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Gary Lesoing
University of Nebraska-Lincoln, glesoing2@unl.edu

Terry Klopfenstein
University of Nebraska-Lincoln, tklopfenstein1@unl.edu

Ivan G. Rush
University of Nebraska-Lincoln, irush1@unl.edu

John Ward

CHEMICAL TREATMENT OF WHEAT STRAW[1]

Gary Lesoing[2], Terry Klopfenstein,
Ivan Rush[3] and John Ward

University of Nebraska[4], Lincoln, 68583

Summary

An *in vitro* digestion study, a lamb growth trial and a lamb digestion trial were conducted to evaluate the effect of different NaOH and $Ca(OH)_2$ treatments on the energy availability of wheat straw. *In vitro* dry matter disappearance (IVDMD) of wheat straw was increased 29% by chemical treatment with 1% NaOH plus 3% $Ca(OH)_2$ and by as much as 86% by a 4% NaOH plus 1% $Ca(OH)_2$ treatment. A significant amount of hemicellulose was solubilized by chemical treatment with NaOH and $Ca(OH)_2$, but little cellulose was solubilized. Rate and extent of both hemicellulose and cellulose digestion of treated wheat straw were increased significantly in comparison to corresponding measures for untreated wheat straw. Lambs fed chemically-treated wheat straw gained significantly faster and more efficiently and consumed more dry matter per day than those fed untreated wheat straw diets. Chemical treatment of wheat straw significantly increased dry matter, organic matter cellulose and hemicellulose digestibilities in the lamb digestion trial. Organic matter digestibility was increased from 51.3% for untreated wheat straw to 65.3% for 4% NaOH-treated wheat straw.

(Key Words: Straw, Sodium Hydroxide, Crop Residues, Chemical Treatment.)

Introduction

Wheat *(Triticum aestivum)* is the most commonly grown crop on a worldwide basis for human consumption. For each kilogram of grain produced, a similar amount of residue is available as feedstuff. As demand for grains for human consumption increases, alternative energy sources such as wheat straw will be used in ruminant diets. To increase utilization of wheat straw as an energy source, it will be necessary to decrease the effect of lignification. Sodium hydroxide (NaOH) treatment increases the energy availability and digestibility of crop residues, including wheat straw (Ololade *et al.*, 1970; Singh and Jackson, 1971; Klopfenstein *et al.*, 1972; Klopfenstein and Woods, 1970). Rounds *et al.* (1976) observed a greater response in growing lambs fed corn cobs treated with various combinations of NaOH and calcium hydroxide $Ca(OH)_2$ than with NaOH alone. Waller (1976) reported that NaOH and $Ca(OH)_2$ treatment of cobs was effective in solubilizing hemicellulose and increasing rate and extent of hemicellulose and cellulose digestion. Digestibility of corn stalklage has also been improved by chemical treatment with NaOH and $Ca(OH)_2$ (Lamm, 1976). This research study was conducted to evaluate the effects of treatment with different combinations of NaOH and $Ca(OH)_2$ on the digestibility and energy value of wheat straw.

Experimental Procedure

Three trials were conducted to evaluate different alkali chemicals for treating wheat straw. In trial 1, measures of *in vitro* dry matter disappearance (IVDMD) and *in vitro* cellulose and hemicellulose digestion were used to evaluate dry ground wheat straw (IRN 1-05-175) subjected to various chemical treatments. Treatments evaluated were: (1) control, water added only; (2) 1% NaOH plus 3% $Ca(OH)_2$; (3) 3% NaOH plus 1% $Ca(OH)_2$; (4) 3% NaOH plus 2% $Ca(OH)_2$; (5) 4% NaOH plus 1% $Ca(OH)_2$ and (6) 4% NaOH. Chemical additions were made on a percentage basis (gram of each hydroxide/100 g straw dry matter). Wheat straw was ground through a 2.54-cm screen before chemical treatment. The

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[2] Present address: North Platte Exp. Sta., North Platte, NE 69101.

[3] Panhandle Station, Scottsbluff, NE 69361.

[4] Dept. of Anim. Sci.

ground wheat straw was then adjusted to 60% moisture with water or the appropriate chemical solution and allowed to mix thoroughly in a ribbon blender before being packed in 208-liter drums with plastic liners. Treated straw was allowed to react a minimum of 5 days before use. Samples were taken after 5 days and dried for 48 hr in a forced air oven (60 C) to a constant weight. For *in vitro* analyses, all samples were ground through a 1-mm screen in a Wiley mill. The two-stage digestion technique of Tilley and Terry (1963) was used for IVDMD determinations.

The artificial rumen was also used to evaluate *in vitro* rate of digestion of cellulose and hemicellulose stated as units mass/time. Three-hundred and thirty milligrams of dry matter were weighed into 50-ml *in vitro* fermentation tubes. Each sample was duplicated for incubation times of 0, 24 and 48 hr by the first stage of the Tilley and Terry (1963) digestion technique. At the termination of incubation, inoculum and residual dry matter were transferred to a 600-ml Berzelius beaker with neutral detergent solution (Waller, 1976). Procedures described by Goering and Van Soest (1970) were used for determination of neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL). Hemicellulose and cellulose were calculated by difference from analysis of NDF, ADF and ADL. Solubilization of cell wall components was calculated from data collected at the 0 hr incubation time. *In vitro* digestibility of cellulose and hemicellulose was calculated from data collected for each incubation time.

Trial 2, a lamb growth trial, was conducted to evaluate chemically-treated wheat straw in a growing diet. Treatments applied to the wheat straw and method of chemical addition were the same as those used in trial 1. Thirty-six crossbred wether lambs (average weight 30 kg) were randomly allotted to the six different diets (six lambs per diet) in this 61-day trial. The lambs were individually fed in an enclosed building with concrete slatted floors. Diets consisted of 75% (dry matter basis) treated or untreated wheat straw and 25% supplement, consisting of brewers dried grains (IRN 5-02-141), cane molasses (IRN 4-04-696) and urea (IRN 5-05-070). The composition of the supplement used in trial 2 is presented in table 1. Diets were formulated for 12% crude protein, .4% calcium, .3% phosphorus and .3% salt. Lambs were weighed initially and at the conclusion of the trial, following a 16-hr period without food or water.

TABLE 1. COMPOSITION OF SUPPLEMENT FOR LAMB GROWTH AND DIGESTION TRIALS[a]

Ingredients	% dry matter
Brewers dried grains	78.37
Cane molasses	12.00
Urea	4.88
Dicalcium phosphate	2.86
Salt	1.20
Limestone	.328
Sulfur	.228
Trace minerals[b]	.120
Antibiotics	.08
Vitamin ADE[c]	.04

[a]Supplement was 25% (dry matter basis) of the diet and contained 37.2% crude protein.

[b]Trace mineral composition: Mn, 10%; Fe, 10%; Zn, 10%; Ca, 4.5%; Cu, 1%; I, .3%; Co, .1%.

[c]Vitamin ADE premix contained 32,000 IU/g vitamin A, 8,000 IU/g vitamin D and 32 IU/g vitamin E.

Trial 3, a lamb digestion trial, was conducted to further evaluate the chemical treatments of wheat straw *in vivo*. Treatments and treatment method applied were as described for trial 1. Twenty-four crossbred wethers (average weight 36 kg) were randomly allotted to the six treatments (four lambs per treatment). After a 14-day adaptation period, total fecal collection was carried out for 7 days. During the collection period, lambs were individually fed 85% of their *ad libitum* intake of a diet similar to that described in trial 2. Grab samples of wheat straw and supplement were taken daily and composited. Total feces collection for each lamb was composited in plastic bags and frozen. At the end of the collection period, the feces were weighed and mixed, and a representative sample was obtained for dry matter and fiber analyses. Dry matter analyses of feed and feces were determined by drying samples in a forced air oven (60 C) to a constant weight. All samples were ground through a 1-mm screen before analyses. Organic matter was determined on feed and feces by ashing. NDF, ADF and ADL were determined by the method of Goering and Van Soest (1970). Hemicellulose and cellulose were calculated by difference from analyses of NDF, ADF and ADL. *In vivo* dry matter, organic matter, hemicellulose and cellulose digestibilities were calculated from results of the chemical analyses. Solubilization of cell wall components due to chemical treatment was also calculated. *In vitro* dry matter disappearance analyses were conducted for comparison with *in vivo* results.

The data from 1, 2 and 3 were analyzed by analyses of variance as described by Steel and Torrie (1960). Orthogonal comparisons were conducted to evaluate treatment mean differences. Comparisons made were: 1 *vs* 2, 3, 4, 5, 6; 2 *vs* 3, 4, 5, 6; 3, 4 *vs* 5, 6; 3 *vs* 4 and 5 *vs* 6.

Results and Discussion

Chemical treatment was very effective in increasing the IVDMD of wheat straw (table 2). All chemically-treated wheat straw diets had significantly higher IVDMD values than the untreated wheat straw. The higher levels of NaOH treatment were the most effective in increasing IVDMD. Similar results have been reported by Ololade *et al.* (1970), Wilson and Pigden (1964) and Rexen and Thomsen (1976). Wheat straw treated with 3 or 4% NaOH had significantly greater IVDMD values than straw treated with 1% NaOH plus 3% $Ca(OH)_2$ combination. Although $Ca(OH)_2$ improved IVDMD of wheat straw, it was much less effective than NaOH. Rounds *et al.* (1976) also found that replacement of NaOH with $Ca(OH)_2$ gave lowered IVDMD of corn cobs. Those authors suggested that the reduction in IVDMD was a result of a lower dissociation constant of $Ca(OH)_2$.

TABLE 2. IVDMD OF CHEMICALLY-TREATED WHEAT STRAW—TRIAL 1

Treatment	$NaOH:Ca(OH)_2$	IVDMD[b], %
1	0:0	40.57
2	1:3	52.45
3	3:1	71.65
4	3:2	72.82
5	4:1	75.64
6	4:0	74.06
Standard error		1.32

[a]Gram of each hydroxide/100 g of straw dry matter.

[b]Treatment differences (P<.05) (1 *vs* 2, 3, 4, 5, 6; and 2 *vs* 3, 4, 5, 6).

In trial 1, little solubilization of cellulose occurred as a result of chemical treatment, but both the rate and extent of digestion were greatly improved (table 3). As much, or more, digestion occurred in 24 hr of incubation for the chemically-treated material as in 48 hr for the untreated wheat straw. A 174% increase in cellulose digestibility was observed at 24 hr when wheat straw was treated with 3% NaOH plus 2% $Ca(OH)_2$. After 48 hr of incubation

TABLE 3. *IN VITRO* CHEMICAL SOLUBILIZATION AND DIGESTION OF CELLULOSE OF TREATED AND UNTREATED WHEAT STRAW—TRIAL 1

Treatment	$NaOH:Ca(OH)_2$[a]	Chemically solubilized[b], %	Digestion[c,d,e,f] 24 hr	48 hr
1	0:0	0	21.5	35.7
2	1:3	1.1	36.6	58.3
3	3:1	1.4	56.1	73.6
4	3:2	2.3	59.0	79.4
5	4:1	2.2	57.6	80.6
6	4:0	1.4	53.4	77.2
Standard error		.5	2.2	

[a]Gram of each hydroxide/100 g of straw dry matter.

[b]% = grams of cellulose solubilized per 100 g of original untreated straw dry matter. Chemically solubilized = cellulose of untreated straw − cellulose recovered after treatment.

[c]Percentage of original cellulose digested after 24 and 48 hr of incubation.

[d]Cellulose digested = (cellulose predigestion − cellulose postdigestion) ÷ (cellulose predigestion × 100).

[e]Statistical analysis was conducted on the average of the 24 and 48 hr digestibility values.

[f]Treatment differences (P<.05) (1 *vs* 2, 3, 4, 5, 6; 2 *vs* 3, 4, 5, 6).

cellulose digestibility of straw treated with either 3 or 4% NaOH was increased by 100% or more. Coombe *et al.* (1979) have found similar increases in potential digestibility of fiber in barley straw. However, they found that NaOH treatment did not affect the rate constant for digestion of barley straw fiber.

Unlike cellulose, a great deal of hemicellulose was solubilized by chemical treatment in trial 1 (table 4). As much as 32.5% of the hemicellulose present in the untreated wheat straw was solubilized upon chemical treatment. Solubilization of hemicellulose of wheat straw was greatest at the 5% NaOH treatment levels. Chemical treatment with 4% NaOH or 3% NaOH plus 1% $Ca(OH)_2$ was also very effective in solubilizing hemicellulose; the 1% NaOH plus 3% $Ca(OH)_2$ treatment was less effective. Waller (1976) found 4% NaOH to be the most effective chemical treatment for solubilizing hemicellulose in cobs, followed by 4% $Ca(OH)_2$, 1% NaOH plus 3% $Ca(OH)_2$, 3% NaOH plus 1% $Ca(OH)_2$ and 2% NaOH plus 2% $Ca(OH)_2$. These results suggest that different crop residues respond differently to the various chemical treatments (Klopfenstein, 1978; Smith *et al.*, 1970).

In trial 2, lambs fed chemically-treated wheat straw consumed more feed and gained faster and more efficiently ($P<.05$) than lambs fed water-ensiled, untreated wheat straw (table 5). Lambs fed untreated wheat straw actually lost weight during the growth trial. This was due primarily to their low dry matter intake. Daily dry matter intake was increased by 225% when lambs were fed 3% NaOH plus 2% $Ca(OH)_2$-treated wheat straw. Chemical treatment decreased the theoretically indigestible residue. This should reduce rumen load of indigestible residue and increase intake (Waldo *et al.*, 1972). Rate of passage may have also been increased (Berger *et al.*, 1980).

Performance tended to improve with the higher NaOH treatment levels. Lambs fed 4% NaOH-treated straw showed the greatest increase in performance, followed closely by the 4% NaOH plus 1% $Ca(OH)_2$ treatment. Chemical treatment with 3% NaOH produced intermediate performance results. Results obtained in trial 2 were similar to those obtained by Hasimoglu *et al.* (1969) in a study in which 4% NaOH-treated wheat straw was fed as 70% of the diet along with soybean meal. Waller (1976), however, found that growing lambs performed best when corn cobs were treated with 3% NaOH plus 1% $Ca(OH)_2$. Treatment with 1% NaOH plus 3% $Ca(OH)_2$ was also shown to be equal to the 4% NaOH treatment.

TABLE 4. *IN VITRO* CHEMICAL SOLUBILIZATION AND DIGESTION OF HEMICELLULOSE OF TREATED AND UNTREATED WHEAT STRAW–TRIAL 1

Treatment	NaOH:$Ca(OH)_2$[a]	Chemically solubilized[b,f,h], %	Digestion[c,d,e,f,g] 24 hr	Digestion[c,d,e,f,g] 48 hr
1	0:0	0	22.7	37.5
2	1:3	5.5	29.7	45.2
3	3:1	7.6	44.5	64.1
4	3:3	8.7	41.4	62.0
5	4:1	8.9	55.7	73.0
6	4:0	7.3	55.2	72.7
Standard error		.3	3.5	

[a]Grams of each hydroxide/100 g of straw dry matter.

[b]% = grams of hemicellulose solubilized per 100 g of original untreated straw dry matter. Chemically solubilized = (hemicellulose of untreated straw − hemicellulose recovered after treatment).

[c]Percentage of original hemicellulose digested after 24 and 48 hr of incubation.

[d]Hemicellulose digested = (hemicellulose predigestion − hemicellulose postdigestion) ÷ (hemicellulose predigestion × 100).

[e]Statistical analysis was conducted on the average of the 24 and 48 hr digestibility values.

[f]Treatment differences ($P<.05$) (1 *vs* 2, 3, 4, 5, 6; 2 *vs* 3, 4, 5, 6).

[g]Treatment differences ($P<.05$) (3, 4 *vs* 5, 6).

[h]Treatment differences ($P<.05$) (3 *vs* 4; 5 *vs* 6).

TABLE 5. PERFORMANCE DATA OF LAMBS FED CHEMICALLY-TREATED STRAW–TRIAL 2

Treatment	$NaOH:Ca(OH)_2$ [a]	Daily gain[b], g	Daily feed[b], g	Gain to feed ratio[b]
1	0:0	– 19	455	–.142
2	1:3	102	830	.123
3	3:1	126	879	.144
4	3:2	137	1,025	.135
5	4:1	151	973	.151
6	4:0	157	978	.157
Standard error		47	130	.049

[a]Grams of each hydroxide/100 g of straw dry matter.

[b]Treatment differences (P<.05) (1 *vs* 2, 3, 4, 5, 6).

Different results were obtained by Lamm *et al.* (1976) in a study in which lambs were fed corn stalklage treated with chemicals. Lambs fed stalklage treated with 3 or 4% NaOH performed similarly, but a marked decrease in performance occurred when the animals were fed 1% NaOH plus 3% $Ca(OH)_2$-treated stalks. These results gave more indication that all crop residues do not react the same way to the different chemical treatments. The lack of response observed for the 1% NaOH and 3% $Ca(OH)_2$ treatment of corn stalklage and wheat straw could be attributed to more lignification in these two residues or a different cell wall structure which requires a stronger base, such as NaOH to exert a positive effect on cell wall availability.

In trial 3, chemical treatment of wheat straw increased (P<.05) organic matter digestibility (OMD) and dry matter digestibility (DMD) above that obtained with untreated wheat straw (table 6). Treatment with 3 or 4% NaOH produced greater (P<.05) digestibilities than 1% NaOH-treated straw. The 4% NaOH treatments were the most effective in increasing OMD and DMD, followed closely by the 3% NaOH and 2% $Ca(OH)_2$ chemical treatments. Hasimoglu *et al.* (1969), Singh and Jackson (1971) and Rexen and Thomsen (1976) reported comparable OMD when straw was treated with 4% NaOH, 3.3% NaOH and 4% NaOH, respectively. Lamm (1976), however, found little increase in OMD for cobs or stalklage treated with 1%

TABLE 6. APPARENT DIGESTIBILITIES OF CHEMICALLY-TREATED WHEAT STRAW–TRIAL 3

Treatment	$NaOH:Ca(OH)_2$	OMD[c,d] %	DMD[c,d] %	IVDMD[b,d,e] %
1	0:0	51.29	47.73	41.06
2	1:3	58.02	53.98	56.15
3	3:1	58.40	55.99	62.47
4	3:2	62.15	58.87	71.60
5	4:1	63.21	61.05	73.65
6	4:0	65.32	62.91	71.75
Standard error		1.60	1.39	1.32

[a]Grams of hydroxide/100 g of straw dry matter.

[b]IVDMD of wheat straw for lamb digestion trial (trial 3).

[c]Digestion coefficients of wheat straw were calculated by difference, assuming the supplement to have OMD and DMD of 66%.

[d]Treatment differences (P<.05) (1 *vs* 2, 3, 4, 5, 6; 2 *vs* 3, 4, 5, 6; 3, 4 *vs* 5, 6).

[e]Treatment differences (P<.05) (3 *vs* 4).

TABLE 7. APPARENT DIGESTIBILITIES OF COMPONENTS OF CHEMICALLY-TREATED WHEAT STRAW

Treatment	$NaOH:Ca(OH)_2$ [a]	Hemicellulose[c,d,e]	Hemicellulose[b,c,d]	Cellulose[c,d]	Cellulose[b,c,d]
		(%)			
1	0:0	53.68	53.68	64.97	64.97
2	1:3	62.74	69.19	74.11	74.32
3	3:1	62.70	71.54	74.97	74.82
4	3:2	73.75	79.68	79.88	79.58
5	4:1	80.74	85.94	80.52	81.02
6	4:0	73.02	81.31	82.16	82.36
Standard error		3.22	2.97	1.84	1.85

[a]Grams of hydroxide/100 g of straw dry matter.

[b]Hemicellulose and cellulose digestibilities based on hemicellulose and cellulose in untreated straw. Percentage digestion = (hemicellulose or cellulose intake of untreated straw − hemicellulose or cellulose in feces) ÷ (hemicellulose or cellulose intake of untreated straw) X 100.

[c]Digestion coefficients of wheat straw were calculated by difference, assuming the supplement to have hemicellulose and cellulose digestibilities of 51.62 and 29.08%, respectively.

[d]Treatment differences ($P<.05$) (1 *vs* 2, 3, 4, 5, 6; 2 *vs* 3, 4, 5, 6; 3, 4 *vs* 5, 6).

[e]Treatment differences ($P<.05$) (3 *vs* 4).

NaOH plus 3% $Ca(OH)_2$, cobs treated with 3% NaOH plus 1% $Ca(OH)_2$ or stalklage treated with 3% NaOH plus 2% $Ca(OH)_2$. These results agree with the earlier reported data that crop residues respond differently to chemical treatments.

Also in trial 3, untreated wheat straw had significantly lower hemicellulose and cellulose digestibilities than the chemically-treated straws (table 7). Chemical treatment of straw with 3 or 4% NaOH increased ($P<.05$) hemicellulose and cellulose digestibilities in comparison to treatment with 1% NaOH plus 3% $Ca(OH)_2$, and 4% NaOH was more effective ($P<.05$) than 3% NaOH in increasing both hemicellulose and cellulose digestibilities. The hemicellulose digestibilities are in agreement with results reported in the *in vitro* trial (trial 1). The cellulose digestibilities in trial 1 gave an indication of the treatment effects found *in vivo* (trial 3) but showed no significant differences between 3 and 4% NaOH treatments. Rexen and Thomsen (1976) found similar coefficients for cellulose digestibility when straw was treated with 4% NaOH. Maeng *et al.* (1971) reported comparable cellulose digestibilities when barley straw was treated with 6% NaOH and fed with alfalfa to lambs in a complete diet.

Although the *in vitro* digestibilities generally gave a good indication of which treatments were best, they tended to overestimate digestibilities of the best treatments (treatments with 3 and 4% NaOH) and underestimate the 1% NaOH plus 3% $Ca(OH)_2$-treated straw and the untreated straw (table 6). The overestimation of the digestibilities of the treated straws may have been due to a shorter rumen retention time for those straws. Rate of passage may be increased by an increase in water or dry matter intake. Maeng *et al.* (1971) reported an increase in water consumption by animals fed NaOH diets and dry matter intake was increased twofold among animals fed treated straw diets in trial 2. The full digestibility potential of the treated straw may not be obtained because it may not be in the rumen long enough.

The underestimation of the digestibility of the untreated straw may have been a result of rumen retention time longer than 48 hours. If straw remains in the rumen long enough, more digestion will occur, which will give a higher *in vivo* digestibility coefficient than *in vitro*. The underestimation of the 1% NaOH and 3% $Ca(OH)_2$ may have been due to physiological effects. The high $Ca(OH)_2$ and the low NaOH treatment may be important in maintaining a more favorable mineral balance in the rumen and in the body.

Results of these trials suggest that 4% NaOH was the best chemical and level for treating wheat straw. More research is needed to determine the effects of balancing for more favorable mineral ratios for treated wheat straw diets.

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