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Influence of mechanical maceration on wheat straw on characteristics of digestion in growing–finishing diets for feedlot cattle

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ABSTRACT

Four Holstein steers (142 ± 3 kg) with cannulas in the rumen and proximal duodenum were used in a 4 × 4 Latin square design to evaluate the influence of mechanical maceration of wheat straw on the characteristics of digestion. Treatments consisted of a steam-flaked corn-based growing–finishing diet supplemented with 21% forage (DM basis) as: 1) sudangrass hay (SG), 2) wheat straw (STRW), 3) macerated wheat straw (MAC) at intensity of 600 psi (MAC600) and 4) macerated wheat straw at intensity of 900 psi (MAC900). All forage treatments were ground to pass through a 3.81 cm screen before incorporation into complete mixed diets. Chromic oxide was used as an indigestible marker to estimate nutrient flows and digestibility. Ruminal NDF kinetics were determined from measures by total evacuation of ruminal content and by NDF duodenal flow. There were no treatment effects ($P \geq 0.11$) on ruminal digestion of OM, NDF, starch, microbial efficiency (MN, g/kg of OM fermented), or protein efficiency (NAN, g/g of N intake). Apparent total tract digestion of OM, NDF and DE diet were greater ($P < 0.01$) for SG than for STRAW. Maceration of wheat straw increased ($P < 0.04$) apparent postruminal and total tact digestion of OM, NDF, N, and dietary DE. Ruminal NDF passage rate was greater ($P \leq 0.05$), and ruminal DM ($P < 0.01$) and NDF fill ($P \leq 0.02$) were lesser for SG and MAC than for STRW. Intensity of maceration (MAC600 *vs.* MAC900) did not affect ($P \geq 0.11$) characteristics of site and extent of digestion. Maceration increased (28%) the DE value of wheat straw. The DE value of MAC tended to be greater (7.5%; $P = 0.08$) for MAC than for SG.

1. Introduction

Maceration applications have been developed to enhance site and extent of digestion of low-moisture, low-quality forages such as rice straw (Plascencia et al., 2007; Torrentera et al., 2000). The process consists of passing forage through sets of opposing corrugated rolls maintained within set tolerances of each other using hydraulic pressure. Opposing corrugated rolls turn at differential speeds so that as the forage is drawn through it is stretched and crushed, but remains otherwise, intact. Indentations produced during maceration by roll corrugations greatly alter the structural integrity and density of the fiber, promoting microbial attachment, digestion, and rate of passage (Plascencia et al., 2007). Although the influence of mechanical maceration on characteristics of digestion of rice

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straw has been studied extensively (Lopez-Soto et al., 2006; Plascencia et al., 2007; Torrentera et al., 2000; Ware et al., 2005), there is no comparable information on the effect of maceration process on digestion of wheat straw.

The objective of this experiment was evaluate the effects of maceration of wheat straw on characteristics of digestion in steers fed a growing–finishing diet containing 21% of forage.

2. Material and methods

2.1. Diets and forage processing

The composition of experimental diets is shown in Table 1. Treatments consisted in a 79% corn-based diet complemented with 21% forage as follows: 1) sudangrass hay (SG), 2) wheat straw (STRW), 3) macerated straw, tension of the rollers was adjusted to provide pressure of 41.3 bars (MAC600) and 4) macerated straw, tension of the rollers was adjusted to provide pressure of 62.0 bars (MAC900). Chromic oxide was used as an indigestible marker to estimate nutrient flows and digestibility. Chromic oxide was premixed with minor ingredients (urea, limestone and trace mineral salt) before incorporation into complete mixed diets. Based on ingredient composition, the sudangrass diet contained (DM basis; NRC, 1996): DE, 3.65 Mcal/kg; NE_m, 2.11 Mcal/kg; NE_g, 1.44 Mcal/kg, CP, 121 g/kg; NDF, 196 g/kg; ether extract, 67 g/kg; calcium, 7.2 g/kg; and phosphorus, 2.7 g/kg. Straw diets contained: DE, 3.51 Mcal/kg; NE_m, 1.99 Mcal/kg, NE_g, 1.34 Mcal/kg, CP, 112 g/kg; NDF, 223 g/kg, ether extract, 67 g/kg, calcium, 6.5 g/kg, and phosphorus, 2.2 g/kg. Sudangrass (*Sorghum sudanense*) was from the second cutting, harvested during the early flag stage. The hay was allowed to field-cure for 6 d before baling using rectangular-bale baler equipment (New Holland, model 575). Bales were stored for 8 months before use in this study. Wheat straw (*var.* Rio Colorado C2003) was baled following grain harvest and stored for one month prior to the study. Wheat straw was moistened by spraying with the addition of 10% water (w/v) before introduction into the macerator. The macerator was designed and built jointly by staff of Universidad Autónoma de Baja California and University of California, Davis. Maceration process (MAC) consisted of a single passage of moistened wheat straw throughout two corrugated rolls (20×68 cm) to be set at 0.0 mm clearance with differential speed of opposing roles of 8 rpm (28 *vs.* 20 rpm). The roll pressures used were 41.341 bars (600 psi; MAC600) and 62.0 bars (900 psi; MAC900). All forage treatments were ground in a hammer mill (Bear Cat #1A-S, Westerns Land and Roller Co., Hastings, NE) with a 3.81-cm screen before incorporation into complete mixed diets.

Table 1
Composition of experimental diets[a].

Item		Wheat straw		
	SG	STRW	MAC600	MAC900
Steam-flaked corn	64.00	64.00	64.00	64.00
Sudangrass hay	21.00			
Wheat straw				
Ground		21.00		
Macerated 41.3 bars			21.00	
Macerated 62.0 bars				21.00
Cane molasses	7.00	7.00	7.00	7.00
Tallow	3.60	3.60	3.60	3.60
Urea	1.40	1.40	1.40	1.40
Limestone	1.40	1.40	1.40	1.40
Magnesium oxide	0.80	0.80	0.80	0.80
Trace mineralized salt[b]	0.40	0.40	0.40	0.40
Chromic oxide	0.40	0.40	0.40	0.40
Nutrient composition, DM basis[c]				
DE, %	3.65	3.51	3.51	3.51
NE_m, Mcal/kg	2.11	1.99	1.99	1.99
NE_g, Mcal/kg	1.44	1.34	1.34	1.34
CP, %	12.10	11.20	11.20	11.20
NDF	19.60	22.30	22.30	22.30
EE, %	6.70	6.70	6.70	6.70
Ca, %	0.72	0.65	0.65	0.65
P, %	0.27	0.22	0.22	0.22

[a] SG = sudangrass hay, STRW = ground wheat straw, MAC 600 = macerated wheat straw at intensity of 43.1 bars (600 psi), MAC 900 macerated wheat straw at intensity of 62.0 bars (900 psi).
[b] Trace mineral salt contained: $CoSO_4$, 0.068%; $CuSO_4$, 1.04%; $FeSO_4$, 3.57%; ZnO, 1.24%; $MnSO_4$, 1.07%; KI, 0.052%; and NaCl, 92.96%.
[c] The estimation was based on tabular values for individual feed ingredients (NRC, 1996).

2.2. Animals and sampling

The trial was conducted at the Ruminant Metabolism Experimental Unit of the Instituto de Investigaciones en Ciencias Veterinarias of the Universidad Autónoma de Baja California located 10 km south of Mexicali City in northwestern Mexico (32° 40′ 7″N and 115° 28′ 6″W) is about 10 m above sea level, and has Sonoran desert conditions (BWh classification according to Köppen). All procedures involving live animals were conducted within the guidelines of approved local official techniques of animal care.

Four Holstein steers (142±3 kg) with ruminal (Álvarez and Zinn, 2001) and duodenal cannulas (Zinn and Plascencia, 1993) were housed (indoor facilities) in individual pens (3.9 m^2) with concrete floor covered by neoprene carpet, automatic waterers and individual feed bunk. All steers received *ad libitum* access to the STRW diet (treatment 1) for 10 d before initiation of the trial. Dry matter intake was restricted to 3.13 kg/d (90% of *ad libitum* intake of steers during the 10-d preliminary period). Diets were fed in two equal proportions at 0800 and 2000 h daily. Experimental periods consisted of a 10-d diet adjustment period followed by a 4-d collection period. During the collection period duodenal and fecal samples were taken from all steers, twice daily as follows: d 1, 0750 and 1350 h; d 2, 0900 and 1500 h; d 3, 1050 and 1650 h; and d 4, 1200 and 1800 h. Individual samples consisted of approximately 500 mL duodenal chyme and 200 g (wet basis) fecal material. Samples from each steer and within each collection period were composited for analysis. During the final day of each collection period, total ruminal contents were evacuated. The most of the ruminal contents were first evacuated manually and the rest was evacuated using a vacumm device (Ridgid vacuum, mod 5.0 HP, St. Louis, MO, USA), via the ruminal cannula. Ruminal content from each steer was mixed, weighed and subsampled (approximately 1 kg ruminal contents/sample) in triplicate before being returned to the animal via the ruminal cannula. Ruminal pH was determined on freshly collected contents. Subsamples were oven dried at 65 °C, before

grinding (Wiley mill) to pass through a 1 mm mesh and stored for later analysis. Upon completion of the trial, ruminal fluid was obtained from all steers and composited for isolation of ruminal bacteria via differential centrifugation (Bergen et al., 1968). The microbial isolate served as the purine:N reference for estimation of microbial N contribution to chyme entering the small intestine (Zinn and Owens, 1986).

2.3. Sample analysis and calculations

Samples were subjected to all or part of the following analysis: DM (oven drying at 105 °C until no further weight loss; method 930.15, AOAC, 2000); ash (method 942.05, AOAC, 2000); Kjeldahl N (method 984.13, AOAC, 2000), ammonia N (method 941.04, AOAC, 2000); purines (Zinn and Owens, 1986); gross energy (GE; adiabatic calorimeter bomb, model 1271, Parr, Moline, IL); chromic oxide (Hill and Anderson, 1958), NDF (ash corrected; Chai and Uden, 1998), and starch (Zinn, 1990). 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 (OMF) was considered equal to OM intake minus the difference between the amount of total OM reaching the duodenum and MOM reaching the duodenum. Feed N escape to the small intestine was considered equal to total N leaving the abomasum minus ammonia-N and MN and, thus, includes any endogenous contributions. Ruminal NDF passage (K_p) and digestion (K_d) kinetics were determined based on the assumption that measure of ruminal NDF (from total ruminal chyme evacuation) represents average ruminal NDF fill (NDF_{RUM}), and $NDF_{DIGRUM} = K_d/(K_d + K_p)$, as follow:

$$K_p, \%/h = \left(\left(NFD_I \times \left(1 - NDF_{DIGRUM/100}\right)\right)/24\right)/\left(NDF_{RUM}\right)$$

$$K_d, \%/h = \left(NDF_{DIGRUM/100} \times K_p\right)/\left(1 - NDF_{DIGRUM/100}\right)$$

where: NDF_I = NDF intake, g; NDF_{RUM} = total ruminal NDF content, g; NDF_{DIGRUM} = observed ruminal NDF digestion, %.

2.4. Statistical design and analysis

The trial was analyzed as a 4×4 Latin square design using the MIXED procedure (SAS Inst. Inc., Cary, NC). Fixed effect consisted of treatment, and random effects consisted of steer and period. The statistical model for the trial was as follows:

$$Y_{ijk} = \mu + S_i + P_j + T_k + E_{ijk},$$

where: Y_{ijk} is the response variable, μ is the common experimental effect, S_i is the steer effect, P_j is the period effect, T_k is the treatment effect and E_{ijk} is the residual error. Treatment effects were tested for the following non-orthogonal comparisons: 1) SG *vs.* STRW; 2) SG *vs.* average observed in both maceration process (MAC), and 3) STRW *vs.* MAC, and 4) MAC600 *vs.* MAC900. Forage composition data (DM, N, NDF and ash) was submitted to analysis of variance and F test, to investigate differences among treatments. Variables with significant variances were submitted to Tukey test ($P<0.05$) for mean comparisons. Contrasts were considered significant when the P-value was ≤0.05, and as a tendency approaching significance with a P-value of ≤0.10.

3. Results and discussion

3.1. Physical and chemical characteristics of test forages

Composition of forages used is shown in Table 2. Consistent with previous reports (NRC, 1996; Torrentera et al., 2000), wheat straw contained less CP (69.6%, N×6.25; $P<0.01$) and more NDF (12.6%; $P<0.01$) than sudangrass hay (SG). Ash and NDF content of macerated and ground wheat straw were similar, although the N content of macerated wheat straw was slightly (14%, $P>0.05$) lower. Changes in composition of N and fibrous fractions have been observed following maceration of freshly cut legumes; presumably the result of leaf loss (Agbossamey et al., 2000) and loss of soluble cellular material during processing and handling (Lu et al., 1980). Petit et al. (1994) detected a 17% increase of N content after maceration of Timothy hay. This was attributed to sampling procedures rather than the process of maceration.

3.2. Characteristics of ruminal and total tract digestion

Treatment effects on characteristics of digestion are shown in Table 3. Although DM intake was restricted to the same level across treatments, differences in chemical composition among test forages resulted in greater NDF (8%, $P\leq0.02$) and lesser N intake (9%, $P\leq0.02$) for STRW *vs* SG treatments.

There were no treatment effects ($P\geq0.11$) on the extent of ruminal digestion of OM, NDF, starch, microbial efficiency (g of microbial N/kg of fermented OM) or ruminal protein efficiency (duodenal nonammonia N/N intake) averaging 61.6, 35.1, 78.7, 23.0, and 1.01, respectively. Likewise, Torrentera et al. (2000) did not detect differences in ruminal digestion OM and NDF when comparing ground *vs.* macerated rice straw at a level of 20% inclusion. In contrast, Plascencia et al. (2007) reported a 28% increase in ruminal NDF digestion of (28%) due to maceration of rice straw (rice straw comprised 14% in the diet DM). Whereas, Lopez-Soto et al. (2006) observed decreased (14%) ruminal NDF digestion for macerated *vs.* ground rice straw (rice straw comprised 40% of diet DM).

Ruminal digestion of feed N was lower for SG (19%, $P=0.01$) than for STRW and MAC treatments. Torrentera et al. (2000)

Table 2
Physicochemical characteristics of the forage sources tested[a].

Item		Wheat straw[b]		
	Sudangrass hay	STRW	MAC600	MAC900
DM (%)	94.80 ± 0.10	95.04 ± 0.14	95.08 ± 0.21	94.95 ± 0.20
N (%)	1.25 ± 0.03[c]	0.38 ± 0.02[d]	0.36 ± 0.03[d]	0.39 ± 0.02[d]
NDF (%)	60.32 ± 0.82[c]	67.90 ± 0.98[d]	68.65 ± 1.96[d]	68.26 ± 2.24[d]
Ash (%)	10.37 ± 0.47	11.05 ± 0.34	10.79 ± 0.47	10.68 ± 0.40

[a]Eight replicates/forage.
[b]STRW = ground wheat straw, MAC 600 = macerated wheat straw at intensity of 41.3 bars, MAC 900 macerated wheat straw at intensity of 62.0 bars.
[c]Rows with different letters differ ($P<0.05$).

observed lower (12%) ruminal N digestion in growing–finishing diets containing 20% forage as sudangrass hay *versus* rice straw, but not with macerated rice straw. In a comparison of ground sudangrass hay *vs.* ground or macerated rice straw in growing-finishing diets containing 14% forage, Plascencia et al. (2007) did not detect differences (P = 0.08) in ruminal N digestion.

Postruminal OM starch and N digestion were similar (P ≥ 0.18) for STRW and SG treatments. Likewise, postruminal and total tract digestion of starch and N digestion were similar (P ≥ 0.49) for SG and MAC treatments. However, postruminal OM digestion tended to be greater (6.2%, P = 0.08) for MAC than for SG diets. Likewise, postruminal (66%; P = 0.09) and total tract (5.3%; P = 0.07) NDF digestion tended to be greater for MAC than for SG diets. As will be discussed later, increased postruminal and total tract NDF digestion due to straw maceration may be attributable to decreased ruminal NDF retention time, resulting in greater presentation of digestible NDF to the cecum and large intestine. Plascencia et al. (2007) also observed greater total tract NDF digestion (48.4 *vs.* 44.4%) with growing–finishing diets containing 14% forage as macerated rice straw *vs.* sudangrass hay. In contrast, Torrentera et al. (2000) observed greater NDF digestion (41.5 *vs.* 32.7%) with diets containing 20% forage as sudangrass hay *vs.* macerated rice straw.

Consistent with previous studies (Moore et al., 1990; Plascencia et al., 2007; Torrentera et al., 2000), total tract digestion of OM digestion (2.7%), NDF (23.9%) and DE (3.4%) were greater (P < 0.01) for SG than for STRW. Postruminal and total tract digestion (P ≤ 0.04) of OM (8.6 and 3.8%), NDF (76 and 27.9%) and N (5.1 and 5.2%), and dietary DE (4.5%, P < 0.01) were greater for MAC than for STRW diets. Likewise, maceration increased total tract digestion of OM and NDF of

Table 3
Treatment [a] effects on characteristics of feed intake and digestion in cannulated Holstein steers (142 kg BW).

Item		Wheat straw			SEM		P value		
	SG	STRW	MAC600	MAC900		SG *vs.* STRW	SG *vs.* MAC	STRW *vs.* MAC	MAC600 *vs.* MAC900
Intake, g/d									
DM	3134	3136	3136	3134	65.3				
OM	2935	2922	2922	2919	66.4				
Starch	1183	1183	1183	1183	25.1				
NDF	620	671	677	673	13.0				
N	57.7	53.3	53.0	52.7	1.14				
GE, Mcal/d	12.82	12.75	12.83	12.78	0.31				
Flow to duodenum, g/d									
OM	1398	1489	1426	1520	59.2	0.30	0.32	0.83	0.28
Starch	252	238	266	312	15.4	0.53	0.07	0.02	0.06
NDF	387	454	440	438	16.3	0.01	0.03	0.40	0.80
Non ammonia N	57	53	52	55	1.90	0.13	0.14	0.78	0.28
Microbial N	31.0	35.5	32.4	35.6	1.74	0.08	0.17	0.48	0.21
Feed N	26.3	17.4	19.7	19.5	1.32	<0.01	<0.01	0.20	0.91
Ruminal digestion, % of intake									
OM	62.9	61.2	62.3	59.9	1.42	0.39	0.32	0.98	0.26
Starch	78.6	79.9	77.6	78.6	1.31	0.51	0.73	0.28	0.59
NDF	37.7	32.3	35.0	35.4	2.24	0.11	0.37	0.30	0.90
Feed N	54.4	67.1	63.1	63.0	2.51	<0.01	0.01	0.20	0.99
Microbial efficiency[b]	22.2	23.9	22.7	23.4	0.70	0.11	0.32	0.37	0.49
Protein efficiency[c]	0.99	1.00	0.98	1.05	0.033	0.95	0.61	0.66	0.17
Fecal excretion, g/d									
OM	579	644	552	561	17.0	0.02	0.28	<0.01	0.71
Starch	21	28	25	26	6.1	0.42	0.59	0.69	0.85
NDF	328	430	339	337	11,4	<0.01	0.42	<0.01	0.88
N	15	16	13	14	0.49	0.52	0.02	<0.01	0.51
GE, Mcal	2.60	2.86	2.46	2.48	0.061	0.02	0.09	<0.01	0.83
Postruminal digestion, % leaving abomasum									
OM	58.4	56.7	61.2	62.9	1.51	0.42	0.08	0.02	0.45
Starch	91.4	88.3	90.8	91.8	1.92	0.28	0.95	0.24	0.74
NDF	14.8	5.2	22.7	22.0	3.41	0.07	0.09	<0.01	0.89
N	73.7	71.0	74.5	75.2	1.34	0.18	0.49	0.04	0.75
Total tract digestion, %									
OM	80.2	77.9	81.1	80.8	0.41	<0.01	0.21	<0.01	0.53
Starch	98.2	97.6	97.9	97.4	0.54	0.40	0.57	0.68	0.81
NDF	47.2	35.9	49.9	49.8	1.13	<0.01	0.07	<0.01	0.99
N	73.5	70.4	74.8	73.7	1.03	0.06	0.58	0.01	0.48
DE, %	79.7	77.5	80.9	80.6	0.22	<0.01	0.04	<0.01	0.65
DE diet, Mcal/kg	3.26	3.15	3.31	3.29	0.023	<0.01	0.08	<0.01	0.38
DE of straw, Mcal/kg[d]		1.91	2.68	2.61	0.012				

[a] SG = sudangrass hay, STRW = ground wheat straw, MAC 600 = macerated wheat straw at intensity of 41.3 bars (600 psi), MAC 900 macerated wheat straw at intensity of 62.0 bars (900 psi).
[b] Duodenal microbial N, g kg^{-1} OM fermented in the rumen.
[c] Duodenal non-ammonia N, g·g^{-1} N intake.
[d] Calculated assuming a DE value of 2.46 Mcal/kg for sudangrass hay (NRC, 1996).

Table 4
Treatment[a] effects on ruminal characteristics and ruminal kinetics of NDF in cannulated Holstein steers (142 kg BW).

Item		Wheat straw			SEM	P value			
	SG	STRW	MAC600	MAC900		SG *vs.* STRW	SG *vs.* MAC	STRW *vs.* MAC	MAC600 *vs.* MAC900
Ruminal pH[b]	6.24	6.15	6.20	6.22	0.163	0.44	0.57	0.55	0.88
Ruminal characteristics									
Total content (kg)	20.8	19.0	21.6	23.5	2.51	0.84	0.79	0.45	0.81
DM content (%)	9.24	15.55	9.37	8.94	1.272	<0.01	0.83	<0.01	0.62
Total DM (g)	1919	2960	2006	2013	157.4	<0.01	0.84	0.02	0.99
NDF (g)	763	1416	1045	968	72.2	<0.01	0.02	<0.01	0.80
NDF kinetics (%/h)									
k_p	2.12	1.34	1.80	1.82	0.10	<0.01	0.03	<0.01	0.92
k_d	1.30	0.64	0.99	1.11	0.146	<0.01	0.18	0.04	0.57

[a] SG = sudangrass hay, STRW = ground wheat straw, MAC 600 = macerated wheat straw at intensity of 41.3 bars (600 psi), MAC 900 macerated wheat straw at intensity of 62.0 bars (900 psi).
[b] Measured at 4-h posprandium (morning meal).

alfalfa hay (Broderick et al., 1999; Petit et al., 1994), and rice straw (Lopez-Soto et al., 2006; Plascencia et al., 2007; Torrentera et al., 2000; Ware et al., 2005). Roll pressure (MAC600 *vs.* MAC900) did not affect ($P \geq 0.11$) site and extent of digestion.

3.3. Ruminal pH and ruminal NDF kinetics

Treatment effects on ruminal pH and NDF digestion kinetics are shown in Table 4. There were no treatment effects ($P = 0.44$) on ruminal pH, averaging 6.20. Consistent with Bowman et al. (1991), ruminal NDF K_d and K_p were greater (51 and 37%, respectively; $P < 0.01$), and ruminal DM and NDF fill were lesser (40 and 46%, respectively; $P < 0.01$) for SG *vs.* STRW diets. Likewise, ruminal NDF K_p and NDF K_d was greater (26%, $P = 0.01$ and 39%, $P = 0.04$, respectively), and ruminal DM and NDF fill were lesser (32 and 29%, respectively; $P < 0.01$) for MAC *vs.* STRW diets. Increased K_d and K_p and reduced ruminal fill due to maceration of rice straw has been previously reported (Lopez-Soto et al., 2006).

Although not quantified, evacuated ruminal contents from steers consuming MAC had a relatively homogeneous aspect, whereas in the case of STRW, evacuated ruminal contents appeared more segregated and stratified. When the particulate passage rate (rare earths) and liquid turnover rates (Co-EDTA) were measured in medium-forage diets, level of stratification of the ruminal contents in diets has an inverse relationship with rate of passage (Moore et al., 1990)

Changes in the structure of fiber particles brought about by mechanical maceration increase the rate of particle hydration, that in turn enhances particle specific gravity and rate of particle size reduction through chewing (Hong et al., 1988); factors that contribute to enhanced rates of digestion and passage (Offer and Dixon, 2000). Roll pressure (MAC600 and MAC900) did not affect ($P \geq 0.80$) digestion kinetics or ruminal fill.

Treatment effects on DM intake were not addressed in this study. However, from the practical standpoint of cattle growth–performance, when dietary energy density is limiting energy intake due to ruminal fill, observed improvements in digestion kinetics due to maceration of straw is expected to enhance DM intake and growth performance (Zinn and Salinas, 1999).

3.4. Energy value of processed straw

Given that the DE value of SG is 2.46 Mcal/kg (NRC, 1996), the DE content in test forages can be estimated using the replacement technique (Plascencia and Zinn, 2002): DE, Mcal/kg of straw = [(DE of straw diet − DE of SG diet)/0.21] + 2.46, where 0.21 represents the amount of straw that replaced sudangrass hay in the diet. Accordingly, DE values of control and macerated wheat straw is 1.91 and 2.65 Mcal/kg, respectively. Thus, the DE value of macerated wheat straw in this study was 7.7% greater than that of sudangrass hay and 39% greater than that of the control, non-macerated straw. These findings with wheat straw are in good agreement with previous studies comparing sudangrass hay *vs.* rice straw and macerated rice straw (Lopez-Soto et al., 2006; Plascencia et al., 2007; Torrentera et al., 2000; Ware et al., 2005), wherein the average increase in DE for macerated rice straw was 3.3 and 39% compared to sudangrass hay and ground rice straw, respectively.

4. Conclusions

Maceration enhances the DE value of wheat to the extent that its value may exceed that of medium-quality sudangrass hay. This improvement is attributable to enhancement in rate of ruminal digestion and passage of NDF fractions, resulting in greater total tract OM and NDF digestion. Increasing the roll pressure during maceration beyond 600 psi may not further enhance the feeding value of macerated straws.

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