Characteristics of Digestion Dynamics of Rice and Oat Straw Relating to Microbial Digestion in the Rumen of Sheep Given High-Concentrate Diets

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ABSTRACT : Rumination behavior, *in vivo* digestibility of cell wall constituents, particle size reduction in the rumen, and retention time in the digestive tract of sheep were examined using rice and oat straw as roughage sources. The *in sacco* digestibility, rumen fermentation, and microbial population and internal adenosine 5-triphosphate (ATP) content were also determined under feeding conditions of high-roughage and high-concentrate diets. Chewing number and time in rumination behavior were higher with rice straw than with oat straw, while the *in sacco* and *in vivo* DMD of rice straw were consistently lower than those of oat straw. Rice straw also showed higher frequency of thinner and longer particles in the rumen contents and lower retention time in the whole digestive tract as compared to those of oat straw. Rice straw was more effective to maintain the ruminal pH than oat straw, being reflected in higher internal ATP content of large-type protozoa on the high-concentrate diet. Changes in the ruminal microflora by shifting from the low- to the high-concentrate diet were also different between rice and oat straw. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 9 : 1219-1227*)

Key Words : Digestion Activity, Microbial ATP, Particle Size Reduction, Passage Rate, Rice Straw, Rumination Behavior

INTRODUCTION

Rice (*Oryza sativa* L.) straw is the only roughage used in the feeding system for traditional fattening of Japanese Black heifer, which is well known as Matsusaka well-finished fat beef. The feeding program is usually started at the age of 7-10 months and continued for 30-36 months, during which time the ratio of roughage to concentrates in feed ingredients should be gradually reduced with advanced fattening stage, especially during the last year. Rice straw could be used for maintaining rumen function capable to keep high rumen digestion and feed intake (Hoshino et al., 1978). Hoshino et al. (1978) reported that the generic composition of protozoa in the rumen of the 75% of the Matsusaka beef examined was *Entodinium, Diplodinium, Epidinium, Isotricha and Dasytricha*. This feature in protozoal composition resembles that of grazing dairy cattle, but differs from those of beef cattle in typical feed lots which usually have only one or two genera of rumen protozoa.

Animals in feedlots are at risk of acute and subacute acidosis which causes death and/or reduced feed intake and feed efficiency of finishing beef cattle. The microbial fermentation of starches contained in grains can proceed rapidly causing the rumen to become acidotic. Since the incidence of acidosis can be reduced by increasing saliva flow and increasing rate of passage, the relatively high percentages of roughage and of cereal grains selected or processed for slower fermentation have been found to have a major impact on profitability of feeding cattle (Stock et al., 1990). However, there is little information available on how forage varieties such as rice and oat straw differ in effectiveness for maintaining rumen function and digestion activities of animals fed on high-energy diets.

In this study, rice and oat straw were examined for *in vivo* digestibility of cell wall constituents, digestion dynamics including particle size reduction in the rumen and retention time in the digestive tract, and effect on rumination behavior, when those were fed as a single feed. The in sacco DM digestibility of fibrous materials, ruminal fermentation, and microbial population and adenosine 5-triphosphate (ATP) content were also determined, when either rice or oat straw was fed as a roughage source in the feeding of high-roughage or high-concentrate diets.

MATERIALS AND METHODS

Two feeding trials of rice and oat straw were conducted using four sheep which weighed 51 kg, fistulated with a 11-cm diameter rumen cannulae, and maintained in metabolism crates during the experiments. Animals were examined on rice and oat straw with small amount of concentrates in Experiment 1, and on each of the two straw under low- and high-concentrate levels in Experiment 2. The amount of the experimental diets offered to the animals was set to the consumption level preliminarily observed. Rice straw used in the present study was grown and harvested at grain-matured stage in the Experimental Farm of Mie University, and oat straw and formulated concentrates were obtained from commercial feed. Both

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straws roughly consisted of 35% of the leaf blade fraction and 65% of the leaf sheath plus stem fraction, and were cut to around 3-4 cm length before feeding.

Experiment 1

In a two-treatment design, animals were fed on a daily mean ration of 800 g of rice or oat straw with 100 g of commercial formula feed in two equal portions at 0830 h and 2030 h, and had access to water and mineral salt licks. Experimental periods consisted of 10 days for adaptation and 12 days for measurement.

The rice and oat straws were analyzed for organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). Apparent digestibility of dry matter (DM), NDF, ADF, hemicellulose (NDF-ADF), and celllulose (ADF-ADL) were also determined by the analysis of feeds and feces collected daily during the first five days of the measurement period. Cell wall constituents were determined according to the method of Van Soest (1991), and CP and OM contents were done by AOAC methods (1970).

Passage rates of both cereal straws through the digestive tract were determined from values of time for first appearance of the marker, rumen retention time (h) and outflow rate ($\times 100$, %/h), lower gut retention time (h) and outflow rate ($\times 100$, %/h), and total mean retention time (h), using chromium-mordanted fiber which was prepared from each cereal straw and administered through the rumen fistula (Uden et al., 1980). Following administration on the sixth day of the measurement period, feces were collected at defined intervals for 6 days and chromium was analyzed by a modified method of Christian and Coup (1954) in which 0.005 M $Fe(NH_4)_2(SO_4)_2$ was used to increase sensitivity.

Particle size of rumen contents was analyzed by a wet sieving of the samples, which were collected at 5 h intervals from the morning feeding on the last day of the measurement period (Ichinohe et al., 1994). The length and width of particles on 500 μm sieve of the 15 h collection was measured using a light microscope equipped with a 10-mm micrometer (n=100 for each animal).

Rumination behavior was observed between the morning and evening feedings on two days before the measurement period. Total rumination time, swallowing number, chewing number, chewing time, and chewing speed were measured using a stopwatch.

Experiment 2

Four experimental diets, comprising two cereal straw and two concentrate levels, were given in experimental periods of 17 days, including 10 days for adaptation and 7 days for measurement. The rice straw (RS) and oat straw (OS) diets consisted of 75% straw-25% commercial formula concentrates (75% RS and 75% OS diets) and 25% straw-75% commercial formula concentrates (25% RS and 25% OS diets), respectively. Animals were fed on a daily ration of 1.28 kg in two equal portions at 0830 h and 2030 h, each of two animals first receiving the 75% RS or 75% OS diets and then the corresponding 25% straw diets. Switches from the 75% straw diets to the 25% straw diets were made by an increase of 10% unit per day of the ratio of concentrates to roughage. The contents of total digestible nutrients and digestible crude protein in the commercial formula concentrates used were 70 % and 14% on a DM basis, respectively.

Dry matter (DM) degradability of rice and oat straw, ground to pass a 1 mm screen, was determined in triplicate by a nylon-bag method of 72 h incubation in the rumen, between the fifth and seventh day of the measurement period. Concentrations of volatile fatty acids (VFAs; formate, lactate, propionate, acetate, n- and iso-butyrate, n- and iso-valerate) and pH value of rumen fluid collected just before the morning feeding (0 h) and 3, 6, 9 and 12 h after feeding on the first day of the measurement period, were determined using a HPLC (Jasco LC-800, Tokyo, Japan) equipped with an ion exchange column (Shimadzu SCR-102(H), 12 mm ID $\times$ 25 cm, Shimadzu Co., Japan) and with a glass electrode, respectively (Goto et al., 1993).

Rumen fluid was collected just before the morning feeding on the third day, strained through 2-layer gauze, and measured for population density and internal adenosine 5-triphosphate (ATP) content of rumen bacteria and protozoa. Mixed bacteria, and small- and large-types of protozoa were immediately separated by the method of Wakita and Hoshino (1989), and then divided to small vials, weighed and kept at -80℃ in deep freezer until the measurement. Fractions of small- and large-types of protozoa were assessed microscopically to mainly consist of *Entodinium spp.*, and of *Isotricha spp.*, *Diplodinium spp.* and *Dasytricha spp.*, respectively. The ATP content of the samples was measured by the firefly luciferin-luciferase system of the method of Brookes et al. (1983).

Total viable count and composition of bacteria (Suto, 1973) and protozoa (Kurihara and Takechi, 1973) were light-microscopically measured, using a portion of rumen fluid samples mixed with a 20% formaldehyde-saline solution and a methylgreen-formaldehyde-saline solution. The number of fungal zoospores was microscopically determined by suspending agar dice for 24 h and staining with lactophenol blue (Ushida et al., 1989) on the last day of the measurement period.

Statistical analysis

Results obtained for *in vivo* digestibility, characteristics of digestion dynamics, and rumination behavior in Experiment 1 and for *in sacco* degradability, total viable counts of bacteria, protozoa and fungal zoospore, and their internal ATP contents in Experiment 2 were analyzed with the F-test (Steel and Torrie, 1980).

RESULTS

Digestion potential and dynamics of rice and oat straw

Animals almost consumed their rice and oat straw in a half hour after offer, and normally started rumination a little later. Rumination time, chewing time, chewing number, and swallowing number, often used for evaluating the effectiveness of roughage, were significantly ($p<0.05$) higher for rice straw than those for oat straw (table 1). Rumination time and chewing number was about 35% and 22% higher with rice straw, while the chewing speed was not different.

Gross composition and *in vivo* digestibility were considerably different between rice and oat straw (table 1). Rice straw had lower cell wall constituents and crude protein than oat straw. Rice straw had significantly ($p<0.05$) lower digestibility of DM, NDF, ADF, hemicellulose, and cellulose than did oat straw. Difference in the digestibility of cell wall components was larger than that for the DM digestibility.

Table 1. Composition and digestibility of rice and oat straw, and rumination behavior of sheep fed on the two cereal straw

	Rice straw	Oat straw
Dry matter (%)	91.0	89.4
DM composition (%)		
OM	94.5	99.4
CP	4.0	8.4
NDF	61.2	77.0
ADF	35.5	44.0
ADL	32.0	4.9
In vivo digestibility (%)		
DM	43.1 ± 3.2^a	58.7 ± 0.6^b
NDF	44.4 ± 3.3^a	67.0 ± 1.0^b
ADF	43.3 ± 3.1^a	65.4 ± 1.3^b
Hemicellulose	46.1 ± 3.7^a	69.1 ± 1.0^b
Cellulose	51.9 ± 2.8^a	73.7 ± 1.4^b
Rumination behavior (12 h observation)		
Rumination time, min.	288.3 ± 31.9^a	214.3 ± 20.1^b
Swallowing number	269.3 ± 17.2^a	241.0 ± 15.9^b
Chewing number, $\times10^3$	21.4 ± 2.3^a	17.4 ± 0.8^b
Chewing time, min.	197.0 ± 6.8^a	157 ± 10.9^b
Chewing speed, bite/min.	110.9 ± 7.5^a	109.0 ± 1.4^a

DM, dry matter; OM, organic matter; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin, hemicellulose, NDF-ADF; cellulose, ADF-ADL.

[a,b] Values with different superscripts within the same row are significantly different ($p<0.05$).

Rice and oat straw showed different patterns of particle size reduction, especially 10 h after feeding (figure 1). Percentages of particle size of rumen contents collected on large (>1 mm), medium (>300 μm), and small (>53 μm) sieves at 6 h after the feeding were almost the same for rice and oat straw, accounting for 42%, 32% and 26% of the total value, respectively. Rice straw showed similar percentages of the small, medium, and large particle fractions collected 10 h later, whereas percentages of the medium particles of oat straw increased with time after the feeding and up to over 45% of the total value at the 24 h collection. The percentage of large particles of both straw decreased in a similar pattern with advancement of time after feeding. In rumen contents collected on the 500 μm sieve 15 h after feeding, rice and oat straw particles ranged from 1 to 9 mm-length and from 0.1 to 1.1 mm-width (figure

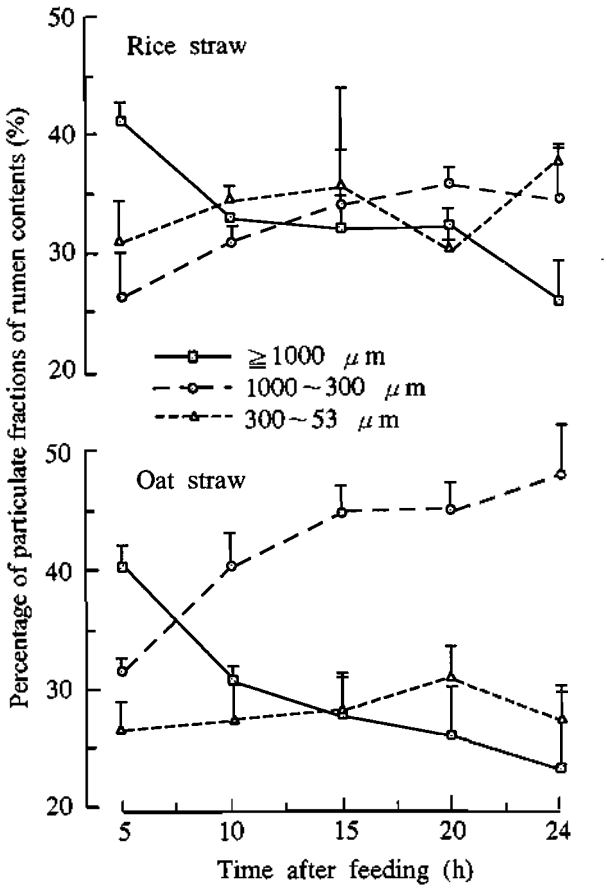

Figure 1. Percentages of particulate fractions of rumen contents in sheep fed rice or oat straw: crossbar indicates standard division

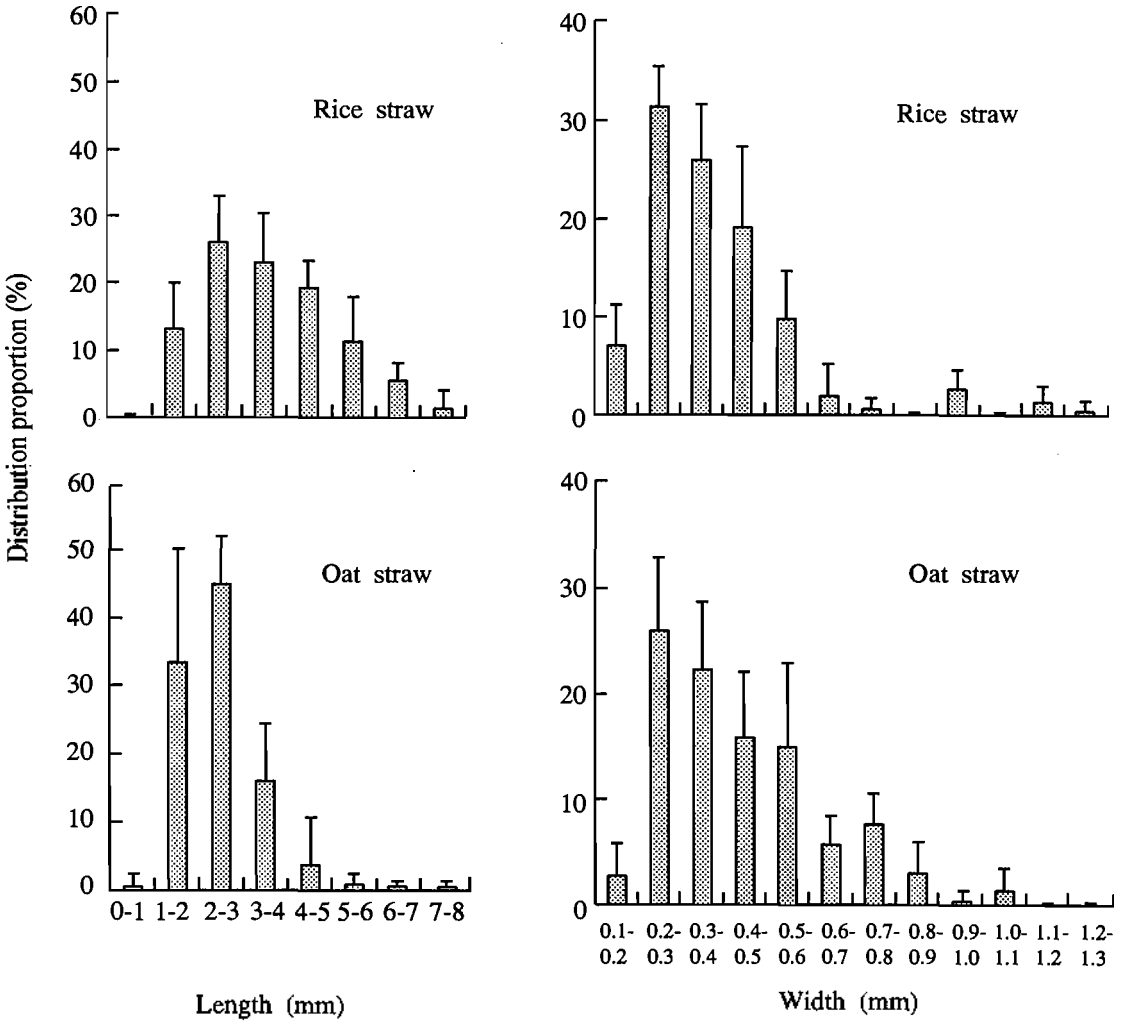

Figure 2. Frequency distribution of length and width of rice and oat straws in rumen contents collected on a 500 μm sieve 15 h after feeding

2). Although the average value of particle length was not significantly different at 23.3±8.8 mm for oat straw and 28.9±12.9 mm for rice straw, rice straw had a higher frequency of longer particles (>4 mm) than oat straw, the values accounting for 40% and 10%, respectively. The percentage of wider particles (>0.6 mm) was, in contrast, higher with oat straw than rice straw.

Differences in the patterns of fecal excretion of rice and oat straw were also observed (figure 3, table 2). Retention time of the chromium-mordanted fiber in the lower digestive tract was significantly ($p<0.05$) lower with rice straw than oat straw, and, thereby, the outflow rate of rice straw was significantly ($p<0.05$) higher than oat straw. These values for rice straw were reflected in a lower total mean value for retention time through the digestive tract compared to that of oat straw ($p<0.05$). The times for first appearance of chromium, ruminal retention time, and ruminal outflow rate of rice and oat straw were not

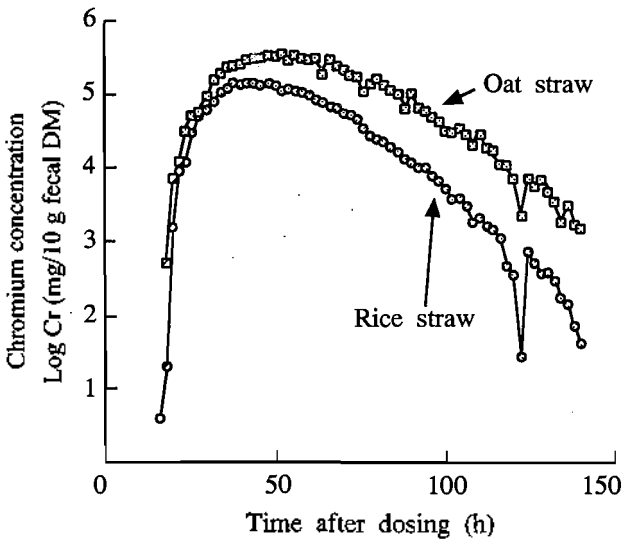

Figure 3. Fecal excretion patterns of chromium-mordanted fiber of the cereal straws dosed into the rumen

Table 2. Characteristics of digestion dynamics of rice and oat straw

	Rice straw	Oat straw
TT, h	19.9 ± 0.8[a]	20.3 ± 2.0[a]
K_1, %/h	2.97 ± 0.14[a]	3.05 ± 0.30[a]
K_2, %/h	7.80 ± 0.49[b]	5.51 ± 0.10[a]
$1/K_1$, h	33.8 ± 1.7[a]	33.1 ± 3.1[a]
$1/K_2$, h	12.9 ± 0.8[a]	18.1 ± 0.3[b]
TMRT, h	66.7 ± 1.3[a]	71.5 ± 4.5[b]

1) K_1, ruminal outflow rate; K_2, lower gut passage rate; $1/K_1$, rumen retention time; $1/K_2$, lower gut retention time; TT, transit time; TMRT, total mean retention time.
[a,b] values with different superscripts within the same row are significantly different ($p<0.05$).

different.

Rumen microorganisms and fermentation on the cereal straw diets with high-roughage and high-concentrate levels

Similar to the Experiment 1, animals almost consumed the four diets in a half hour after offer and normally started rumination a little later. Changes in the ruminal microflora by shifting from the low- to the high-concentrate diet were different between rice and oat straw. Total viable counts of bacteria in the rumen fluid of the RS diets were around 2.0×10^{10}/ml, very similar between two concentrate levels (table 3). Gram-negative cocci, the major bacteria accounting for over 60% of the total value, were however significantly ($p<0.05$) decreased by changing to the high-concentrate diet. The percentages of gram-negative rod bacteria on the 75% RS and 25% RS diets were similar, and the same was true for gram-negative curved rods and gram-positive cocci and rods. Protozoal population were not different, the two major genus of Entodiniiae and Diplodiniinae accounting for around 66% and 23% of the total value, respectively. Zoospore number was significantly ($p<0.01$) lower with the 25% RS diet than with the 75% RS diet.

Within the OS diets, total viable counts and composition of rumen bacteria were not different between the low- and high-concentrate diets. Protozoal counts were significantly higher ($p<0.05$) at 17.1×10^{10}/ml with the 25% OS diet than at 6.1×10^{10}/ml with the 75% OS diet. The composition of the genus Entodininae and Diplodininae was not different between the two OS diets, accounting for 60% and 28% of the total values, respectively. The number of the zoospores was 0.5×10^3/cm^2 of the agar dice with the 75% OS diet, while no zoospores were detected with the 25% OS diet.

The internal ATP contents of mixed bacteria and small-type protozoa were very similar between the 75% RS and 25% RS diets and between the 75% OS and 25% OS diets (table 4). However, a significant decrease in the ATP content by shifting from the low- to the high-concentrate diets was observed for the large-type protozoa when the oat straw was used as roughage, while, irrespective of concentrate levels, ATP remained similar with the rice straw diets.

Total VFA concentration in the rumen fluid for the 75% RS diet varied rather little with time after the feeding, while that for the 25% RS diet showed the maximal peak at the 3h collection and was significantly ($p<0.05$) higher at the 3 h, 6 h and 9 h

Table 3. Total viable counts of bacteria, protozoa, and fungal zoospores in the rumen of sheep fed on the four diets formulated by two cereal straw and two concentrate levels

	Rice straw		Oat straw	
	75% RS	25% RS	75% OS	25% OS
Bacterial count, $\times 10^{10}$/ml	2.2	2.0	2.2	2.2
Composition, %				
(-) cocci	69.5[a]	60.7[b]	60.6	62.5
(-) rods	25.5	27.1	28.2	24.7
(-) curved rods	3.3	5.2	4.0	4.3
(+) cocci	1.8	1.6	2.1	2.8
(+) rods	2.2	3.8	4.0	4.5
Others	1.3	1.6	1.1	1.2
Protozoal count, $\times 10^4$/ml	6.4	9.8	6.1[a]	17.1[b]
Composition, %				
Entodiniinae	65.4	66.6	61.0	58.8
Diplodiniinae	22.8	22.8	25.0	30.5
Isotrichidae	6.6	7.6	10.6	7.1
Others	5.2	3.0	3.4	3.6
Zoospores $\times 10^3$/cm^2	13.3[a]	0.1[b]	0.5	0

75% RS and 75% OS diets, 75% cereal straw and 25% formulated concentrates; 25% RS and 25% OS diets, 25% cereal straw and 75% formulated concentrates.
[a,b] Values with different superscripts within the same row are significantly different ($p<0.05$).

Table 4. The ATP contents (nmol/mg BSA protein) of mixed bacteria, and small-type and large-type protozoa in the rumen

	Rice straw		Oat straw	
	75% RS	25% RS	75% OS	25% OS
Mixed bacteria	26.8	27.3	39.5	36.5
Protozoa				
Small-type	56.3	37.0	18.1	26.3
Large-type	45.5	76.9	103[a]	56.3[b]

75% RS, 25% RS, 75% OS, and 25% OS diets were noted in table 3.
[a,b] Values with different superscripts within the same row are significantly different ($p<0.05$).

collection than with the 75% RS diet (figure 4). Similarly, on the OS diets, the 25% OS diet had significantly higher VFA concentrations at the 3 h and 6 h collections than the 75% OS diet. Correspondingly, the 75% RS diet had significantly ($p<0.05$) higher pH value at the 3h collection than that of the 25% RS diet, and the 75% OS diet had significantly ($p<0.05$) higher pH at the 3 h, 6 h, 9 h, and 12 h collection than the 25% OS diet. The lowest pH value on the 25% RS and 25% OS diets was around 5.9 and 5.6 at the 3 h collection, respectively, showing a greater drop and thereafter slower rise of that value on the 25% OS diet compared to the 25% RS diet.

The *in sacco* DMD of rice and oat straw was, as determined for digestion activity of fiber digestion in the rumen, changed by shifting from the 75% RS and OS diets to their respective 25% diets (table 5). The DMD of the cereal straw was significantly ($p<0.05$) higher on the 25% RS diet compared to that on the 75% RS diet, whereas it was significantly ($p<0.05$) higher on the 75% OS diet than the 25% OS diet. The DMD of rice straw was also lower through the four diets than that of oat straw, ranging 40-45% and 56-62%, respectively.

DISCUSSION

Rice straw is the fibrous material of choice to maintain rumen function of fattening Japanese Black beef cattle. The major concerns of the straw quality on Matsusaka well-finished fat beef production are especially color, drying condition, and elasticity. Elasticity can be associated with the digestion potential and dynamics of rice straw, as recognized by the farmers experience. In this study, rice and oat straw were evaluated for rumination behavior, particle size

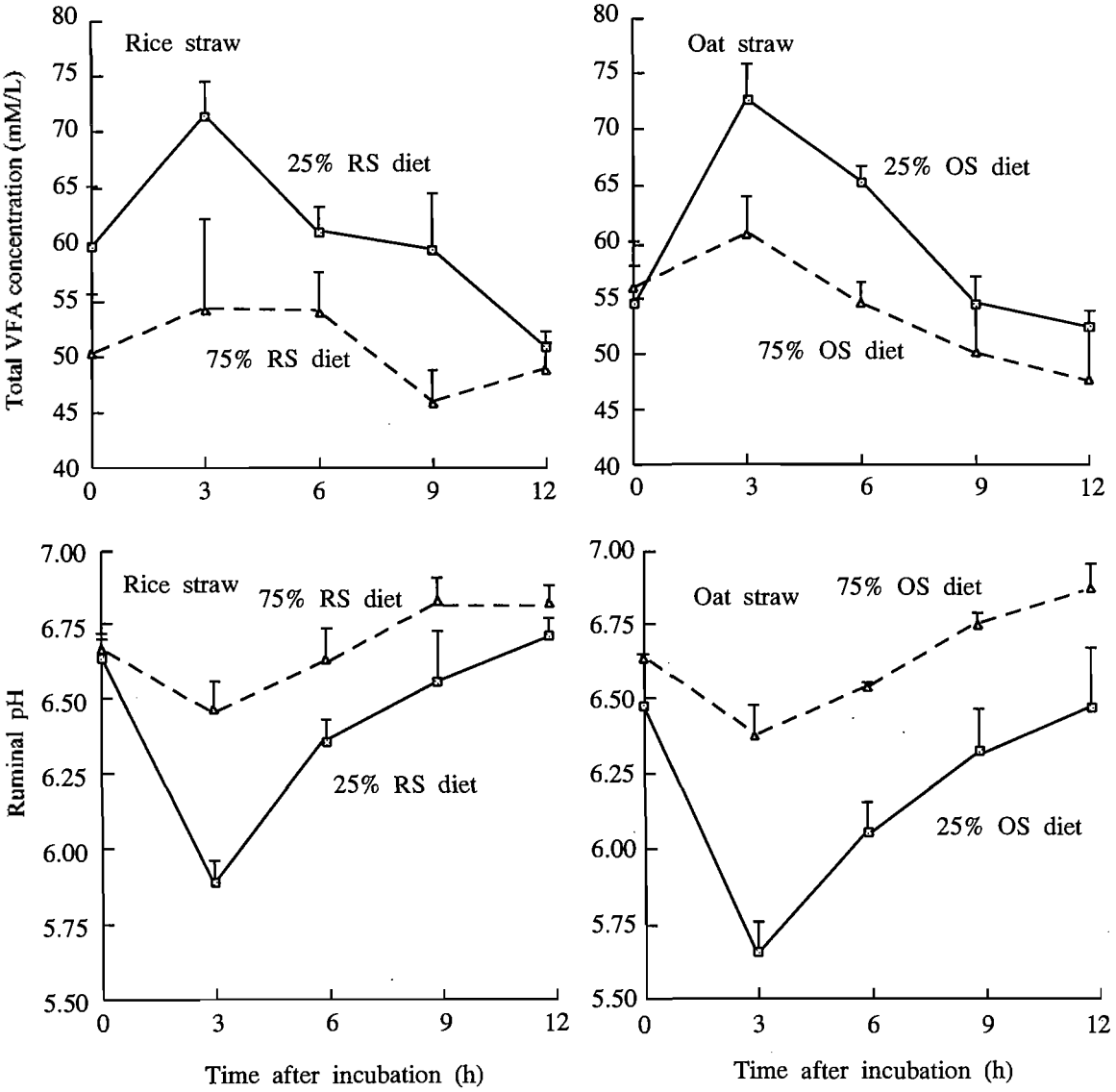

Figure 4. Ruminal pH value and total VFA concentration in the rumen

reduction, passage rate, and cell wall digestibility, and their association with microbial activity and population and digestion activity when the ruminants were fed on high-concentrate fattening diets.

The *in sacco* and *in vivo* digestibility of rice straw obtained from the two feeding trials in this study were almost the same, and consistent with the results of previous work (Takahashi, 1985; Liu et al., 1988a, b; Warly et al., 1994). The *in sacco* and *in vivo* DMD of rice straw was also consistently lower than those of oat straw, although the rice straw had much lower contents of cell wall constituents such as NDF, ADF, and ADL than had the oat straw. In rice plants, the more degradable cultivars generally had a lower composition of the leaf fraction (Goto et al., 1994), in contrast with previous result obtained from other cereal straw, which showed that the more degradable cultivars had higher composition of leaf fraction than the less degradable cultivars (Terry and Tilley, 1964; Wilman and Altimimi, 1982; Kernan et al., 1984; Ramanzin et al., 1986; Goto et al., 1991). The lower degradabilities of leaf blade and leaf sheath fractions in rice straw compared to that of stem fraction seem to be closely related to their higher silica contents, because silica content is generally known to be inversely related to forage digestibility. Van Soest and Jones (1968) reported an average decline of 3.0 units of digestibility per unit of silica in dry matter of a wide range of forage grasses. Scanning electron microscopy of tall fescue (*Festuca arundinacea*) and big bluestem (*Andropogon gerardi*) revealed that silica protected forage tissues from microbial degradation (Harbers et al., 1981). Thus, extensive deposition of silica on the surface of epidermal cell walls in leaf blades and leaf sheaths would be associated with lower digestibility of rice straw compared to that of oat straw in this study, although the adhesion of rumen bacteria on the cell-wall tissues of rice and oat straw was not examined. Since the value of *in vivo* digestibility of rice straw was similar to the value of *in sacco* digestibility, the lower digestibility of rice straw compared to that of oat straw would be not related to its lower total mean retention time in the digestive tract of sheep.

The pattern of particle size reduction of rumen contents collected was different between rice and oat straw. Rice straw constantly had similar percentages of large, medium, and small particles, while oat straw had an increasing percentage of medium particles with the advancement of time. This would suggest that rice straw was balanced in the breakdown of large, medium, and small particles and in the outflow from rumen into the lower digestive tract. Another distinct difference in the particle size reduction was, as shown by the samples collected on a 500 μm-sieve at 15 h of feeding, that rice straw was highly degraded to thinner and longer particles through silicated cells. These would be reflected in the higher outflow rate and lower retention time in the lower digestive tract and, in turn, the lower total mean retention time of rice straw compared to those of oat straw. Furthermore, thinner particles of rice straw were expected to increase the outflow rate of rice straw in the rumen, since the particle size of rumen contents is generally critical for passage into the lower digestive tract (Ichinohe et al., 1994). That was however not detected, probably because chromium-mordanted straw, which cannot be degraded by rumen microorganisms, was used in this study.

Digestion function in the rumen was also enhanced by rice straw, being resulted from its higher rumination which was probably associated with longitudinal breakdown by physical mastication. Grant et al. (1990) reported that the rumination time of dairy cattle was increased from 374 min/d to 531 min/d with a shift from fine ground alfalfa silage (cutting length, 2 mm) to coarse ground (3.1 mm) and also that an altered microbial growth in the rumen and glucose metabolism increased milk protein yield. In this study, the greater chewing time and chewing number for rice straw would be attributed to the higher *in sacco* DM degradability of the cereal straw with the feeding of high-concentrate than with the feeding of high- roughage, showing contrast with results of the oat straw diets. That was certainly due to higher and more stable ruminal pH values and higher biomass and/or activity of rumen micro-organisms as shown by the internal ATP content. The internal ATP content of large-type protozoa on rice straw diets varied within a narrow limit depending upon the concentrate levels, whereas, on oat straw diet, it was lower with the high-concentrate feeding although the number and generic composition of the protozoa were not different. Therefore, rice straw can be more effective to maintain the activity of fiber-degrading bacteria, protozoa, and fungi in the rumen and, thereby, to increase feed intake and feed efficiency on high-concentrate feeding. Rumen protozoa including *Diplodinium*, *Epidinium*, and *Dasytricha spp.*, a category of large-type in this study, were reported to

Table 5. The *in sacco* dry matter degradability of rice and oat straw

	Rice straw		Oat straw	
Tested sample	75% RS	25% RS	75% OS	25% OS
Rice straw	395[a]	438[b]	457[a]	418[b]
Oat straw	587[a]	618[b]	598[a]	559[b]

75% RS, 25% RS, 75% OS, and 25% OS diets were noted in table 3.

[a,b] Values with different superscripts are significantly different ($p<0.05$).

contribute to around 20% of fiber degradation in the rumen (Williams and Coleman, 1992).

In conclusion, it was suggested that rice straw can improve rumination, rumen function, and digestion dynamics more effectively than oat straw, because of extensive deposition of silicated dumbbell-shaped bodies on the leaf tissues. Further research is, however, needed to elucidate the possibility of increasing the effectiveness of roughage of rice straw by changing morphological/anatomical features associated with agronomic characteristics.

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REFERENCES

AOAC. 1970. Official Methods of Analysis (11th ed). Association of Official Analytical Chemists, Washington, DC. pp. 122-131.

Brookes, P. C., K. R. Tate and D. S. Jenkinson. 1983. The adenylate energy charge of the soil microbial biomass. Soil Biol. Biochem. 15:9-16.

Christian, R. R. and M. R. Coup. 1954. Measurement of feed intake by grazing cattle and sheep. VI. The determination of chromic oxide in feces. New Zealand J. Sci. Tech. Sec. A. 36:328-330.

Goto, M., O. Morita and A. Chesson. 1991. Morphological and anatomical variations among barley cultivars influence straw degradability. Crop Sci. 31:1536-1541.

Goto, M., O. Morita, T. Sato, S. Nakaminami, S. Wakasa and H. Ehara. 1994. Morphological and anatomical variations among rice (*Oryza sativa* L.) cultivars influence straw degradability. J. Jpn. Grassl. Sci. 40:38-45.

Goto, M., Y. Yokoe, K. Takabe, S. Nishikawa and O. Morita. 1993. Effects of gaseous ammonia on chemical and structural features of cell walls in spring barley straw. Anim. Feed Sci. Technol. 40:207-221.

Grant, R. J., V. F. Colenbrander and D. R. Mertens. 1990. Milk fat depression in dairy cows: Role of silage particle size. J. Dairy Sci. 73:1834-1842.

Harbers, L. H., D. J. Raiten and G. M. Paulsen. 1981. The role of plant epidermal silica as a structural inhibitor of rumen microbial digestion in steers. Nutr. Repor. Int. 24:1057-1066.

Hoshino, S., R. Sakauchi and M. Wakita. 1978. Feed and care of Matsusaka beef cattle-characteristics of the rumen liquor and rumination. Jpn. J. Zootech. Sci. 49:23-29.

Ichinohe, T., T. Tamura, K. Ueda, M. Okubo and Y. Asahida. 1994. The particle size distributions of ingested boli, rumen digesta and feces in sheep fed orchardgrass hay harvested at different stages of maturity. Anim. Sci. Technol. (Jpn). 65:701-708.

Kernan, J. A., E. C. Coxworth, W. L. Crowle and D. T. Spurr. 1984. The nutritional value of crop residue components from several wheat cultivars grown at different fertilizer levels. Anim. Feed Sci. Technol. 11:301-311.

Kurihara, Y. and T. Takechi. 1973. Methods in the clinical examination of the bovine. In: Examination of the Rumen (in Japanese) (Ed. R. Nakamura, T. Yonemura, and T. Suto). Nosan Gyoson Bunka Kyokai., Tokyo. pp. 14-39.

Liu, J. X., M. Okubo and Y. Asahida. 1988a. Effects of soybean meal supplementation on fiber digestion in the rumen and voluntary intake of rice straw by sheep. Jpn. J. Zootech. Sci. 59:1034-1039.

Liu, J. X., M. Okubo and Y. Asahida 1988b. Voluntary intake and ruminal fiber digestion of rice straw as influenced by sodium hydroxide treatment and soybean meal supplementation. Jpn. J. Zootech. Sci. 59:1040-1046.

Ramanzin, M., E. R. Orskov and A. K. Tuah. 1986. Rumen degradation of straw: II. Botanical fractions of straws from two barley cultivars. Anim. Prod. 43:271-278.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and Procedures of Statistics. 2nd. McGraw-Hill Book Co., New York.

Stock, R. A., M. H. Sindt, J. C. Parrott and F. K. Goedeken. 1990. Effects of grain type, roughage level, and monesin level on finishing cattle performance. J. Anim. Sci. 68:3441-3455.

Suto, T. 1973. Methods in the clinical examination of the bovine. In: Examination of the Rumen (in Japanese) (Ed. R. Nakamura, T. Yonemura and T. Suto). Nosan Gyoson Bunka Kyokai., Tokyo. pp. 39-42.

Takahashi, M. 1985. Effect of urea supplementation on intake and digestibility of ensiled sodium hydroxide-treated rice straw. J. Jpn. Grassl. Sci. 31:130-136.

Terry, R. D. and J. M. A. Tilley. 1964. The digestibility of the leaves and stems of perrenial ryegrass, cockfoot, timothy, tall fescue, lucerne and sainfoin, as measured by an in vitro procedure. J. Br. Grassl. Soc. 19:363-372.

Uden, P., P. E. Colucci and P. J. Van Soest. 1980. Investigation of chromium, cerium and cobalt as markers in digesta rate of passage studies. J. Sci. Food Agric. 31:625-632.

Ushida, K., H. Tanaka and Y. Kojima. 1989. A simple in situ method for estimating fungal population size in the rumen. Letters in Applied Microbiol. 9:109-111.

Van Soest, P. J. and L. H. P. Jones. 1968. Effect of silica in forages upon digestibility. J. Dairy Sci. 51:1644-1648.

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

Wakita, M. and S. Hoshino. 1989. Enzymatic properties of pyruvate kinase from the rumen ciliates genus Entodinium. Int. J. Biochem. 21:777-781.

Warly, L., A. Fariani, O. P. Mawuenyegah, T. Matsui, T. Fujihara and T. Harumoto. Studies on the utilization of rice straw by sheep. III. Effect of soybean meal and barley supplementation on voluntary intake, digestibility and ruminal fermentation. Asian-Aus. J. Anim. Sci. 7: 265-271.

Williams, A. G. and G. S. Coleman. 1992. Metabolism of Entodiniomorphid protozoa. In: The Rumen Protozoa. Springer-Verlag., New York, USA. pp. 173-235.

Wilman, D. and M. A. K. Altimini. 1982. The digestibility and chemical composition of plant parts in Italian and perennial ryegrass during primary growth. J. Sci. Food Agric. 33:595-602.