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Song, Young-Han
Department of Animal Science, Faculty of Agriculture, Kyushu University

Shimojo, Masataka
Department of Animal Science, Faculty of Agriculture, Kyushu University

Goto, Ichiro
Department of Animal Science, Faculty of Agriculture, Kyushu University

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Improvement of Nutritive Value of Barley Straw by Treatment with Ammonia and Sulphur Dioxide

Young-Han Song, Masataka Shimojo and Ichiro Goto

Department of Animal Science, Faculty of Agriculture,
Kyushu University, Fukuoka 812, JAPAN

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Barley straw was treated with anhydrous ammonia (30 g/kg DM) for 28 days at 20°C and/or sulphur dioxide (40 g/kg DM) for 24hours at 20°C to study the effect on the nutritive value. Barley straw was moistened with water (*300* or *450* g/kg DM) before the treatment. Digestibility of the sample was measured with nylon bags suspended for 48hours in the rumen of Tokara goats fitted with a rumen cannular and fed on alfalfa hay. Ammonia and $NH_3 \cdot SO_2$ treatments improved the crude protein content of barley straw by approximately 3.5-fold. Contents of NDF and hemicellulose were reduced by ammonia and $NH_3 \cdot SO_2$ treatment, however ADF and cellulose contents were slightly affected. Lignin and silica contents were reduced by ammonia and $NH_3 \cdot SO_2$ treatments. These two treatments improved the digestibilities in *sacco* of barley straw and its cell wall components. Mild application of sulphur dioxide to ammoniated barley straw showed similar improvement in nutritive value over ammoniation alone. Sulphuration alone less affected the nutritive value of barley straw compared to the other treatment. Improvement in digestibility was strongly related to decrease in contents of lignin and silica and increased digestibility of lignin.

INTRODUCTION

Cereal straws are characterized by low contents of crude protein and available energy. Among the methods to improve the nutritive value of cereal straws, ammonia treatment is effective for increasing both crude protein and digestible energy. In addition to such treatment conditions as amount of ammonia, temperature and duration of treatment, moisture content of straw also influences ammoniation's effects, and its recommended levels are 10% to 50% (Sundstøl et *al., 1979).* Recently, additional applications of sulphur dioxide to ammoniated barley straw (Dryden and Leng, 1986, 1988) and rice straw (Song et al., 1991) have been found to retain more NH,-N in the straws and give higher digestibility, compared to ammoniation alone. Song et *al.* (1991) also showed that improvement in digestibility of rice straw was related to decreased contents of lignin and silica and increased digestibility of lignin.

The objective of this study is to investigate the effects of anhydrous ammonia, sulphur dioxide and combinations of these, on the nutritive value of barley straw under different moisture contents and on the relationship between digestibility and lignin or silica.

MATERIALS AND METHODS

Straw samples

Straw from barley plant (japonica type, var. Nijo) was collected at the Kyushu University Farm in 1989. The straw was dried for 48hr at 70°C and cut in 1-2cm length.

Treatments

Barley straw was moistened with water (300 or 450 g/kg DM) and incubated at 20” C for 4days in a sealed polyvinyl bag. The prepared straw was then treated with anhydrous ammonia (0 or 30 g/kg DM) for 28 days at 20°C and then treated with sulphur dioxide (0 or 40 g/kg DM) for 24hr at 20°C.

Analytical methods

The treated straw was aired for 3days to exclude excess chemicals and ground through a 1 mm aperture screen. Crude protein content was determined by the Kjeldahl method (AOAC, 1984) and ash content by combustion at 600°C for 3hr. Cell wall components were determined by the methods of Georing and van Soest (1970). Lignin was determined by Morrison’s method (1972). The straw digestibilities in the rumen for 48hr was determined by the nylon bag technique (Mehrez and Ørskov, 1977) using two Tokara goats fitted with rumen cannulae and fed on alfalfa hay.

Statistical analysis

The digestibility and chemical components were fitted to analysis of variance differnce and the least significant difference (LSD). The relations between digestibility and lignin or silica were analyzed by linear regression.

Table 1. Effect of NH, and SO, treatments on chemical compositions’) of barley straw with different moisture contents.

Moisture (%)	0	30				45			
NH, (%)	0	0		3		0		3	
SO, (%)	0	0	4	0	4	0	4	0	4
Crude protein	$4.8^{ab5)}$	5.1^{b}	4.7^{a}	15.9^{d}	15.7’	5.0^{b}	4.7”	19.8”	20.2’
NDF[2]	77.7”	74.7’	73.4^{d}	66.7”	64.1^{f}	77.1^{b}	74.3	63.2^{g}	61.8^{h}
ADF[3]	49.0^{b}	47.8”	46.0^{d}	45.3”	44.0^{f}	49.7”	45.4”	44.0’	43.6’
Hemicellulose	28.7^{ab}	27.0^{b}	27.4^{b}	21.5^{c}	20.1^{d}	27.5’	28.8”	19.3^{d}	18.2”
Cellulose	42.4^{b}	42.3^{b}	41.2’	41.3”	40.6^{d}	44.1”	41.0”	40.3^{de}	39.8”
ABL[4]	13.2”	13.1”	12.6^{ab}	11.6^{bc}	11.1’	12.8”	12.1^{b}	11.3^{c}	10.1^{d}
Silica	1.6”	0.9^{b}	0.8^{bc}	0.4^{d}	0.3”	0.7’	1.5”	0.6^{cd}	0.5^{d}

[1] % Dry matter basis, [2] Neutral detergent fibre, [3] Acid detergent fibre,
[4] Acetyl bromide lignin,
[5] Figures with different superscripts in the same row differ significantly ($P<0.01$)

RESULTS AND DISCUSSION

1. Effects of ammonia and sulphur dioxide treatments on chemical composition of barley straw

Table 1 shows the chemical composition of barley straw untreated and treated with NH, and SO, under different moisture contents. Ammonia treatment improved the crude protein content of the straw by approximately 3.3-fold with a 30% moisture level and 3.7-fold with a 45% moisture. Sulphuration after ammoniation increased crude protein content by similar values to those given by ammoniation alone. This observation was caused by milder application of SO, (40 g/kg DM) than that for 223g/kg DM by Dryden Leng (1986), who reported further increase of crude protein. Sulphuration alone did not affect the content of crude protein. Crude protein content was more improved with a 45% moisture level than with a 30% moisture because the higher moisture content retained more nitrogen in the straw.

Neutral detergent fibre (NDF) and hemicellulose contents were reduced by ammonia and $NH_3 \cdot SO_2$ treatments and showed lower values with higher moisture level. Reduction in NDF by ammoniation was mainly caused by the solubilization of hemicellulose (Dryden and Leng, 1988). Acid detergent fibre (ADF) and cellulose contents were slightly reduced by treatments with ammonia and $NH_3 \cdot SO_2$.

Contents of lignin and silica were reduced by ammonia and $NH_3 \cdot SO_2$ treatments.

Sulphuration with or without ammoniation seemed to have little effect on cell wall components due to its mild condition (40 g/kg for 24hr at 20°C).

2. Effects of ammonia and sulphur dioxide treatments on *in sacco* digestibility of barley straw

Table 2 shows the digestibilities of dry matter (DM), organic matter (OM) and cell wall components of barley straw treated chemically. Ammoniation increased the digestibillities of DM and OM by approximatly 25%, respectively. Straw digestibility with 45% moisture level showed slightly higher values compared to 30% moisture.

Ammonia and $NH_3 \cdot SO_2$ treatment greatly improved the digestibilities of NDF,

Table 2. Effect of NH, and SO, treatments on digestibilites in sacco of barley straw with different moisture contents.

Moisture (%)	0	30				45			
NH, (%)	0	0		3		0		3	
SO_2 (%)	0	0	4	0	4	0	4	0	4
DM”	$51.1^{a6)}$	50.2”	52.6”	75.4”	75.2”	57.3^{b}	55.8^{b}	77.9’	78.4^{d}
OM[2)]	52.6”	52.0”	53.7”	76.2’	76.9’	61.3^{b}	58.6^{b}	79.1^{d}	79.4^{d}
NDF[3)]	43.3’	40.2”	42.1”	67.9^{g}	66.4^{f}	50.0”	46.7^{d}	69.9^{h}	70.1^{h}
ADF[4)]	41.7^{b}	40.4”	42.0^{b}	66.0’	65.0”	50.5^{d}	44.8’	67.5^{g}	66.9^{g}
Hemicellulose	46.1”	39.0”	42.6^{b}	71.8’	69.4^{e}	49.1^{d}	49.7^{d}	75.4^{g}	77.9^{h}
Cellulose	45.4^{a}	44.5”	45.8”	70.5^{de}	69.0^{d}	54.5’	49.9^{b}	71.5^{c}	70.8”
ABL[5)]	42.9^{b}	42.3”’	34.3”	58.3’	57.3’	42.4^{ab}	40.9^{ab}	64.9”	60.0’

[1)] Dry matter, [2)] Organic matter, [3)] Neutral detergent fibre, [4)] Acid detergent fibre,
[5)] Acetyl bromide lignin,
[6)] Figures with different superscripts in the same row differ significantly ($P < 0.01$).

ADF, hemicellulose and cellulose. These two treatments gave similar values and showed digestibilities of NDF and hemicellulose which were higher with a 45% moisture level than with a 30% moisture. Higher moisture in straw is more effective for improvement of its digestibility (Waiss et al., 1972 ; Solaiman *et al., 1979* ; Borhami and Sundstøl, 1982).

Digestibility of acetyl bromide lignin (ABL) was increased greatly by treatments with NH_3 and $NH_3 \cdot SO_2$, and these two treatments gave similar values. Ammonia may saponify ester bonds between lignin and hemicellulose (Chesson, 1988) and saturate *H* bonds linking the matrix polysaccharides (Dryden and Leng, 1988). Ammonia increases the digestibility of the remaining cell wall, perhaps by allowing intra-crystalline swelling of cellulose microfibrils (Millet *et al., 1976).*

In this study, application of sulphur dioxide to ammoniated barley straw gave similar digestibilities to those given by ammoniation alone, a fact which differs from the findings of Dryden and Leng (1986) who showed higher improvements in digestibilities of barley straw treated with $NH_3 \cdot SO_2$. A major reason for this difference is the difference in quantities of SO_2 applied (40 g/kg DM vs 223 g/kg DM). The extent of improvement in digestibility was smaller with barley straw than with rice straw, which had been less digestible than barley straw before treatment (Song et *al.,*1991). This result was partly caused by less improvement in lignin digestibility with barley straw compared to rice straw (Song et *al.,* 1991).
Sulphuration alone gave slight improvements in digestibility of barley straw only with higher moisture content.

3. Relation between *in sacco* digestibility and lignin or silica of barley straw

Dry matter digestibility *in sacco* of barley straw was negatively correlated to lignin content (Fig. 1). Organic matter digestibility also had an inverse correlation to lignin content ($r = -0.896$, $p < 0.01$). Lignin content is likely to be the major constraint

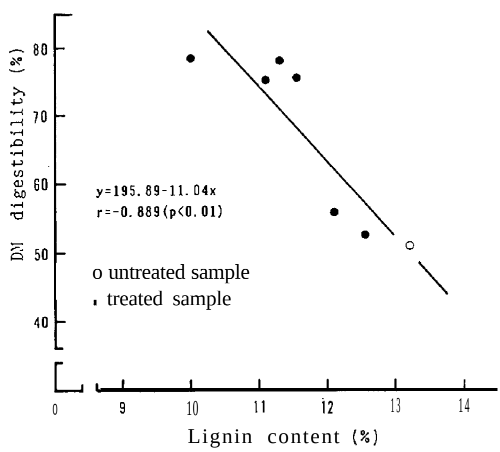

Fig. 1. Relation between in *sacco* dry matter (DM) digestibility and lignin content of barley straw.

on potential degradability (Smith et al., 1972).

Dry matter digestibility in *sacco* was positively correlated with lignin digestibility (Fig. 2). This indicated that improvement in DM digestibility was partly due to the increased digestibility of lignin, which had been labile by ammoniation. Chesson (1981) reported that when about 50% of the straw was degraded, further digestibility of the cellulose and hemicellulose depended on the prior removal of lignin.

Digestibility *in sacco* of barley straw was negatively correlated with content of silica (Fig. 3). Silica in barley straw is, however, a secondary factor limiting diges-

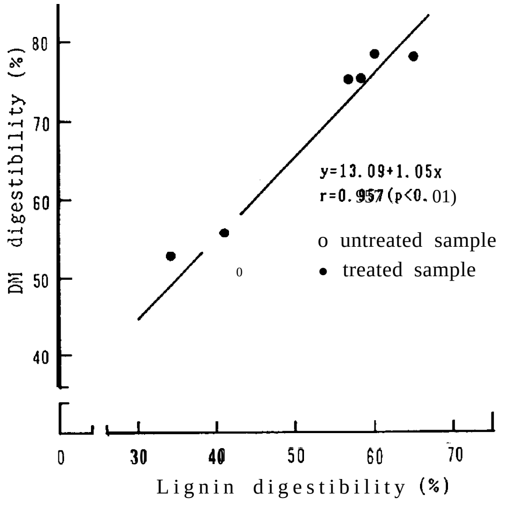

Fig. 2. Relation between in sacco dry matter (DM) digestibility and lignin diges tibility of barley straw.

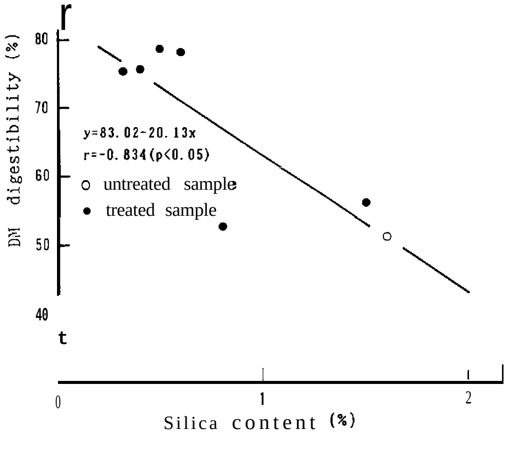

Fig. 3. Relation between *in sacco* dry matter (DM) digestibility and silica content of barley straw.

tibility due to its lower content than lignin in contrast to rice straw (Song et *al.,* 1991).

From the result of this study, milder application of sulphur dioxide to ammoniated barley straw showed similar improvement in nutritive value to that given by ammoniation alone with more improvement under higher moisture content. Improvement in straw digestibility was related to decreased contents of lignin and silica and increased digestibility of lignin.

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