (%)	46.3	48.6	50.6	42.4	38.5	44.2	1.79
	L (h)	2.4[c]	0.9[c]	0.6[c]	3.4[bc]	5.8[ab]	6.7[a]	1.04
	AED (%)[3,4]	16.5[b]	21.8[a]	24.7[a]	11.8[bc]	9.1[c]	11.9[bc]	2.51

[abc] Means with different superscripts in the same row are significantly different (p<0.05).

[1] DM=dry matter, NDF=neutral detergent fiber, ADF=acid detergent fiber, HC=hemicellulose, CEL=cellulose.

[2] k=ruminal digesta passage rate, a=readily available fraction, b=degradable part of insoluble fraction, c=fractional degradation rate, L=lag time, a+b=potential degradable fraction, AED=apparent effective degradability.

[3] Linear SC to NSC ratio effect (p<0.01), [4] Quadratic SC to NSC ratio effect (p<0.05), [5] Quadratic SC to NSC ratio effect (p<0.01).

digestive tract as well as the rumen digestion percent at the range of SC to NSC ratios from 2.64 to 1.88 were higher (p<0.05) than those of the range of SC to NSC ratios from 3.52 to 2.86. From 3.52 to 1.88, DM digestibilities increased (linear, p<0.05 or p<0.01) with decreasing dietary SC to NSC ratios. However, there were not significant differences (p>0.05) among these of 2.64, 2.40 and 1.88 of SC to NSC ratio diets, or among these 3.52, 3.32 and 2.86 of SC to NSC ratio diets. According to the results in the range of SC to NSC ratios from 2.64 to 1.88, when dietary NSC concentration was increased, the DM digestibility in rumen and DM ruminal digestion percent slightly decreased. Considering of the 2.40 of SC to NSC ratio diet, because of slightly increased DM digestion in the hindgut, the DM digestibility in the total tract also slightly increased.

The digestibilities of NDF, ADF, HC and CEL in the rumen and in the total digestive tract were also significantly (p<0.05 or p<0.01) influenced by different dietary SC to NSC ratios. There were not significant differences (p>0.05) for the ruminal NDF digestibilities among the 3.52, 2.64, 2.40 and 1.88 of SC to NSC ratios. But the ruminal NDF digestibilities of the 2.64 and 2.40 of SC to NSC ratios were significantly higher (p<0.05) than those of the 3.32 and 2.86 of SC to NSC ratios. While dietary SC to NSC ratios were 2.64 and 2.40, the NDF digestibilities in the total tract were higher (p<0.05) than those of 3.52, 3.32 and 2.86 of SC to NSC ratios. The ruminal digestibility of ADF in the 2.86 SC to NSC ratio was lower (p<0.05) than those of the 2.64 and 2.40 of SC to NSC ratios. The ADF total digestibilities were higher (p<0.05) for the 2.64 and 2.40 of SC to NSC ratios than for the 3.52, 3.32 and 2.86 of SC to NSC ratios. The ruminal and total HC digestibilities of the 2.64 and 2.40 of

Table 5. Effect of different structural carbohydrate to non-structural carbohydrate ratios on digestion of dry matter, neutral detergent fiber, acid detergent fiber, hemi-cellulose and cellulose in the sheep

Items[1]	Dietary structural carbohydrate to non-structural carbohydrate ratios						
	3.52	3.32	2.86	2.64	2.40	1.88	SEM
DM (g/day)							
In feed	634	696	690	734	788	748	21.8
At proximal duodenum	381	385	427	276	300	326	23.5
In feces	209	226	249	142	146	189	17.6
Digestibility of DM (%)							
In the rumen[3]	40.0[b]	43.6[b]	38.0[b]	62.4[a]	61.8[a]	55.6[a]	4.5
In the total tract[2]	67.0[b]	66.6[b]	64.2[b]	80.6[a]	81.2[a]	73.6[ab]	3.0
Rumen (total)[1, 3]	59.6[b]	65.5[ab]	59.2[b]	77.4[a]	76.1[a]	75.6[a]	3.5
NDF (g/day)							
In feed	406	442	424	446	469	415	9.5
At proximal duodenum	232	266	278	170	196	198	17.5
In feces	174	191	198	113	113	146	15.5
Digestibility of NDF (%)							
In the rumen[3]	42.8[abc]	38.7[bc]	34.2[c]	62.0[a]	58.1[a]	51.2[ab]	4.5
In the total tract[2]	57.1[bc]	55.4[bc]	53.4[bc]	74.8[a]	75.6[a]	63.0[ab]	4.0
Rumen (total)[1]	75.0[ab]	69.8[bc]	64.1[c]	82.9[a]	76.8[ab]	81.2[ab]	2.9
ADF (g/day)							
In feed	283	308	296	311	327	288	6.6
At proximal duodenum	163	176	188	128	149	143	9.1
In feces	129	133	142	79	82	104	11.0
Digestibility of ADF (%)							
In the rumen[2]	42.4[bc]	41.8[bc]	35.9[cd]	58.9[ab]	54.2[ab]	49.5[abc]	3.5
In the total tract[2]	54.3[bc]	55.6[bc]	52.2[bcd]	74.4[a]	74.6[a]	62.1[ab]	4.1
Rumen (total)[1]	78.1	75.1	68.9	79.2	72.7	79.7	1.8
HC (g/day)							
In feed	123	133	128	134	141	125	2.8
At proximal duodenum	80	88	85	42	47	55	8.5
In feces	52	58	59	33	31	42	5.0
Digestibility of HC (%)							
In the rumen[3]	34.4[c]	32.5[c]	33.2[c]	68.8[ab]	66.6[ab]	54.5[b]	7.0
In the total tract[2]	57.6[b]	54.8[b]	54.0[b]	75.3[a]	77.8[a]	64.7[ab]	4.3
Rumen (total)[1,3]	59.6[b]	59.2[b]	61.5[b]	91.4[a]	85.6[a]	84.3[a]	6.2
CEL (g/day)							
In feed	220	241	230	243	256	226	5.3
At proximal duodenum	123	124	133	91	109	101	6.5
In feces	94	98	105	58	60	76	8.4
Digestibility of CEL (%)							
In the rumen[2]	44.2[cd]	48.1[bcd]	41.6[d]	62.6[abc]	57.2[bcd]	54.2[bcd]	3.3
In the total tract[2]	57.1[bc]	57.9[abc]	54.6[bc]	76.3[a]	76.4[a]	64.4[ab]	4.0
Rumen (total)[1]	77.4	83.0	76.3	82.0	74.9	84.3	1.6

[abcd] Means with different superscripts in the same row are significantly different ($p<0.05$).

[1] DM=dry matter, NDF=neutral detergent fiber, ADF=acid detergent fiber, HC=hemicellulose, CEL=cellulose.

[2] Linear SC to NSC ratio effect ($p<0.05$), [3] Linear SC to NSC ratio effect ($p<0.01$).

SC to NSC ratios were also higher ($p<0.05$) than those of the 3.52, 3.32 and 2.86 of SC to NSC ratios. For ruminal CEL digestibilities, the significant difference ($p<0.05$) was noted only between the 2.86 and 2.64 of SC to NSC ratios, however the CEL total digestibilities were higher ($p<0.05$) for the 2.64 and 2.40 of SC to NSC ratios than for the 3.52 and 2.86 of SC to NSC ratios. Generally speaking, when the dietary SC to NSC ratios were below 2.64 or above 2.64, the digestibilities of NDF, ADF, HC and CEL in the rumen usually decreased. In the meantime, the results also showed that when the dietary SC to NSC ratio was 2.40, although fiber digestion may be slightly depressed in the sheep rumen, the reduced ruminal digestibility of cell wall carbohydrates could be partially compensated for by increased microbial fermentation in the hindgut.

From 3.52 to 1.88, although NDF, ADF, HC and CEL digestibilities in the rumen and total digestive tract increased (linear, $p<0.05$ or $p<0.01$) with decreasing dietary SC to NSC ratios, their highest values were still observed at 2.64 and 2.40 respectively. From 2.64 or 2.40 to 1.88, NDF, ADF, HC and CEL digestibilities tended to decrease gradually (see Table 5). So the suitable range of dietary SC to NSC ratios which is beneficial to improve fiber digestibilities should be between 2.64 and 2.40.

Rumen fluid characteristics

The average of rumen pH, NH_3-N concentration and VFA concentration are presented in Table 6. Different dietary SC to NSC ratios did not significantly affect means of pH and NH_3-N concentrations ($p>0.05$), but significantly influenced the ruminal acetate ($p<0.01$), propionate ($p<0.05$) and butyrate ($p<0.05$) concentrations. When the dietary SC to NSC ratio was below 2.64, the acetate concentrations of rumen fluid were lower ($p<0.05$) than those in 3.52, 3.32 and 2.86 of SC to NSC ratio diets. Only when the dietary SC to NSC ratios were below 2.40, the propionate concentration in the rumen fluid significantly ($p<0.05$ or $p<0.01$) decreased in comparison with the 3.52, 3.32 and 2.86 of SC to NSC ratio diets. The butyrate concentration in the rumen fluids was higher ($p<0.05$ or $p<0.01$) for these 3.32 and 2.86 of SC to NSC ratios than those 2.64, 2.40 and 1.88 of SC to NSC ratios. However, the linear descending trends were observed for the acetate ($p<0.01$), propionate ($p<0.05$) and butyrate ($p<0.01$) concentrations with decreasing dietary SC to NSC ratios. Therefore, at the range of experimental SC to NSC ratios, pH would not become the adverse factor of affecting fiber digestion; because the dietary SC to NSC ratios were adjusted with free-nitrogen cornstarch, there were no significant effects on the ruminal NH_3-N concentrations.

DISCUSSION

It is well known that rumen microbes need the dietary degradable nitrogen and non-structural carbohydrate to satisfy with their amylolytic activity. It may be necessary to supplement with concentrate in the diet when ruminants are only fed with straw. In this study, the levels of dietary nitrogen were the same for all treatments and the dietary SC to NSC ratios were adjusted by adding cornstarch. Therefore, the effects of SC to NSC ratios on fiber degradation and digestion were due to the supplementation of the nonstructural carbohydrates.

Table 6. Effect of different dietary structural carbohydrate to non-structural carbohydrate ratios on pH, NH_3-N concentration (mg/100 ml) and VFA concentration (mmol/l) of rumen fluids for sheep

Items	Dietary structural carbohydrate to non-structural carbohydrate ratios						
	3.52	3.32	2.86	2.64	2.40	1.88	SEM
pH	6.4	6.5	6.5	6.8	6.6	6.7	0.07
NH_3-N	18.7	20.1	20.2	21.3	20.6	18.3	0.44
Acetate[2]	33.8[a]	35.6[a]	33.6[a]	29.1[b]	27.4[b]	27.2[b]	1.49
Propionate[1]	17.0[a]	16.6[ab]	14.6[bc]	16.3[ab]	14.4[bc]	13.8[c]	0.55
Butyrate[2]	7.5[ab]	8.6[a]	8.0[a]	4.8[c]	6.6[b]	4.7[c]	0.68

[abc] Means with different superscripts in the same row are significantly different (P<0.05).

[1] Linear SC to NSC ratio effect (p<0.05).

[2] Linear SC to NSC ratio effect (p<0.01).

Some researchers reported that the increased level of nonstructural carbohydrate would resulted in the decline of rumen fluid pH, the reduced microbial activity and the depression of fiber digestion (Mould et al., 1983; Doyle et al., 1988; Ortigues et al., 1989; Kennedy et al., 1992). In the mean time, some authors concluded that fiber degradation and digestion and rumen environment would not be affected by supplementing the suitable amount of carbohydrate concentrate (for example, corn grain and rice grain and wheat grain). However if a large amount of carbohydrate concentrates were supplemented into the ruminant diets, the fiber digestion and degradation and rumen environment would be seriously depressed (Nelson et al., 1989; Stokes et al., 1991; Castrillo et al., 1995). So it is very important to probe the suitable dietary SC to NSC ratios which are beneficial to fiber degradation and digestion in the rumen and total digestive tract.

In this study, pH and NH_3-N concentration were scarcely affected by different dietary SC to NSC ratios, but the highest acetate concentration occurred in 2.86 of SC to NSC ratio diet. The effective degradabilities of DM and fiber compositions were highest when the dietary SC to NSC ratio was 2.86, but the highest digestibilities of DM, NDF, ADF, HC and CEL in rumen were observed in 2.64 of SC to NSC ratio diet. There were quadratic effects on the ruminal AED values of NDF, ADF, HC and CEL (see Table 4), it was proposed that there was a suitable dietary SC to NSC ratio of improving fiber digestion in the rumen of sheep. While the dietary SC to NSC ratio was 2.40, because of partial compensation for by increased microbial fermentation in the hindgut, the highest digestibility in the total tract occurred in 2.40 of SC to NSC ratio diet. This digestion compensation phenomenon in the hindgut is similar with some previous study as the increased level of energy supplementation (Ortigues et al., 1989; Khalili and Huhtanen, 1991).

CONCLUSIONS

In conclusion, the present results confirmed that there was a suitable dietary SC to NSC ratio range that was advantageous to improve the fiber degradation and digestion. The dietary 2.86 to 2.40 of SC to NSC ratio range is suitable for the fiber degradation and digestion in sheep. The ruminal pH and NH_3-N would not be significantly affected at the range of experimental dietary SC to NSC ratios, but the ruminal acetate, propionate and butyrate concentrations can be significantly influenced by the dietary

SC to NSC ratios.

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REFERENCES

Association of Official Analytical Chemists. 1980. Official methods of Analysis. 13th Ed. Association Official Analytical Chemists, Washington, DC.

Castrillo, C., M. Fondevila, J. A. Guada and A. D. Vega. 1995. Effect of ammonia treatment and carbohydrate supplementation on the intake and digestibility of barley straw diets by sheep. Anim. Feed Sci. Technol. 51:73-90.

Dhanoa, M. S. 1988. On the analysis of dacron bag data for low degradability feeds. Grass and Forage Sci. 43: 441-444

Doyle, P. T., H. Dove, M. Freer, F. J. Hart, R. M. Dixon and A. R. Egan. 1988. Effects of a concentrate supplement on the intake and digestion of a low-quality forage by lambs. J. Agric. Sci. 111:503-512.

Erwin, E. S., G. J. Marco and E. Emery. 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44: 1768-1771.

Fahmy, S. T. M., N. Y. Lee and E. R. Ørskov. 1984. Digestion and utilization of straw. 2. Effect of different supplements on the digestion of ammonia treated straw. Anim. Prod. 38:75-82.

Feng, Z. C. and M. Gao. 1993. An improved method measuring ruminal NH_3-N concentration. Inner Mongolian J. Anim. Sci. 4: 40-41.

Forbes, J. M. 1986. The Voluntary Food Intake of Farm Animals. Butterworth, London.

Gao, M. and Z. C. Feng. 1993. An improved method measuring Chromium. Inner Mongolian J. Anim. Sci. 3: 40-41.

Henning, P. A., Y. Van der Linden, M. E. Mattheyse, W. K. Nauhaus and H. M. Schwartz. 1980. Factors affecting the intake and digestion of roughage by sheep fed maize straw supplemented with maize grain. J. Agric. Sci. 94:565-573.

Kennedy, D. W. and L. D. Bunting. 1992. Effects of starch on ruminal fermentation and detergent fiber digestion in lambs fed bermudagrass hay. Anim. Feed Sci. Technol. 36:91-100.

Khalili, H. and P. Huhtanen. 1991. Sucrose supplements in cattle given grass silage based diet. 2. Digestion of cell wall carbohydrates. Anim. Feed Sci. Technol. 33:263-273.

Lu, D. X. and C. W. Xie. 1991. Modern Method and Technology on Ruminant Nutrition Research. Agricultural Press, Beijing.

McDonald, I. 1981. A revised model for the estimation of protein degradability in the rumen. J. Agric. Sci. 96:251-252.

Mould, F. L., E. R. Ørskov and S. O. Mann. 1983a. Associative effects of mixed feeds. 1. Effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis *in vivo* and dry matter digestion of various roughages. Anim. Feed Sci. Technol. 10:15-30.

Nelson, M. L. and J. W. Finley. 1989. Effect of soft white wheat addition to alfalfa-grass forage on heifer gain, diet digestibility and in vitro digestion kinetics. Anim. Feed Sci. Technol. 24:141-150.

Orr, R. J., T. R. Treacher and V. C. Mason. 1985. The effect of ammonia treatment on the intake of straw and hay when offered with rations of concentrate to ewes in late pregnancy. Anim. Prod. 40:101-109.

Ørskov, E. R. and I. McDonald. 1979. The estimation of crude protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci. (Camb.) 92:499-503.

Ortigues, I., T. Smith, J. D. Oldham, A. B. McAllan and J. W. Siviter. 1989. Nutrient supply and growth of cattle offered straw-based diets. Br. J. Nutr. 62:601-619.

Poore, M. H., J. A. Moore and R. S. Swingle. 1990. Differential passage rate and digestion of neutral detergent fiber from grain and forages in 30, 60, and 90% concentrate diets fed to steers. J. Anim. Sci. 68:2965-2973.

SIMA, Standards of Inner Mongolian Autonomy, 1992. Feeding Standards of Inner Mongolian Sheep. Huhhot.

Statistical Analysis Systeems Institute. 1985. SAS User's Guide: Basics. SAS Institute Inc., Cary, NC.

Stokes, S. R., W. H. Hoover, T. K. Miller and R. Blauweikel. 1991. Ruminal digestion and microbial utilization of diets varying in type of carbohydrate and protein. J. Dairy Sci. 74:871-881.

Tan, Z. L., D. X. Lu, M. Hu, W. Y. Niu, C. Y. Han, X. P.Ren, R. Na and S. L. Lin. 2001. Effects of dietary nitrogen sources on fiber digestion and ruminal fluid characteristics in sheep fed wheat straw. Asian-Aust. J. Anim. Sci. 14:1374-1382.

Uden, P., P. E. Colucci and P. J. Van Soest. 1980. Investigation of chromium and cobalt as markers in digesta rate of passage studies. J. Sci. Food Agric. 35:625-632.

Van der Linden, Y., N. O. van Gylswyk and H. M. Schwartz. 1984. Influence of supplementation on corn stover with corn grain on the fibrolytic bacteria in the rumen of sheep and their relation to the intake and digestion of fibre. J. Anim. Sci. 59:772-783.

Van Soest, P. J., J. B. Robertson and B. A. Lewis. 1991. Symposium: Carbohydrate Methodology, Metabolism and Nutritional Implications in Dairy Cattle. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-3597.

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