Digestion and energy value of macerated sudangrass hay used in growing-finishing diets for feedlot cattle

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ABSTRACT: Mechanical maceration enhances site and extent of digestion of low-moisture, low-quality forages. Four Holstein steers (172 ± 8 kg) with cannulas in rumen and proximal duodenum were used in 4x4 Latin square design to evaluate the process of mechanical maceration of sudangrass hay on the characteristics of ruminal and total tract digestion. Treatments consisted of a steam-flaked corn-based growing diet supplemented with 21 % forage (DM basis) as: i) wheat straw (*Triticum aestivum*, STRW), ii) sudangrass hay (*Sorghum sudanense*, SG), iii) macerated SG at intensity of 4,134 kPa (MAC600) and 4) macerated SG at intensity of 6,200 kPa (MAC900). All forages were ground to pass through a 3.8 cm screen before incorporation into complete mixed diets (21:79 forage to concentrate ratio). Maceration did not affect ($p \geq 0.17$) on site and extent of OM, N and ADF, and DE of sudangrass supplemented diets. Characteristics of ruminal digestion of OM, ADF, starch, as well as, microbial efficiency (microbial N, g kg^{-1} of OM fermentad) and protein efficiency (nonammonia N, g g^{-1} of N intake) were not different ($p \geq 0.11$) for wheat straw versus sudangrass supplemented diets. However, total tract digestion of OM, ADF, N, and DE diet were greater ($p \leq 0.05$) for sudangrass than for wheat straw supplemented diets. Using the replacement technique, DE value of SG averaged 9.59 MJ kg^{-1}, very close to the expected value given its chemical composition. Mechanical maceration did not enhance the feeding value of sudangrass hay. Increase the intensity of maceration from 4,134 to 6,200 kPa did not altered ruminal or total tract digestion of OM, NDF or energy value of processed hay.
Key words: *Sorghum sudanense,* feed value, maceration, steers, forages

Introduction

Mechanical maceration was initially developed to enhance drying rate and reduce selective leaf loss of freshly cut alfalfa (*Medicago sativa*; Hong et al., 1988; Shinners et al., 1988; Broderick et al., 1999). However, maceration applications have also been developed to enhance site and extent of digestion of low-moisture, low-quality forages such rice (*Oryza sativa*) straw (Plascencia et al., 2007), and the improvements in digestion and in digestible energy due to maceration may be more pronounced when the level of inclusion of macerated straws in growing-finishing diets is moderated (Ware et al., 2005). The latter process consists of 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 forage remains otherwise, intact. Indentation during maceration greatly alters the fiber structural integrity and density, promoting microbial attachment, digestion and fast passage rate of fiber in high-quality high-moisture forage (Hintz et al., 1999). Very little information is presently available regarding the efficacy of mechanical maceration on digestion of grasses. In a preliminary study with lambs (Petit et al., 1994), maceration increased *in situ* ruminal DM, fiber digestion and total tract digestible energy of freshly cut timothy grass (*Phleum pretense*). However, in a subsequent study (Petit et al., 1997) *in situ* digestion was not affected by maceration of timothy grass. In contrast, Chiquette et al. (1994) reported decreased digestibility of OM, and NDF for macerated *vs.* conventional timothy hay when fed as the as the sole ingredient to mature beef steers. Maceration intensity may be a reason for these inconsistencies. In these sense, Agbossamey et al. (2000) reported that total tract digestion of DM and fiber decreased linearly ($p < 0.01$) with the level of intensity of maceration of freshly cut alfalfa. In northwestern Mexico, typical growing-finishing diet containing from 15 to 25 % of forage and sudangrass hay is a primary source of forage used.

This experiment aimed at evaluating the effects of mechanical maceration of sudangrass hay on comparative site and extent of nutrient digestion in cannulated Holstein steers fed a growing-finishing diet containing 21 % of forage.

Materials and Methods

The trial was conducted in northwestern Mexico (32°40'7" N; 115°28'6" W, about 10 m a.s.l, and under Sonoran desert conditions (BWh classification according Köppen). All procedures involving live animals were conducted within the guidelines of approved local official techniques of animal care.

Four Holstein steers (172 ± 8 kg) with ruminal (80 mm diameter) and duodenal cannulas (Zinn and Plascencia, 1993)

were used in a 4 × 4 Latin square experiment design to evaluate the influence of maceration of sudangrass hay on the characteristics of ruminal and total tract digestion. Experimental diets were total mixed ration (TMR) and contained (DM basis) 64.0 % steam-flaked corn, 7.0 % cane molasses, 3.7 % fat, 1.4 % urea, 1.4 % limestone, 0.4 % trace mineralized salt, 0.3 % chromic oxide (Cr_2O_3), and 21 % forage as: i) wheat straw (STRW), ii) sudangrass hay (SG), iii) macerated SG, tension of the rollers was adjusted to provide pressure of 4,134 kPa (MAC600), and iv) macerated SG, tension of the rollers was adjusted to provide pressure of 6,200 kPa (MAC900). All forages were ground to pass through a 3.8-cm screen before incorporation into complete mixed diets. Cr_2O_3 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 to reach a final concentration of 0.3 %. The Cr_2O_3 concentration measured, according to the technique described by Hill and Anderson (1958), was 0.00289 ± 6.75E-06 g kg^{-1} of diet DM in close agreement with the targeted 0.0030 g kg^{-1} diet, and therefore, daily intake of Cr_2O_3 averaged 11.04 ± 0.47 g during experiment. All animals began to consume Cr_2O_3 10 days before starting the experiment.

Sudangrass (*Sorghum sudanense*) was harvested, from the second growth, field cured for 6 days, and baled using rectangular-bale baler equipment (New Holland, model 575). The bales were stored for 8 months before use in this study. Wheat straw (*var*. Rio Colorado C2003) was baled (New Holland, model 575) following grain harvest and stored for one month before its use in this study. In order to facilitate the tearing of the fiber, sudangrass hay was moistened by spraying with the addition of 10 % water (w/v) before introduction into the macerator. The maceration processing (MAC) consisted of a single passage of moistened sudangrass hay throughout two corrugated rolls (0.20 × 0.68 m) set at 0.0 mm clearance with differential speed of 8 rpm (7×10^{-3} g). Speed rolls were adjust to reach 20 rpm (45×10^{-3} g) and 28 rpm (88×10^{-3} g). The roll pressures used were 4,134 kPa (MAC600) and 6,200 kPa (MAC900). All forage treatments were ground in a hammer mill (Bear Cat #1A-S, Westerns Land and Roller Co., Hastings, NE) with a 38-mm screen before incorporation into complete mixed diets.

Steers were housed (indoors facilities) in individual pens (3.9 m^2) with concrete floor covered by neoprene carpet, automatic waterers and individual feed bunk. All steers received straw treatment (Treatment 1) for ten days before initiation of the trial. Dry matter intake was restricted to 3.83 kg per day (90 % of *ad libitum* intake by steers at start of the experiment). Diets were fed in two equal proportions at 8h00 and 20h00 daily. Experimental periods consisted of a 10 day diet adjustment period followed by a 4 day collection period. During the collection period duodenal and fecal samples were taken from all steers, twice daily as follows: day 1, 7h50 and 13h50; day 2, 9h00 and 15h00; day 3, 10h50 and 16h50; and day 4, 12h00 and 18h00. Individual samples consisted of approximately 500 mL duodenal chyme and 200 g (wet basis) of fecal material. Samples from each steer and within each collection period were composited for analysis.

During the final day of each collection period, a ruminal sample was obtained from each steer 4 h after feeding via the ruminal cannula. Ruminal fluid was taken from ruminal ventral sac by vacuum pump (Cole Parmer Instrument, Vernon Hill, IL) using a tygon tube (¾"; USP Lima, Ohio), and pH was determined (Orion 261S, Fisher Scientific, Pittsburgh, PA.) on fresh samples. 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). 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, 1986); 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), ADF (Goering and Van Soest, 1970), 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. The comparative digestible energy (DE, MJ kg^{-1}) values for tested forages were estimated using the replacement technique (Plascencia and Zinn, 2002). It was assumed that the DE values of STRW are equal to the DE value of SG it replaced plus the change in the content in the complete diet brought about by the replacement. Given that the DE value of STRW is 7.54 MJ kg^{-1} (NRC, 1996), the DE values of sudangrass treatments were estimated as follow: DE, MJ kg^{-1} of sudangrass = [(DE of test sudangrass diet - DE of straw diet)/0.21] + 7.54. The constant 0.21 represents the amount of forage in the diet.

The trial was analyzed as a 4 × 4 Latin square design using the MIXED procedure (SAS Institute, 2009). Fixed effect consisted of treatment, and random effects consisted of steer and period. Treatment effects were tested for the following orthogonal components: i) STRW *vs.* SG; ii) SG *vs.* MAC, and ii) MAC600 *vs.* MAC900. Forage composition data was submitted to analysis of variance and F test, to investigate differences among forage fractions (N, ADF and ash). Variables with variances were submitted to Tukey test ($p < 0.05$) for mean comparisons. Contrasts were considered at *P*-value ≤ 0.05, with a *P*-value of ≤ 0.10 considered as a tendency approaching significance.

Results and Discussion

As expected (NRC, 1996; López-Soto et al., 2006), sudangrass contained ($p < 0.01$) 64.6 % more N and 18.9 % less ADF than straw (Table 1). The Maceration of sudangrass tended ($p = 0.09$) to increased fiber content (4.1 %) and increased ($p < 0.01$) ash value. N content of sudangrass hay was not affected by maceration. Changes in composition of N and fibrous frac-

tions have been observed following maceration of freshly cut legumes. This effect was presumably the result of leaf loss (Agbossamey et al., 2000), and loss of soluble cellular material during processing and handling of freshly cut forage (Lu et al., 1980). However, the tendency to increase on fiber and ash content in macerated hay is more apparent than real, and in agreement with Petit et al. (1994), these differences can be attributed to sampling procedures rather than the process of maceration. As a result of different chemical composition from SG treatments and STRW (Table 1), the average ADF intake was lower (12.8 %, $p < 0.01$) and N intake was higher (8.3 %, $p < 0.01$) for SG treatments (Table 2).

Ruminal digestion of OM and starch were similar ($p \geq 0.11$) between SG and STRW. Measures of ruminal ADF digestion, ruminal microbial efficiency and ruminal N efficiency were not different ($p \geq 0.27$) for SG *vs.* STRW. Ruminal digestion of feed N was lower (15.4 %, $p = 0.03$) for SG than for STRW. In a comparison of ground sudangrass hay *vs.* ground wheat straw in growing-finishing diets containing 14 % forage, Plascencia et al. (2007) did not detect differences ($p = 0.08$) in ruminal fiber and N digestion. Consistent with previous studies (Moore, 1990; Plascencia et al., 2007), total tract digestion of OM (2.7 %, $p < 0.01$), ADF (20.1 %, $p < 0.01$) and N (5.2 %, $p < 0.01$) were greater for SG than for STRW. Ruminal digestion of

Table 1 – Physiochemical characteristic of forages tested[A].

Item	STRW[C]	Sudangras hay[B]		
		SG	MAC600	MAC900
DM (%)	95.01 ± 0.10	94.74 ± 0.14	94.65 ± 0.21	94.95 ± 0.20
N (%)	0.40 ± 0.03[D]	1.13 ± 0.02[E]	1.12 ± 0.03[E]	1.13 ± 0.02[E]
ADF (%)	52.09 ± 0.82[D]	42.25 ± 0.98[E]	43.35 ± 1.96[E]	44.76 ± 2.24[E]
Ash (%)	11.05 ± 0.47[D]	9.63 ± 0.34[E]	10.79 ± 0.47[D]	10.68 ± 0.40[D]

[A]Eight replicates/forage. [B]SG = sudangrass hay, MAC 600 = macerated sudangrass intensity 4,134 kPa, MAC 900= macerated sudangrass intensity 6,200 kPa .[C]STRW = wheat straw. [D,E] Rows with different letters differ ($p < 0.05$).

Table 2 – Influence of maceration of sudangras hay on site and extent of digestion in cannulated Holstein steers (173 ± 7.8 kg) fed a growing-finishing diet contained 21 % of forage (Dry matter basis).

Item	STRW[B]	Sudangrass hay[A]				P value		
		SG	MAC600	MAC900	SEM	STRW vs. SG	SG *vs.* MAC	MAC600 *vs.* MAC900
Intake (g per day)								
DM [C]	3,835	3,832	3,835	3,832	13.7	0.62	0.77	0.62
OM [D]	3,569	3,578	3,571	3,569	12.8	0.57	0.83	0.88
Starch	1,447	1,447	1,447	1,446	1.1	0.99	0.99	0.92
ADF [E]	543	463	473	484	4.1	< 0.01	0.48	0.44
N	66	72	72	72	0.3	< 0.01	0.99	0.99
GE, MJ per day [F]	65.23	65.65	65.61	65.40	0.77	0.13	0.95	0.27
Ruminal digestion (% intake)								
OM	56.18	58.71	57.74	57.83	1.341	0.11	0.46	0.95
Starch	79.68	77.59	77.66	78.96	1.961	0.39	0.72	0.59
ADF	25.54	29.99	26.70	28.66	2.893	0.32	0.54	0.65
Feed N	74.55	63.06	66.27	65.15	3.563	0.03	0.50	0.80
Microbial efficiency [G]	23.3	24.3	24.6	24.8	0.69	0.31	0.72	0.83
N efficency [H]	0.97	1.03	1.02	1.03	0.27	0.11	0.91	0.89
Total tract digestion (%)								
OM	78.87	81.10	80.10	80.22	1.011	< 0.01	0.17	0.87
Starch	97.51	98.26	97.82	97.70	1.51	0.18	0.26	0.75
ADF	32.91	41.22	38.15	42.18	2.94	0.04	0.73	0.28
N	73.08	77.08	77.80	76.76	1.353	< 0.01	0.23	0.63
DE diet,%	78.04	80.57	79.89	79.96	0.945	0.02	0.38	0.93
DE diet, MJ kg^{-1}	13.27	13.77	13.69	13.65	0.038	< 0.01	0.26	0.85

[A]SG = sudangrass hay, MAC 600 = macerated sudangrass intensity 4,134 kPa, MAC 900 = macerated sudangrass intensity 6,200 kPa. [B] STRW = wheat straw. [C] Dry matter. [D] Organic matter. [E] Acid detergent fiber. [F] Gross energy. [G] Microbial N, g kg^{-1} OM fermented. [H] Nonammonia N entering the small intestine, g g^{-1} N intake. [I] Digestible energy

OM, ADF and starch were not different ($p \geq 0.46$) for SG and MAC. To our knowledge, no comparable information about the impact of maceration on in vivo ruminal digestion of macerated grass hay is available in the literature. In a preliminary study (Petit et al., 1994), maceration increased *in situ* ruminal DM and fiber digestion of freshly cut timothy grass. However, in a subsequent study (Petit et al., 1997) *in situ* digestion was not affected by maceration of timothy grass.

Total tract digestibility of OM, ADF, N and starch were not different ($p \geq 0.17$) for SG *vs.* MAC. Likewise, Petit et al. (1997) reported no effect of maceration on total tract OM and fiber digestion of timothy hay. In contrast, Hong et al. (1988) and Petit et al. (1994) reported greater total tract OM digestion for macerated *vs.* conventional timothy grass hay. Chiquette et al. (1994) reported decreased digestibility of OM, and NDF for macerated *vs.* conventional timothy hay when fed as the as the sole ingredient to mature beef steers. The variation in results of macerated timothy hay on ruminal digestion of OM and NDF is not clear. In these studies, the maceration process was carried out with freshly cut forage and at different stages of maturity (early head stage, 10 % of head stage or flowering stage), and therefore with different moisture content at time of processing. Furthermore, different drying processes were utilized after that forage was macerated (forced-air-dried or field dried). These conditions could be the main reason for variation in results observed between these studies. Another possibility is the level of forage inclusion. In studies conducted with macerated straw: inclusion at a level of 14 % improved digestion (Plascencia et al., 2007); inclusion at 40 %, reduced it (Lopez-Soto et al., 2006); while in this study, inclusion at 15 % of macerated straw did not show differences (Ware et al., 2005).

Intensity of the maceration process (MAC600 *vs.* MAC900) did not affect ($p \geq 0.28$) measures of site and extent of digestion. Agbossamey et al. (2000) reported that total tract digestion of DM and fiber decreased linearly ($p < 0.01$) with the level of intensity (one, two or three passages through three knurled steel rolls) of maceration of freshly cut alfalfa under poor drying conditions (precipitation in first 48 h). Increases in alfalfa content of NDF and ADF with more intensive mechanical conditioning may be explained partly by leaf shatter, partly by enhanced leaching under rainy conditions (Savoie et al. 1993) and partly by increased respiration during prolonged wilting (Kraus et al. 1998). These losses tend to be greater in the leaf and non-fibrous fractions (cell content), thereby resulting in higher final fiber content, and a lower digestion of DM. Contrary to the present study, the study conducted by Agbosammey et al. (2000) did not specified the pressure exerted between rollers and the "intensity" was means by the number of times that the freshly cut alfalfa was passed through the rollers.

Maceration did not affect ($p = 0.38$) DE value of sudangrass hay supplemented diets. Accordingly to the replacement technique, the DE values of sudangrass treatments averaged 9.59 MJ kg^{-1} (9.92, 9.55 and 9.34 MJ kg^{-1}, for SG, MAC600 and MAC9000, respectively). This value is 0.93 the tabular DE value (NRC, 1996), and 0.99 of expected DE value based on its ADF content of [DE, MJ kg^{-1} = (((59.2 + 1.32*ADF%) – (0.0338ADF^2)) * 0.04409) * 4.1868; Rohweder et al., 1978]. Petit et al. (1997) reported no effect of maceration of timothy hay on diet DE. In contrast, higher values of digestibility energy content of forage were reported by Hong et al. (1988) and Petit et al. (1994) for sheep fed macerated hay compared with conventional hay.

Conclusions

At the level of forage inclusion (21 %), the energy value of medium-quality hay (such sudangrass hay) did not enhanced by mechanical maceration. Increase the intensity of maceration from 4,134 to 6,200 kPa did not altered ruminal or total tract digestion of OM, NDF or energy value of processed hay.

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