Changes in the Density of the Particle Mass of Diverse Kinds of Hay Incubated in the Rumen of Sheep Given Oat Hay as Their Sole Diet

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Abstract To determine changes in the true density and specific gravity of the dietary particle mass and the bulk density of forages in the course of ruminal fermentation, seven kinds of hay were incubated *in situ* in the rumen of sheep given oat hay as their sole diet. The true density of the forage ranged from 1.6 to 1.8 g/ml and showed no change with incubation time. The fractional specific gravity of the samples increased from around 0.7 g/ml at the start of incubation to about 1.3 g/ml at 2 h after incubation, and then stayed at nearly a constant level up to 96 h of the incubation time. The bulk density of the forage particulates changed a little within 4 h incubation, and thereafter decreased to about 70% of the original density after 24 h of incubation without significant change for up to 96 h of incubation. The degradation pattern of neutral detergent fiber was similar to the change in bulk density. A significant correlation was found between them ($P < 0.01$). It was concluded that bulk density was related to the digestion of fibrous fraction through a change in the conformation of the forage particles. The true density and functional specific gravity, however, were not related.

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Key words : True density, Functional specific gravity, Bulk density, NDF degradation, Forage

Feed is a source of nutrients for animals. The control of feed intake, therefore, determines the production response of farm animals. The feed intake of ruminants has been believed to be governed by chemical and physical factors. For bulky feeds such as forage for ruminants, the limiting factors for feed intake are the digestion rate of fibrous fractions and the physical properties of the feed associated with the fill of the digestive tract concerned. The dry bulk density of diverse kinds of hay has been found to be one of controlling factors for forage intake by cows and sheep given hay as a sole diet^{2,4)}. However, the bulk density merely shows the physical space of the rumen

to be occupied by the ingested feed. The physical properties of forage other than the bulk density, therefore, need to be considered. The passage rate of the ingesta also is related to the ruminal fill of ruminants given forage. The specific gravity of the ingesta in the rumen may be one of factors that controls the rate of the passage of particulates as has been reported¹⁾, although the particles should be reduced particle size to the extent possible to pass through the reticulo-omasal orifice⁶⁾.

The present study was carried out to determine what underlies in the changes in the specific gravity of the dietary particle mass in the course of ruminal fermentation.

Materials and Methods

Four Corriedale wethers (33.4 ± 7.5 kg live weight) with ruminal cannulae were given oat hay at a maintenance level in two equal portions twice daily for 14 days as a preliminary period after an adaptation period of about 1 month. Following the preliminary period, samples of 7 kinds of hay : alfalfa (AL), bermuda grass (BG), Italian ryegrass (IR), oats (OA), perennial ryegrass (PR), sudan grass (SG) and timothy (TI) were incubated in the rumen for 0, 2, 4, 8, 12, 24, 48 and 96 hours by using the nylon bag technique. The bags (pore size, $45 \mu\text{m}$; bag size, 100×200 mm) were filled with 8 g of samples of each hay cut through an 8 mm screen and a stainless steel ball (about 33 g) as a weight. Before incubation started, bags were immersed into Burrough's solution for 1.5 min. with gentle massaging to eliminate excess air in the samples. Two bags were fixed to a 2×7 -cm silicone tube with a 10-cm fishing line (No. 8; standard diameter, 0.471 mm) to connect to the cover of cannulae. Six bags were incubated simultaneously. For incubation of bags for 2 and 4 hours, the care was taken not so as to coincide with 2 hours before or after the feeding of diets. After incubation, the bags were washed with tap water for 3 min. to eliminate ruminal residues on the bag. The

pycnometer was specially prepared by the use of a 200-ml boiling flask with flattened bottoms so as to accommodate incubated samples. Incubated samples in the bag were totally evacuated into the 200-ml pycnometer. The pycnometer was warmed to 38°C for 5 min. and weighed to determine the functional specific gravity (F sp. gr.). Then, the pycnometer was placed under a vacuum of 35 mm Hg for 10 min. and was then weighed again at 38°C to determine the true density of particulate mass. Incubated samples were determined for dry matter (DM), and bulk density was then measured using a 100-ml glass cell under pressure applied at the rate of 10 g/cm^2 . Neutral detergent fiber (NDF) was determined by air-dried incubated samples ground through a 1 mm screen after measurement of the bulk density.

Results and Discussion

Table 1 shows the chemical composition of hays used for incubation in the rumen of sheep given oat hay as a sole diet. The crude protein contents of the IR, OA, PR, SG and TI hays were less than 10% of DM. The fibrous fractions were fairly similar among grass hays except for OA in which the fibrous fractions were contained less than the others. Also AL tended to contain less fibrous fractions in which hemicellulose was contained about half

Table 1. Chemical composition of hays used for incubation in the rumen of sheep

	AL ¹⁾	BG	IR	OA	PR	SG	TI
	% as is						
Dry matter	92.9	93.1	92.3	92.5	92.8	91.0	92.9
	% DM						
Crude protein	17.7	10.7	7.6	6.7	5.3	8.5	4.4
NDF	49.4	74.4	74.9	57.5	69.0	69.7	72.9
ADF	39.2	38.9	49.1	32.7	42.4	41.0	46.8
ADL	7.8	5.0	5.3	3.6	5.2	3.4	6.8
Cellulose	31.4	33.9	43.8	29.1	37.2	37.6	40.0
Hemicellulose	10.2	35.5	25.8	24.8	26.6	28.7	26.1

¹⁾ Abbreviated notations are as follows : AL, alfalfa hay ; BG, Bermuda grass hay ; IR, Italian ryegrass hay ; OA, oats hay ; PR, perennial ryegrass hay ; SG, sudan grass hay ; TI, timothy hay ; NDF, neutral detergent fiber ; ADF, acid detergent fiber and ADL, acid detergent lignin.

of the other hays.

Fig. 1 shows changes in the true density of the forage particulates examined in the present study. True density was similar among the hays ranging from 1.6 to 1.8 g/ml and did not change with the incubation time irrespective of the kinds of hay. Gases in the inner voids formed within the particles by microbial fermentation are inferred to be evacuated and replaced by liquid by the application of a vacuum. Siciliano-Jones and Murphy³⁾ found that the true specific gravity determined by centrifuging various feedstuffs ranged from 1.3 to 1.5 and showed no significant difference among feedstuffs or particle sizes. Results in the present study agreed well with their findings, although our method for measuring true density differed from theirs. Thus, it is inferred that the true density of forages is essentially the same among forages with a little variation irrespective of the kinds of hay.

The F sp. gr. at 0 h incubation ranged from 0.6 to 0.8 g/ml among the kinds of hay. The F sp. gr. for AL, OA, PR and TI hays increased to 1.2 to 1.4 g/ml after 2 h of incubation, and then stayed at about a constant level for the remainder of the incubation time. Those for BG, IR and SG increased gradually to about 1.2 g/ml up to 24 h of incubation. The particles escaped from the rumen have been found to have 1.2 g/ml or more of F sp. gr.⁷⁾ The particulates of hays examined in the present study, therefore, may have reached a possible F sp. gr. to pass through the rumen after 2 h of incubation except for BG, IR and SG which may require more time to reach it. Thereafter, ruminal fermentation may not have influence upon changes in the F sp. gr. of forage particulates. The results were inconsistent with those obtained by Wattiaux *et al.*⁶⁾ in the study by incubation *in vitro* in which the F sp. gr. of alfalfa hay particles decreased from 3 h to 9 h of the incubation period, then increased up to 27 h of incubation, and thereafter stayed at a constant level up to 30 h. They inferred that an

increase in F sp. gr. was resulted from the exceeded escape of gas over the formation of gas bubbles in particles due to the decreased gas production from 6 h to 27 h of incubation. Feed particles incubated *in situ* may be subjected to considerable pressure and abrasion by the continuous movement of the rumen. This may cause the rapid hydration of the inner voids formed by the microbial fermentation of particles, which thereby results in an increase in the F sp. gr. of particles. Therefore, particles incubated in the rumen may reach a constant F sp. gr. in an earlier time than those incubated *in vitro*. The level reached at a plateau agreed well between the present study and the *in vitro* study⁶⁾ irrespective of kinds of hay. Wattiaux *et al.*⁵⁾ reported that *in situ* incubation in the rumen changed the distribution of residual dry matter with a given specific gravity within 4 h. Their results, however, showed no major shift of dry matter from one fraction of specific gravity to another from 4 to 96 h of incubation. This implies that a major change in specific gravity of particulates occurs within 4 h incubation time for alfalfa hay, alfalfa silage and corn silage⁵⁾. This implication is consistent with the results obtained for AL, OA, PR and TI in the present study.

Changes in the bulk density of diverse kinds of hay were presented in Fig. 2. The bulk density of the grass hay particulates ranged from 0.07 to 0.09 g/ml and that of the alfalfa hay was 0.12 g/ml. The bulk density of forages showed little change within 4 h of incubation. After 24 h of incubation, it decreased to about 70% of the original density, but it showed a small change for the rest of the incubation time. Changes in the volume of the residual dry-matter that were obtained in the *in vitro* study⁵⁾ showed a similar tendency except after 4 h to 6 h of incubation, which started to decrease⁵⁾. It is assumed, therefore, that the conformation of the forage particles may not change until the structural carbohydrates begin to be degraded by the microbial activity. The structural car-

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Fig. 1. Changes in the true density and the functional specific gravity of the particulates of diverse kinds of hay incubated in the rumen of sheep.

Abbreviated notations for kinds of hay are shown in the text.

Each solid circle with the vertical bar shows mean true density of four sheep with the standard deviation at each incubation time. Each open circle represents mean functional specific gravity of four sheep with the standard deviation at each incubation time.

Fig. 2. Changes in the bulk density and the particulates of diverse kinds of hay incubated in the rumen of sheep.

Abbreviated notations for kinds of hay are shown in the text.

Each solid circle with the vertical bar shows mean of four sheep with the standard deviation at each incubation time.

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bohydrates mainly consist of NDF. Thus, main factor controlling rigidity or fragility of brittleness of NDF may be speculated to be a forage particles.

Fig. 3. Changes in residual neutral detergent fiber of particulates of diverse kinds of hay incubated in the rumen of sheep. Abbreviated notations for kinds of hay are shown in the text. Each open circle shows mean of four sheep.

The changes in residual NDF revealed that its degradation appeared to begin after 4 h of incubation (Fig. 3). As a significant relationship was assumed between changes in the bulk density of residual hay particulates and their NDF degradation pattern in the present study, the correlation coefficients between them were calculated. The results revealed that there was a significant correlation between the proportion of residual NDF and the bulk density of the residual particulates for each hay as follows: AL, $r=0.983$; BG, $r=0.926$; IR, $r=0.983$; OA, $r=0.982$; PR, $r=0.970$; SG, $r=0.984$ and TI, $r=0.800$ ($P<0.01$), respectively. Changes in the F sp. gr. in the forage particle mass did not show any significant relation to NDF degradation, although the F sp. gr. tended to increase as the proportion of residual NDF decreased ($r=-0.063\sim-0.341$). Provided it is correct that the buoyancy effect of gases of fermentation is a potent discriminator in extent of digestion as suggested from *in vitro* experiment by Wattiaux *et al.*⁶⁾, the effect of gases may be considerably reduced because gases produced by ruminal fermentation would be evacuated from a particle by vigorous ruminal movement *in vivo*. Thus, from the results obtained in the present study, it is not speculated that the NDF degradation is related to the change in F sp. gr. of particulates in the rumen.

The true density of the particulates did not show any significant correlation to the proportion of residual NDF ($r=-0.003\sim0.184$). These results support the above assumption because particles were completely evacuated fermentation gas.

From the results and the discussion above,

we conclude that the true density of a forage particle mass is a factor that by no means affects the kinetics of the particulates in the rumen. The F sp. gr. of the particle mass of the digesta in the rumen may be little related to the digestion of fibrous fractions, if any. Changes in the bulk density of the ingested hay may be a factor that affects forage intake concurrently with NDF digestion, although the rate of ruminal passage was not considered in the present study.

References

- 1) deBordes CK, Welch JG. Influence of specific gravity on rumination and passage of indigestible particles. *J. Anim. Sci.*, 59 : 470-475. 1984.
- 2) Sekine J, Ueda J, Jin Hai, Kamel HEM, Oura R, Morita Z. Effects of chemical and physical characteristics of forage on dry-matter intake of cattle. *Ann. Zootech.*, 44 (Suppl. 1) : 253. 1995.
- 3) Siciliano-Jones J, Murphy MR. Specific gravity of various feedstuffs as affected by particle size and *in vitro* fermentation. *J. Dairy Sci.*, 74 : 896-901. 1991.
- 4) Tomari T, Kamel HEM, Jin Hai, Oura R, Sekine J. Effects of crude protein, neutral detergent fiber, dry bulk density, and brittleness of the hay on feed intake of sheep. *Jpn. J. Sheep Sci.*, 32 : 7-13. 1995.
- 5) Wattiaux MA, Mertens MD, Satter LD. Effect of source and amount of fiber on kinetics of digestion and specific gravity of forage particles in the rumen. *J. Dairy Sci.*, 74 : 3872-3883. 1991.
- 6) Wattiaux MA, Satter LD, Mertens MD. Effect of microbial fermentation on functional specific gravity of small forage particles. *J. Anim. Sci.*, 70 : 1262-1270. 1992.
- 7) Welch JG. Physical parameters of fiber affecting passage from the rumen. *J. Dairy Sci.*, 69 : 2750-2754. 1986.

オーツヘイ単独給与めん羊の反芻胃内で培養した 種々の乾草粒子の密度変化

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反芻胃内発酵の過程における飼料粒子の真密度, 比重およびかさ密度の変化を測定するため, オーツヘイ単独給与めん羊の反芻胃内で7種類の乾草を培養した。7種類の乾草の真密度は, 1.6 から 1.8 g/ml の範囲にあり, 培養時間による違いは認められなかった。乾草の実効比重は, 培養開始時の 0.7 g/ml から培養2時間後の約 1.3 g/ml まで増加した。その後は, ほぼ一定の水準で培養96時間まで推移した。乾草粒子のかさ密度は, 培養4時間まではほとんど変化が認められなかったが, その後, 培養24時間までにもとの値の70%まで減少した。それ以降は培養96時間まで著しい変化は認められなかった。中性デタージェント繊維の分解様相は, かさ密度の変化と同様であった。この両者には, 有意な相関関係が認められた ($P < 0.01$)。かさ密度は, 乾草粒子の構造との関連により繊維分画の消化過程と関係していると結論された。しかしながら, 乾草の真密度および実効比重は, 繊維分画の消化過程とは関連がないと推察された。

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