THE INFLUENCE OF SELECTED CHEMICAL TREATMENTS ON THE RUMINAL DEGRADATION AND SUBSEQUENT INTESTINAL DIGESTION OF CEREAL STRAW

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Summary

An experiment was conducted with three ruminally and intestinally cannulated non-lactating cows of Finnish Ayrshire breed, to assess the ruminal degradation characteristics of oat *(Avena sativa)*, rye (*Secale cereale*) and rice *(Oryza sativa)* straw by the nylon bag technique, and the subsequent post-ruminal degradation of their rumen-undegraded residues by using the mobile bag technique, respectively. The straw samples were untreated or treated with aqueous NH_3 or with urea solution in cold or hot water. The untreated straw samples were milled or chopped, and the treated straw samples were chopped.

The constant values a, b, and c were computed according to the exponential equation, where a = intercept of degradation curve at time 0, b = potentially degradable material, c = rate of degradation of b and (a+b) = maximum potential degradability (asymptote).

It was found that nitrogen contents of chemically treated straw were markedly increased by both NH_3 and urea treatments. Milling the samples attributed to a remarkable loss at 0 h incubation time as compared to chopping of the respective samples. However, chemical treatment markedly improved the b value and the subsequent (a+b) values for dry matter, organic matter, neutral-detergent fiber, and acid-detergent fiber of the samples. Furthermore, temperature of the water used in the urea solutions was considered essential, since urea in hot water rather than in cold water seemed to enhance the overall degradability. The disappearance of rumen-incubated straw residues from the mobile bags ranged from 4.5 to 9.6% for the parameters measured. On average, the OM disappearance from bags was clearly higher for the residues of urea treated straw compared to those of ammonia treated straw, but the disappearance of NDF tended, however, to be higher on the ammonia treatment.

(Key Words: Mobile Bag, Treated Straw, Ruminal Degradations, Intestinal Degradation)

Introduction

Cereal straw is of great importance as an alternative and vital source of roughage crop residue for ruminant feeding, particularly when natural fodders are scarce both quantitatively and qualitatively. However, it often contains a low level of essential nutrients but a high level of structural polysaccharides, which drastically affect the animal intake, digestion and ultimate performance (Sundstol and Owen, 1984; Wanapat, 1985, 1986; Doyle et al., 1986; Devendra, 1988). There are numerous published reports that demonstrate various means and applications to improve the nutritive value of cereal straw in ruminant feeding (Jackson, 1977; Sundstol et al., 1978; Jayasuriya and Perera, 1982; Ørskov et al., 1983; Wanapat et al., 1985, 1986; Cottyn and de Boever, 1988). The changes occurring in the ruminal degradability of straw in vivo are easily verified by the nylon bag method (Ørskov and McDonald, 1979; Ørskov et al., 1980), which is widely accepted for estimation of the ruminal degradability of feeds of varying nature. This technique has also been shown to acquire a close relationship with dry matter intake of roughage (Hovell et al., 1986; Ørskov et al., 1988), digestible dry matter intake and growth rate (Ørskov et al., 1988), digestible dry matter intake and growth rate (Ørskov et al., 1988) by ruminants. Although the digestion of straw in the ruminant gastro-intestinal tract predominantly takes place in the rumen, there is evidence that 40% or more of digested organic matter (OM) of straw may disappear beyond the rumen (Demeyer, 1984). To study the intestinal digestion of feeds in the ruminant, a modified nylon-bag method has been applied. Although the technical details of this mobile bag version are less accurately de-

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fined, it seems to provide a handy tool for digestion studies (Voigt et al., 1985; Hvelplund, 1985; Varvikko and Vanhatalo, 1988). The present experiment was designed to study the effect of chemical treatment and also physical form on the ruminal degradation characteristics of oat, rye and rice straw, and on the subsequent intestinal digestion of their rumen-undegraded residues.

Materials and Methods

Animals and their feeding

Three non-lactating cows of Finnish Ayrshire breed, equipped with cannulae in the rumen and duodenum were used. They were fed, at the maintenance level, 2 kg hay and 2 kg barley straw with additional 1.5 kg of barley, given as two equal meals per day, at 0.800 and 16.00 hours. Minerals were given according to requirements.

Experimental feeds

The experimental feeds were oat straw, rye straw and rice straw. The detailed treatment of the straw samples is given in table 1.

TABLE 1. TREATMENT [a] OF STRAW [b] SAMPLES PRIOR TO RUMEN INCUBATION IN NYLON BAGS

Straw	Treatment	Number
Oat	chopped to length < 10 mm	1
	milled, 2.0 mm screen	2
	aqueous NH_3, chopped	3
	urea in cold tap water, chopped	4
	urea in boiling tap water, chopped	5
Rye	aqueous NH_3, chopped	6
Rice	milled, 1.0mm screen	7
	urea in water, chopped	8

[a] Ammonia treatment was made by injecting NH_3 into the straw (oat straw, 73% DM; rye straw, approximately 50% DM) in polyethene bags to reach the final concentration of 30 g NH_3 kg^{-1} straw. Urea treatment of the straw was made by spraying urea (46% N) mixed with tap water (oat straw, cold or boiling water; rice straw, ambient temperature ~30°C) to the final water content of 60-50% with 5 % urea (w/w). The treated straws were immediately closed, removing the air, into polyethene bags or kept under plastic sheet for six weeks (oat straw) or ten days (rice straw).

[b] Oat (*Avena sativa*) and rye (*Secale cereale*) straw were of Finnish origin, oat straw samples being of the same batch. Rice (*Oryza sativa*) straw was of glutinous variety, collected and prepared at Khon Kaen University, Thailand.

The nylon bag procedures

The effect of physical form or chemical treatment on the ruminal degradation of straw samples and subsequent intestinal digestion of their rumen-undegraded residues was studied by using the nylon-bag technique and mobile bag technique, respectively. The details of the procedures are given in the following paragraphs.

Degradation in the rumen

The rumen degradation values were obtained by weighing the average of 2.3 g dry matter (DM) of straw into the nylon bags (outer dimensions 6x12 cm; pore size (μm)/free surface area (%) of the cloth 41/33) and suspending the bags into the rumen of the animals before morning feeding. A bunch of three bags for each feed was incubated in the rumen for 0, 2, 8, 24, 48 or 72 hours, washed with running cold tap water in a rotating cylinder for 20 minutes, and dried at 60°C for 24 hours. After weighing the bags individually, the three bags of each feed at each incubation period were pooled to make one representative sample for each occasion. Oat straw and rye straw samples were collected from all the three animals. Due to inadequate amount of rice straw material at time, samples were collected only from two (milled untreated rice straw) or one (urea-treated rice straw) animal. To characterize the degradation of the straw samples in the rumen, the degradation values were fitted to the equation (Ørskov and McDonald, 1979):

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

where p is degradation at time t and a, b and c are the constants for the instantly degradable and slowly degradable fraction of the feed and rate of degradation of the latter, respectively. The constants were computed by means of SAS (1987) program (PROC NLIN).

Degradation in the intestine

A modified nylon bag technique, here called the mobile bag technique, was used to study the intestinal degradation of rumen-undegraded residual straw. To collect material for this purpose, straw samples were incubated in the rumen in

nylon bags for 72 hours, and the bags were washed and dried as described above. A total of 900 mg of milled (1 mm screen) straw residue was weighed into polyamide bags sized 3.0x5.0 cm (pore size/free surface area 10 μm/2%), which were heat sealed. Five bags were introduced into the duodenum and sent through the intestine to be collected approximately 23 hours later from the faeces. The collected bags were thoroughly rinsed and washed in tap water (38°C) in a rotating cylinder for one and a half hours, and dried at 60°C for 24 hours. The bags were individually weighed, and the five bags were then pooled to form one sample to be chemically analysed. Oat straw and rye straw were collected from all of the three animals, rice straw was collected only from two (milled untreated rice straw) or one (chopped urea-treated rice straw) animal.

Chemical analyses

The straw samples and their rumen-undergraded as well as intestinally undigested residues were analysed for DM, ash (550°C for 3 hours), Kjeldahl-N, neutral detergent fiber (NDF; Van Soest and Wine, 1967), acid detergent fiber (ADF; Van Soest, 1963).

Statistical analyses

The experiment followed a completely randomized design with 6x8 factorial arrangements of the treatments (incubation hours, straw samples). The results were statistically analysed according to analysis of variance for each incubation period.

Results

Detailed composition of all straw used in the experiment are presented in table 2. The disappearance of straw samples from nylon bags during the rumen incubation and intestinal exposure are given in table 3.

The dry matter contents (%) of chemically treated straw were markedly reduced, while the organic matter (g/kg DM) were similar in all straw samples. More than twofold increase was found for total N (g/kg DM) in oat straw treated with either aqueous NH_3 or urea. However, NH_3-N was more than 60% of total N for urea-treated oat straw and NH_3-treated rye straw, while the respective value for urea-N was found to be less than 1.1 cell wall (NDF) and ADF contents (g/kg DM) varied among different types of straw, NDF being highest (83.5%) in oat straw and lowest (68.9%) in rice straw, and ADF being highest in rye straw and lowest in rice straw (59.5% and 40.7%), respectively. Treatments tended to de-

TABLE 2. CHEMICAL COMPOSITION OF THE STRAW USED IN THE EXPERIMENT

Treatment	Oat straw					Rye straw	Rice straw	
	1	2	3	4	5	6	7	8
g/kg								
Dry matter	880	889	739	449	398	486	948	382
g/kg Dry matter								
Nitrogen	7	7	20	18	26	34	6	11
Organic matter	928	928	928	927	935	958	838	842
NDF	835	832	711	801	784	801	689	723
ADF	540	533	508	516	494	595	407	506
Hemicellulose	294	299	203	285	290	206	282	217
Cellulose	440	438	426	427	410	492	359	436
g/kg Total N								
NH_3-N	–	–	157	690	725	602	–	–
Urea-N	–	–	0.8	1.1	0.9	0.6	–	–

Treatment: 1 = untreated, chopped; 2 = untreated, milled; 3 = aqueous NH_3 treated chopped; 4 = urea-treated cold, chopped; 5 = urea-treated hot, chopped; 6 = aqueous NH_3-treated, chopped; 7 = untreated, milled; 8 = urea-treated, chopped.

NDF = neutral detergent fiber; ADF = acid detergent fiber.

TABLE 3. DISAPPEARANCE (%) OF CEREAL STRAW, UNTREATED OR CHEMICALLY TREATED, FROM NYLON BAGS INCUBATED IN THE RUMEN AND DISAPPEARANCE OF THEIR RUMEN-UNDEGRADED (72 h) RESIDUES FROM MOBILE BAGS PASSED THROUGH THE INTESTINE

Treatment	Oat straw				Rye straw		Rice straw		SEM	Statistical significance
	1	2	3	4	5	6	7	8		
Ruminal disappearance										
Incubation hours	Dry matter									
0	7.0	9.2	15.3	11.2	12.1	4.3	23.1	9.0	1.07	***
2	9.4	10.7	16.5	15.0	15.6	9.6	24.3	13.1	1.39	***
8	14.1	17.5	28.0	18.1	24.3	13.7	29.6	14.0	1.83	***
24	31.8	36.1	48.3	40.5	40.5	31.0	48.3	37.5	1.66	***
48	46.7	52.4	62.8	57.1	58.0	49.2	63.9	59.9	2.00	***
72	50.4	56.5	67.7	63.0	66.5	56.4	68.1	66.0	3.12	**
Constants										
a	-0.6	2.0	11.7	0.1	13.0	0.8	14.2	-5.0		
b	55.0	59.2	59.5	67.2	66.8	65.7	58.2	78.8		
c	0.04	0.04	0.04	0.04	0.02	0.03	0.04	0.03		
a+b	54.4	61.2	71.2	67.3	79.8	66.5	72.4	73.8		
Intestinal disappearance										
	6.6	4.5	6.6	6.6	7.0	4.5	6.8	6.6	1.52	NS
	Organic matter									
0	4.6	5.8	13.6	9.4	10.7	4.4	19.7	5.9	1.13	***
2	5.8	7.0	14.3	12.8	13.9	9.5	20.6	9.1	1.45	***
8	10.4	13.9	25.8	16.0	22.8	13.5	26.5	10.0	1.95	***
24	29.2	33.7	46.6	39.3	39.5	31.1	47.0	35.9	1.74	***
48	44.9	51.0	61.5	56.6	57.7	49.5	63.8	60.5	2.03	***
72	49.0	55.4	66.7	62.9	66.6	57.0	68.2	67.3	3.21	**
Constants										
a	-5.1	-2.4	9.2	-2.5	11.1	0.5	9.4	-10.9		
b	58.4	62.8	61.2	70.0	69.6	66.8	63.2	86.9		
c	0.04	0.04	0.04	0.04	0.02	0.03	0.04	0.03		
a+b	53.3	60.4	70.4	67.5	80.7	67.3	72.6	76.0		
Intestinal disappearance										
	6.9	5.7	7.5	8.3	8.4	5.4	7.8	8.9	1.64	NS
	Neutral detergent fiber									
0	3.3	2.6	6.8	5.4	4.6	-1.7	11.0	-0.8	0.77	***
2	4.6	3.7	6.3	8.4	7.4	3.4	12.9	4.3	1.89	NS
8	10.5	12.7	18.8	12.3	17.4	7.3	19.3	6.0	2.12	**
24	30.2	34.1	42.4	38.3	37.7	28.2	43.1	33.7	1.77	***
48	47.8	52.7	58.8	57.1	57.6	49.1	61.2	61.6	2.55	**
72	52.0	58.6	65.5	64.7	67.7	58.2	66.8	68.4	3.97	NS

TABLE 3. (CONTINUED)

Treatment	Oat straw					Rye straw	Rice straw		SEM	Statistical significance
	1	2	3	4	5	6	7	8		
Constants										
a	−5.9	−4.2	0.4	−7.9	3.6	−7.9	−0.1	−16.7		
b	63.0	69.0	69.3	77.8	77.8	77.9	71.6	95.1		
c	0.04	0.03	0.04	0.04	0.02	0.03	0.04	0.03		
a+b	57.1	64.8	69.7	69.9	81.4	70.0	71.5	78.4		
Intestinal disappearance										
	8.2	5.6	9.6	6.6	7.3	7.6	7.4	5.1	0.75	*
	Acid detergent fiber									
0	2.6	2.5	4.1	4.7	2.6	−2.7	11.2	−4.2	1.00	***
2	4.0	4.2	2.2	7.2	5.7	2.2	14.1	2.6	1.79	**
8	10.2	13.7	14.3	11.3	14.8	6.1	21.2	4.3	2.32	*
24	30.3	33.9	38.9	37.4	35.7	27.3	45.3	32.2	1.96	**
48	48.6	52.1	55.7	56.3	57.0	48.7	64.0	63.4	2.90	*
72	52.3	59.3	63.0	64.8	67.5	58.4	69.9	69.8	4.30	NS
Constants										
a	−6.8	−1.5	−4.8	−8.4	0.4	−9.1	1.7	19.3		
b	64.2	68.4	72.1	78.9	82.1	80.4	73.2	100.8		
c	0.04	0.03	0.04	0.04	0.02	0.03	0.04	0.03		
a+b	57.4	66.9	67.3	70.5	82.5	71.3	74.9	81.5		
Intestinal disappearance										
	6.3	7.8	6.7	5.1	7.4	5.8	5.8	3.7	0.86	NS

Treatment: 1 = untreated, chopped; 2 = untreated, milled; 3 = aqueous NH_3-treated, chopped; 4 = urea-treated cold, chopped; 5 = urea-treated hot, chopped; 6 = aqueous NH_3-treated, chopped; 7 = untreated, milled; 8 = urea-treated, chopped.

crease NDF and ADF in oat straw and to increase the respective values in rice straw. Degradation of DM and OM was highly significant across treatments for each incubation period.

Table 3 contains the degradation data of all straws tested by the nylon bags in the rumen and of the straw residues after 72 h ruminal incubation tested by the mobile bag method in the intestine. As shown, there was a notable loss (ranging from 4.3 to 23.1%) of DM or OM in all samples, when bags were washed with tap water at 0 h. A remarkable loss from bags at 0 h was obviously attributed to using milled samples as compared to chopped samples. Increases in degradation were found for all feeds up to 72 h of incubation.

The rate constant (c) of ruminal degradation was similar in all treatments. Nevertheless, the instantly degradable fraction (a) of DM and OM were highest in urea-treated (hot) oat straw (13.0% and 11.1%), as compared to urea-treated (cold) (0.1% and −2.5%) or NH_3-treated (11.7% and 9.2%) oat straw. It should also be noted that the respective values of DM and OM for untreated rice straw were exceedingly higher than those for urea-treated straw.

The maximum potential degradation values (a+b), however, were highest for oat straw treated with hot water-urea solution, the values being 79.8, 80.7% for DM and OM, respectively. The respective values were 71.2 and 70.4% for NH_3-treated oat straw, and 54.4% and 53.3% for un-

treated, chopped oat straw. Due to a great loss at 0 h incubation, urea treatment resulted in only 4% increase in (a+b) value of OM. The (a+b) value of DM and OM for urea treated rice straw were 73.8% and 76.0%, as compared to the respective values of 72.4% and 72.6% for untreated, milled rice straw.

The degradation of NDF and ADF linearly increased with increasing hours of incubation, and a significant ($p < 0.05$) treatment effect was found across the straw samples for most of the incubation periods. Preparation of straw either by milling or chopping had a remarkable effect especially on potential degradation (a+b), as found with oat straw. However, NH_3 and urea markedly -- improved the potential degradation values (a+b) of NDF and ADF. The b values for NDF and ADF were particularly high with urea-treated rice straw, the values being 95.1 and 100.8%, respectively.

Losses of NDF and ADF from the bags passing through the small intestine were similar to those of DM and OM for all straws. However, statistically significant ($p < 0.05$) treatment effect was found for intestinal disappearance of NDF.

The intestinal disappearance of rumen-undegraded residual DM or OM from mobile bags was on average 6.8%, ranging from 4.5 to 8.9%, and was not statistically different ($p > 0.05$) between the straw samples. The averaged OM disappearance from bags was clearly higher for the residues of urea treated straw (8.5%) compared to those of ammonia treated straw (6.5%). The disappearance of NDF tended, however, to be high compared to other parameters measured, especially on ammonia treatment.

Discussion

Chemical composition

Significant increase in nitrogen by NH_3 and urea treatments were obtained due to additional non-protein-nitrogen (NPN) as shown by the presence of NH_3-N in the straw. This result supported earlier reports by Waagepetersen and Vestergaard Thomsen (1977), Sundstol et al. (1979) and Wanapat et al. (1985). However, it should be pointed out that analyses of N and NH_3-N herein were performed out on wet samples as high levels could have been expected. As found by Sundstol et al. (1979) and Wanapat (1985) the fibrous fractions (NDF and ADF) were reduced by chemical treatments particularly by NaOH due to possible solubilization. This finding was similar both for NDF and ADF (g/kg DM), but not for rice straw.

Degradability

Ruminal degradation values were measured with repeated incubations of up to 72 hours, and the degradation constants a, b and c were calculated. These constants are known to characterize the rumen degradation of feeds fairly well. As it was proposed by Chenost et al. (1970) and Ørskov and McDonald (1979) and later confirmed by Hovell et al. (1986) and Ørskov et al. (1988), the constants were closely correlated with in vivo DM intake, digestible DM intake and growth performance in sheep and cattle, respectively. However, one must be careful with low degradability feeds, because incubation periods should be carried out at least up to 72 hours to reasonably define the asymptote (a+b), otherwise fitting of the model (Ørskov and McDonald, 1979) may not be possible (Dhanoa, 1988).

As measured by degradation characteristics and the respective constants a, b, and c, aqueous NH_3 and urea treatments improved DM, OM, NDF and ADF degradation in all straw. The asymptote (a+b) was used to explain any improvement. Loss of samples due to milling, as compared to chopping, was very marked with rice straw at 0 h incubation (0 h wash value). Rice straw, milled through a Wiley mill with a 1.0 mm screen, was obviously broken into small particles both lengthwise and sidewise, probably due to its brittleness. Straw dustiness and smaller particle size may have rendered greater loss at 0 h incubation.

It also seemed apparent that urea caused a higher degradation of DM, OM, NDF and ADF in oat straw, when hot water was used. Hydrolysis of urea into ammonia by heat treatment also resulted in enhanced degradation of straw as reported by Williams et al. (1984). Temperature of the water mixed with urea needs to be increased to obtain optimal treatment effect. In practical scale, ambient temperature above 30°C should likewise improve the degradability of urea treated straw. Urea treatment of straw carried out in a temperate climate resulted in a lower degree of effectiveness, as compared to other chemical treatments and also urea treatment respectively done in the tropical climate (Wanapat et al., 1985; Wanapat, 1986). In

addition, many other factors, such as moisture content, concentration of chemicals or duration of treatment (Sundstol et al., 1979) could involve in the efficiency of straw treatment. To substantiate urea-treatment effect, Hart and Wanapat (1986) found an increase of 10-12% in OM digestibility to be attributed to urea treatment per se, when the digestibility was compared between urea treated straw and respective untreated isonitrogenous straw.

In spite of milling effect, treatments with aqueous NH_3 and urea remarkably upgraded the maximum potential degradabilities (a+b) of DM, OM, NDF and ADF with oat straw, while with urea treated rice straw a more pronounced influence was seen for NDF and ADF. With urea treated rice straw, the (a+b) values for DM and OM were much lower than with urea treated oat straw (hot), but for NDF and ADF the values were more or less similar.

The chemical composition of different types of straw may also have influence on the rates of degradation. Previous results suggest that genetic variation of cereal straw has an impact on the digestibility and its overall nutritive value (Erickson et al., 1982; Capper, 1986, 1988) as well as on the degree of response to chemical treatment (Wanapat, 1985). However, the remarkable improvement in (a+b) values due to both NH_3 and urea treatment could be explained by a larger microbial colonization of treated straw (Cheng and Hungate, 1986; Silva and Ørskov, 1988). According to Bhat et al. (1988) the rate of ruminal degradation of straw is determined by the way of development of microbial colonization rather than by the initial rate of microbial attachment on the straw.

Ternrud et al. (1988) suggested that increase in the digestibility of cell walls due to chemical treatment is caused by the breakdown of ester and hydrogen bonds in polysaccharides and alkalilabile linkages in lignin as well as changes in the surface layer of the treated straw. It was also found that the liberation of arabinose residues was faster than that of xylose and glucose residues. Equal rate of release of xylose and glucose was found on NH_3 treatment, and they were similar to those on dry NaOH treatment. The release was, however, faster for xylose than glucose on wet NaOH treatment. In the present experiment, urea treatment of oat straw with hot water resulted in an improved degradability, the degradation (a+b) being slightly higher in oat than in rice straw.

According to Demeyer (1984) several published reports suggest that even 44.5% of digested OM of straw may disappear beyond the rumen. Ternrud et al. (1987) reported that most of the digestion and absorption of polysaccarides took place in the rumen. For alkali-treated straw, a lower-gut fermentation could also be noted especially for cellulose. Ferulic acid was observed to be more readily lost in the rumen than p-coumaric acid. According to Varvikko and Vanhatalo (1989, unpublished), nearly 20% of DM of intact barley straw or rapeseed straw disappeared from mobile bags passing through the small intestine. Rumen incubation (72 h) clearly decreased the respective values of DM of various straw samples in this experiment to 4.5-7.0%. The mobile bag values for OM indicated that urea treatment increased the intestinal digestion of straw residues more than NH_3 treatment. On the other hand, NH_3 rather than urea seemed to increase the disappearance of NDF from the mobile bags. Generally, the higher level of disappearance from the mobile bags of NDF compared to ADF is in agreement with previous findings with hay (Varvikko and Vanhatalo, 1989, unpublished) that hemicellulose disappeared from the bags more than cellulose.

These results do not confirm the potentially high digestion of treated straw within the intestine, but they, however, indicate a notable digestion of straw residues to take place in the lower gut, regardless of the treatment. As the rumen incubation affects the subsequent mobile bag digestion values in the lower gut (Varvikko and Vanhatalo, 1988), shorter incubation time in the rumen would obviously result in higher intestinal degradation of straw samples.

The present results provide additional relevant information for the degradation of treated straw in the rumen, considering particularly the constants a, b and c, as well as for post-ruminal degradation of low-quality roughages and crop residues using the mobile bag technique. The further studies, however, should be carried out using samples of similar physical forms under varying chemical treatments.

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