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Influence of Maceration and Fibrolytic Enzymes on the Feeding Value of Rice Straw

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Abstract: Ninety Holstein yearling steers (467 kg) were used in a 116-d trial to evaluate the influence of maceration on the feeding value of rice straw. Treatments consisted of a steam-flaked corn-based diet containing 15% forage (DM basis) as sudangrass, rice straw or macerated rice straw. All forages were ground to pass through a 2.6 cm screen prior to incorporation into complete mixed diets. There were no treatment effects ($P > 0.20$) on dressing percentage. However, there was a forage by enzyme interaction ($P < 0.10$) on DMI and ADG. Enzyme supplementation increased (5%) DMI and ADG of cattle fed diets containing macerated rice straw. Enzyme supplementation did not affect ($P > 0.20$) dietary NE, thus the improvement in ADG with enzyme supplementation of the macerated rice straw supplemented diet was due to increased in DMI. Gain efficiency, and dietary NE were greater (5 and 4%, respectively; $P < 0.05$) for macerated rice straw than for ground rice straw supplemented diets. The estimated NEm and NEg values for ground rice straw were 0.72 and 0.22 Mcal/kg, respectively. The corresponding values for macerated rice straw were 1.45 and 0.86 Mcal/kg, respectively. Enzyme supplementation did not affect ($P > 0.20$) dietary NE. Six steers with cannulas in the rumen and proximal duodenum were used to evaluate treatment effects on digestion. There were no treatment interactions ($P > 0.20$). Ruminal digestion of organic matter was similar across treatments (60.9%, $P = 0.35$). Ruminal NDF digestion was greater (25%, $P < 0.10$) for sudangrass than for rice straw supplemented diets, averaging 54 and 44%, respectively. Likewise, ruminal ADF digestion was also greater (43%, $P < 0.10$) for sudangrass than for rice straw, averaging 30.6 and 21.4 %. respectively. Maceration of rice straw did not affect ($P > 0.20$) extent of ruminal fiber digestion. Maceration increased (8%, $P < 0.05$) ruminal degradation of feed N over that of ground rice straw. Enzyme supplementation did not enhance ($P = 0.95$) ruminal NDF digestion, but increased total tract digestion of DM (4%, $P = 0.06$), OM (4%, $P = 0.06$), and NDF ($P = 0.12$). Total tract digestion of DM (4%, $P < 0.01$), OM (3%, $P < 0.05$), and NDF (31%; $P < 0.01$) were greater for sudangrass than for rice straw supplemented treatments. Maceration did affect ($P > 0.20$) total tract digestion of OM and fiber. We conclude that enzyme supplementation works synergistically with maceration to enhance the feeding value of low quality forages such as rice straw. The beneficial effects of fibrolytic enzymes on ruminal digestion are expected to increase as ruminal retention time of the fibrous components of the diet decrease.

Key words: Rice Straw, Enzyme, Maceration, Cattle, Performance, Metabolism

Introduction

In its native state, rice straw is poorly digested (38 to 44%; White *et al.*, 1971). Consequently, its inclusion (20% rice straw) in finishing diets has negatively affected DMI (White *et al.*, 1975). Coarse grinding (to pass through a 3.30 cm screen) enhances its feeding value in finishing diets. However, finely processing (grinding to pass through a 1.27 cm screen) elicits no additional benefit (Oh *et al.*, 1971; White *et al.*, 1971). Pelletizing increases particle density, allowing for greater ruminal turnover rate, and permitting increased DMI (Moore, 1964; Coleman *et al.*, 1978; Mertens and Ely, 1979 and Zinn, 1987). When included in growing-finishing diets at levels of 15% or greater, pelletizing straw has markedly (60%) increased its NE value, comparable to that of good quality alfalfa hay (1.39 to 1.49 Mcal/kg NEm; Zinn, 1987 and Ware *et al.*, 2003). However, this effect is attributable to positive associative effects on energy retention, as pelletizing does not enhance digestibility, per se. Maceration, a comparatively new technique in forage processing, has increased both digestibility and NE value of rice straw (Torrentera *et al.*, 2000). The macerator is designed to simulate chewing, or mastication (Fig. 1). It consists of two sets of opposing corrugated rolls maintained within set tolerances of each other using hydraulic pressure. Opposing rolls turning at differential speeds, crush and stretch the fiber, but the forage remains otherwise, intact. The effects of indentition during maceration greatly alters the structural integrity and density of the fiber, promoting microbial attachment and digestion (Hong 1988a, Rodney, 1999 and Torrentera *et al.*, 2000). Supplementation of rumen-stable combinations of xylanases and cellulases has also increased ruminal fiber digestion and DMI (Howes , 1998; Zinn and Salinas, 1999 and Lopez-Soto *et al.*, 2000). The objective of this study is to evaluate the influence of maceration and fibrolytic enzyme supplementation on the comparative feeding value of rice straw in growing-finishing diet for feedlot cattle.

Materials and Methods

Trial 1: Ninety Holstein yearling steers (467 kg) were blocked by weight and randomly assigned within weight groups to 18 pens (five steers per pen). Pens were 43 m^2 with 22 m^2 overhead shade, automatic waterers and 2.4 m fence-line feed bunks. Treatments consisted of a steam-flaked corn-based diet containing 15% sudangrass (SG), 15% ground rice straw (RSG)or 15% macerated rice straw (RSM) and Fibrozyme® (an enzyme complex having both xylanase and cellulase activity; Alltech Inc., Nicholasville, KY; 0 vs 15g/d) to evaluate the effect of fibrolytic enzyme supplementation and maceration on growth performance. Sudangrass hay and rice straw were ground in a hammer mill (Bear Cat #1A-S, Westerns Land and Roller Co., Hastings, NE) with a 2.54-cm screen before incorporation into complete-mixed diets. Rice straw was macerated through two sets of corrugated rollers as shown in Fig. 1. Maceration is a process designed to simulate bovine mastication. Straw is passed through two pairs of rollers which are set at zero tolerance, one pair located above the second pair. The macerator runs the rollers on a differential gearing, permitting the two rollers aligned vertically at the left to turn at a rate different than the two rollers on the right. This type of construction has two principle functions designed to model chewing action: 1) to create in the straw, 2) to shear open the straw. As straw passes through the rollers, corrugations on the rolls produce "bites" in the

straw (openings through which bacteria and enzymes may have access. Because the rollers are moving at different velocities, a shearing effect is produced, further opening the straw to the enzymatic process. This permits the surface area of the straw fiber to be increased without excessive reduction in fiber length. By altering structural integrity and bulk density, maceration has increased fiber digestion, and hence, DM intake of forages (Hong 1988a, Rodney, 1999). Composition of experimental diets is shown in Table 1. Forage net energy values for maintenance and gain were calculated using the following equations: NEm = 0.78 + 2.53*CP/NDF (Sumner, 1968), where Nem=net energy for m a intenance, CP = percent crude protein, and NDF = percent neutral detergent fiber (Sumner, 1968) ; NEg = .877NEm - 0.41. Steers had ad libitum access to feed and water. Fresh feed was added twice daily. Steers were implanted with Synovex-S® (Forte dodge Animal Health, Forte Dodge, IA) on d 1 and Revalor-S® (Intervet Inc., Millsboro, DE), on d 56 of the trial. Energy gain (EG, Mcal/d) was calculated by the equation: $EG = ADG^{1.095} .0493W^{.75}$ (NRC, 1984). Maintenance energy (EM) was calculated by the equation: $EM = .O77\ W^{.75}$. From the derived estimates of energy required for maintenance and gain, the NE_m and NE_g values of the diet were obtained using the quadratic formula: where a = -.41EM, b = .877EM + .41DMI + EG, and c = -.877DMI, and $NE_g = .877NE_m - .41$ (Zinn and Shen, 1998). For calculating steer performance, initial and final full weights were reduced 4% to account for digestive tract fill. Final weight was adjusted for carcass weight by dividing carcass weights by the average dressing percentage. Pens were used as experimental units. The trial was analyzed as a randomized complete block design experiment. Treatment effects were separated by means of orthogonal polynomials (Hicks, 1973).

Trial 2: Six Holstein steers (298 kg) with ruminal and duodenal cannulas (Zinn and Plascencia, 1993) were used in a replicated 3 × 3 Latin square experiment to evaluate treatment effects on characteristics of ruminal and total tract digestion. Composition of experimental diets is shown in Table 1, except for the inclusion of 0.4% chromic oxide (added as a digesta marker). Steers were maintained in individual pens with access to water at all times. Diets were fed at 0800 and 2000 daily. Fibrozyme® was added to the basal diet (7.5 g/feeding) at the time of feeding. Dry matter intake was restricted to 2.2% of body weight. Experimental periods were 2 wk, with 10 d for diet adjustment and 4 d for collection. During collection, duodenal and fecal samples were taken twice daily as follows: d 1, 0750 and 1350; d 2, 0900 and 1500; d 3, 1050 and 1650, and d 4, 1200 and 1800. Upon completion of the trial, feed, duodenal and fecal samples were prepared for analysis by oven drying at 70°C and grinding in a lab mill (Micro-Mill, Bel-Arts Products, Pequannock, NJ). Samples were oven dried at 105°C until no further weight was lost and stored in tightly sealed glass jars. Samples were subjected to all or part of the following analyses: ash, ammonia N, Kjeldahl N (AOAC, 1984); ash corrected NDF (adapted from Goering and Van Soest, 1970), chromic oxide (Hill and Anderson, 1958) and purines (Zinn and Owens, 1986). Microbial organic matter (MOM) and N (MN) leaving the abomasum were calculated using purines as a microbial marker (Zinn and Owens, 1986). Organic matter fermented in the rumen was considered equal to organic matter intake minus the difference between the amount of total organic matter reaching the duodenum and microbial organic matter reaching the duodenum. Feed N escape to the small intestine was considered equal to total N leaving the abomasum minus ammonia-N and microbial N, and thus, includes any endogenous additions. This trial was analyzed as a replicated 3 × 3 Latin square according to the following statistical model: $Y_{ijkl}=i + B_i + A_{j(i)} + P_k + T_l + E_{ijkl}$, where B_i is block, $A_{j(i)}$ is steer within block, P_k is period, T_l is treatment and E_{ijkl} is residual error. Treatment effects were separated by means of orthogonal polynomials (Hicks, 1973)

Results and Discussion

Trial 1: Treatment effects on cattle growth-performance are shown in Table 2. Notwithstanding differences in forage NDF intake, there were no treatment effects ($P > 0.20$) on dressing percentage. This is consistent with NRC (2000), where empty body weight is considered largely a function of shrunk body weight (EBW = 0.891 * SBW; $r^2 = 0.971$). However, Williams *et al.* (1992) observed that the level of forage NDF, and physical form of forage were also important determinates of digestive tract fill. Likewise, Zinn and Salinas (1999) observed that with high concentrate diets, digestive tract fill increases to a physiological maximum with increasing dietary concentration of indigestible NDF.

There was a forage by enzyme interaction ($P < 0.10$) on DMI and ADG. Enzyme supplementation increased (5%) DMI and ADG of cattle fed diets containing macerated rice straw. The basis for the interaction is not certain. Because enzyme supplementation did not affect ($P > 0.20$) dietary NE, the improvement in ADG with enzyme supplementation of the macerated rice straw supplemented diet was largely a reflection of the increase in DMI. The increased DMI may have been due to increased ruminal NDF turnover rate. Lopez-Soto *et al.* (2000) observed that maceration of rice straw increased the passage rate of NDF from the rumen by 53%.

Consistent with previous studies (Petit *et al.*, 1997; Charmley *et al.*, 1999 and Torrentera *et al.*, 2000), gain efficiency, and dietary NE were greater (5 and 4%, respectively; $P < 0.05$) for macerated rice straw than for ground rice straw supplemented diets. Indeed, the NE values for the macerated rice straw supplemented diets were at least equivalent ($P = 0.82$) to that of sudangrass supplemented diets. Given that the NEm and NEg values of sudangrass used in this trial were 1.12 and .57 Mcal/kg, respectively (Table 1), the corresponding NEm and NEg values for rice straw are 0.72 and 0.22 Mcal/kg, respectively, for ground, and 1.45 and 0.86 Mcal/kg for the macerated straw. Enzyme supplementation did not affect ($P > 0.20$) dietary NE.

The NEm value for ground rice straw corresponds to a TDN value of 42% (TDN = 19.65 + 31.18NEm; $r^2 = 0.998$, derived from NRC, 1996), in good agreement with White *et al.* (1974) and Willis et al. (1980) who observed TDN values for rice straw ranging from 38 to 44%. The low energy value of rice straw can be attributed to its comparatively low soluble carbohydrate and protein content, and to its distribution of highly lignified sclerenchymatous layer and tissues of the vascular bundles, making it resistant to penetration by digestive enzymes. Improving rice straw as an energy source in cattle rations requires disruption of the fiber matrix. Grinding enhances intake, but not digestibility of rice straw. Fine grinding (1 vs 4 cm screen) is of little benefit (Stone *et al.*, 1969 and White *et al.*, 1971), and may even reduce digestibility to the extent that it decreases ruminal retention time (Coombe *et al.*, 1979). However, of particular concern with rice straw is that rate of ruminal digestion and particle size reduction may be so slow that straw accumulates in the rumen, limiting feed intake.

Trial 2: Treatment effects on characteristics of digestion are shown in Table 3. There were no treatment interactions. Ruminal digestion of organic matter was similar across treatments (60.9%, $P = 0.35$). As expected (Moore *et al.*, 1990 and Lopez-Soto *et al.*, 2000), ruminal NDF digestion was greater (25%, $P < 0.10$) for sudangrass than for rice straw supplemented diets, averaging 54 and 44%, respectively. Likewise, ruminal ADF digestion was also greater (43%, $P < 0.10$) for sudangrass than for rice straw, averaging 30.6 and 21.4 %.

Table 1: Composition of diets fed to feedlot cattle

	Treatments[a]		
Item	Sudan	RSG	RSM
Ingredient Composition (DMB%)			
Steam-flaked Corn	75.10	75.10	75.10
Sudangrass hay	15.20	0.00	0.00
Ground rice straw	0.00	15.20	0.00
Macerated rice straw	0.00	0.00	15.20
Urea	1.20	1.20	1.20
Yellow grease	3.50	3.50	3.50
Cane molasses	5.00	5.00	5.00
Net Energy, Mcal/kg			
Maintenance	2.26	2.15	2.08
Gain	1.57	1.48	1.48
Forage Nutrient Composition, %			
DM			
CP	7.3	4.1	4.8
ADF	30.4	34.0	35.7
NDF	54.5	57.5	59.9
ASH	8.6	12.8	12.6
Ether Extract	1.8	1.9	2.3
Net Energy, Mcal/kg			
Maintenance	1.12	0.96	0.98
Gain	0.57	0.43	0.45
NRC NE Tabular Values, Mcal/kg			
Maintenance	1.17	0.64	0.64
Gain	0.61	0.11	0.11

[a]With and without 15g of Fibrozyme

Table 2: Treatment effects on feedlot cattle growth performance

	Fibrozyme ®, g/d						Main Effect					
	0			15			Forage Source			Enzyme Level		
Item	Sudan	RSG	RSM	Sudan	RSG	RSM	Sudan	RSG	RSM	0 g	15 g	SD
Pen Replicates	5	5	5	5	5	5						
Weight, kg												
IW	467	469	467	465	468	466	467	468	467	468	466	
FW	606	604	603	598	603	609	602	604	606	605	603	
DM Intake, kg/d[a]	9.06	9.23	8.76	8.95	9.15	9.20	9.01	9.19	8.98	9.02	9.10	0.29
Avg Daily intake[a]	1.19	1.17	1.17	1.14	1.17	1.23	1.17	1.17	1.2	1.18	1.18	0.05
Gain/DM intake[b]	0.131	0.127	0.134	0.128	0.128	0.134	0.130	0.127	0.134	0.131	0.130	0.005
Diet net energy, Mcal/kg												
Maintenance[b]	2.25	2.19	2.3	2.22	2.21	2.27	2.24	2.20	2.28	2.25	2.23	0.06
Gain[b]	1.57	1.51	1.61	1.54	1.53	1.58	1.55	1.52	1.59	1.56	1.55	0.05
Observed/Expected Net Energy												
Maintenance[bc]	1.02	1.04	1.09	1.01	1.04	1.04	1.07	1.02	1.04	1.08	1.04	0.03
Gain[bc]	1.03	1.05	1.11	1.01	1.05	1.05	1.09	1.02	1.05	1.1	1.05	0.04
Dressing %	61.7	62.5	62.1	62.6	62.6	62.1	62.0	62.1	62.3	62.1	62.2	0.90

[a]Forage x Enzyme Interaction, (P<0.10) [b]Macerated vs. Chopped, (P<0.05) [c]Sudan vs. Rice Straw (P<0.05)

respectively. Maceration of rice straw did not affect (P > 0.20) extent of ruminal fiber digestion. However, Lopez-Soto *et al.* (2000) observed that maceration of rice straw increases rate of passage of NDF from the rumen by 53%. Accordingly, it may be concluded that because extent of ruminal fiber digestion was similar for ground and macerated rice straw, rate of digestion of macerated rice straw increased in direct proportion with changes in rate of passage (rate of ruminal fiber digestion = extent of digestion times rate of passage/ one minus extent of digestion). Maceration increased (8%, P < 0.05) ruminal degradation of feed N over that of ground rice straw.

Table 3: Treatment effects on characteristics of ruminal and total tract digestion

	Fibrozyme ®, g/d						Main Effect					
	0			15			Forage Source			Enzyme ®		
Item	Sudan	RSG	RSM	Sudan	RSG	RSM	Sudan	RSG	RSM	0 g	15 g	SD
Steer Wt., kg	298	298	298	298	298	298	298	298	298	298	298	
Intake, g/d												
DM	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560	
OM	6,163	6,140	6,117	6,172	6,140	6,117	6168	6140	6117	6140	6143	2
ADF	380	457	465	384	457	465	382	457	465	434	436	6
NDF	981	963	959	860	963	959	920	963	959	968	927	38
Starch	2,922	3,001	2,995	3,118	3,001	2,995	3020	3001	2955	2960	3025	57
N	122	111	112	114	111	112	118	111	112	115	112	2
Ruminal Digestion, %												
OM	58.2	61.7	55.9	69.8	57.3	62.4	64.0	59.5	59.2	58.6	63.2	5.8
ADF[a]	17.4	16.5	15.1	43.6	26.9	27.2	30.6	21.7	21.1	16.4	32.5	8.7
NDF[a]	48.6	39.1	38.2	55.2	41.5	40.6	51.9	40.3	39.4	42.0	45.8	7.3
Starch	72.3	78.5	73.5	82.3	77.3	79.6	77.3	77.9	76.5	74.8	79.7	5.5
Feed-N[b]	64.7	71.8	66.3	70.1	52.0	67.5	67.4	61.9	66.9	67.6	63.2	4.2
Microbial Efficiency[c]	23.2	20.9	25.6	15.1	23.0	19.0	19.2	22.0	22.3	23.3	19.0	4.9
N Efficiencyd	1.02	0.97	1.08	0.86	1.21	0.97	0.94	1.09	1.03	1.03	1.01	0.11
Total Tract Digestion, %												
DM[ef]	77.9	76.4	74.1	81.8	77.9	78.6	79.8	77.2	76.3	76.1	79.4	1.8
OM[fg]	79.5	78.4	76.2	83.4	80.1	80.7	81.4	79.3	78.4	78.0	81.4	1.8
ADF[g]	39.7	40.3	37.3	57.5	39.6	44.9	48.6	40.0	41.1	39.1	47.4	6.1
NDF[e]	51.5	41.4	38.4	61.7	45.1	47.1	56.6	43.3	42.8	43.8	51.3	5.3
Starch	96.2	95.6	94.4	97.1	97.3	97.3	96.7	96.4	95.9	95.4	97.2	1.5
N	72.7	67.6	67.6	69.1	70.4	71.7	70.9	69.0	69.7	69.3	70.4	2.5

[a]Effect of Sudan vs. Rice Straw (P<0.10) [b]Ground vs. Macerated 9P<0.05) [c]Microbial N, g/kg OM fermented
[d]Nonammonia N entering the small intestine/N intake [e]Effect of Sudan vs. Rice Straw (P<0.01)
[f]Effect of Fibrozyme (P<0.10) [g]Effect of Sudan vs. Rice Sraw (P<0.05)

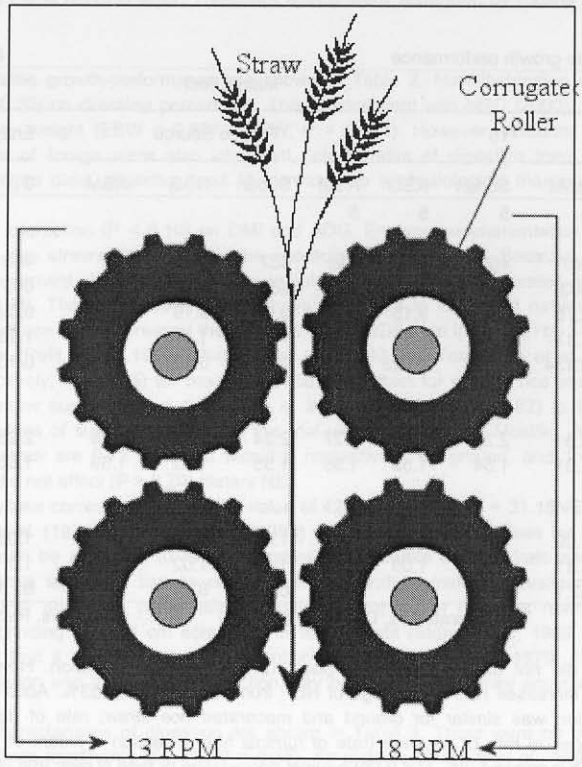

Fig. 1: Macerator Design Concepts

In contrast with previous studies (Feng *et al.*, 1996; Beauchemin *et al.*, 1999; Lopez-Soto *et al.*, 2000 and Murillo, *et al.*, 2000), enzyme supplementation did not enhance (P = 0.95) ruminal NDF digestion. However, when ruminal NDF digestion is greater than 40, as was the case in the present study (Trial 2, Table 3), responses to enzyme supplementation have been small or non-appreciable (Murillo *et al.*, 2000; Ambrozio *et al.*, 2001 and Ware and Zinn, 2001), the primary limitation being the nature of the fiber itself, and its accessibility to the fibrolytic process.

In agreement with previous work (Moore, 1990 and Lopez-Soto *et al.*, 2000), total tract digestion of DM (4%, P < 0.01), OM (5%, P < 0.05), and NDF (31%; P < 0.01) were greater for sudangrass than for rice straw supplemented treatments. However, contrary to Lopez-Soto *et al.* (2000) and Torrentera *et al.* (2000), maceration did not enhance (P > 0.20) total tract digestion of OM and fiber. Enzyme supplementation increased total tract digestion of DM (4%, P = 0.06), OM (4%, P = 0.06), and NDF (P = 0.12). Similar increases in total tract digestion have been reported previously (Lewis *et al.*, 1996; Murillo *et al.*, 2000; Ware and Zinn, 2001), although it was anticipated that the greater response to enzyme supplementation occurs within the rumen (Zinn and Salinas, 1999 and Lopez-Soto *et al.*, 2000). Ruminal pH (as a function of forage level) and quality may contribute to this disparity. When ruminal digestion of otherwise highly digestible fiber is retarded due to low ruminal pH, there is often a compensating post ruminal digestion so that differences in total tract fiber digestion due to enzyme supplementation become small (Murillo *et al.*, 2000).

Total tract OM digestion was greater (3.2%, P < 0.05) for sudangrass than for rice straw supplemented diets. The expected difference based on forage inclusion rate (15%) and tabular TDN values (NRC, 1996) for sudangrass (56%) and straw (41%) was 2.5%. Consistent with previous studies (Moore et al., 1990; Lopez-Soto *et al.*, 2000; Torrentera *et al.*, 2000), total tract NDF digestion was lower (31%; P < 0.01) for rice straw than for sudangrass supplemented diets, explaining 57% of the difference in total tract OM digestion.

Conclusion

Enzyme supplementation works synergistically with maceration to enhance the feeding value of low quality forages such as rice straw. The beneficial effects of fibrolytic enzymes on ruminal digestion are expected to increase as ruminal retention time of the fibrous components of the diet decrease.

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