J. Trop. Agric. and Fd. Sc. 29(1)(2001): 103–111

Effects of level and physical form of cottonseed hulls on microbial protein synthesis in the rumen of steers fed high concentrate diets

(Kesan tahap dan bentuk fizikal kulit biji kapas terhadap sintesis protein mikrob di dalam rumen lembu yang diberi makanan konsentrat)

A. Yusof Hamali*, R. Pucala** and F. N. Owens***

Key words: effective neutral detergent fiber, peptide-N, microbial synthesis, ruminal digestion, protozoa, cottonseed hull

Abstrak

Enam ekor lembu jantan kembiri yang dipasang kanula pada rumen dan duodenum telah digunakan dalam kajian menggunakan replikat 3 x 3 reka bentuk latin segi empat. Pencernaan di dalam rumen dan kecekapan sintesis protein mikrob telah diukur. Tiga jenis diet berasaskan jagung yang digunakan mengandungi kulit biji kapas (CSH) dan "*effective neutral detergent fiber*" (eNDF) seperti berikut: a) 18% CSH dan 10.4% eNDF, b) 18% CSH (dikisar) dan 6.1% eNDF dan c) 25% CSH dan 14.1% eNDF. Purata nilai pH rumen meningkat dengan penambahan kandungan eNDF di dalam diet. Kandungan NH_3-N, peptide-N, dan asid amino-N di dalam rumen adalah sama antara perlakuan, dengan nilai purata 96.4, 1.56 dan 2.56 mg/L. Kecekapan sintesis protein mikrob di dalam rumen tidak dipengaruhi oleh aras eNDF di dalam diet. Purata protein mikrob bagi semua perlakuan adalah sebanyak 13.87 g N mikrob sekilogram bahan organik. Peningkatan eNDF di dalam diet turut meningkatkan kadar percernaan sebenar bahan organik dan kanji di dalam rumen. Pengisaran CSH telah merendahkan kadar pencernaan kanji di dalam rumen. Pengurangan eNDF di dalam diet telah menurunkan pH rumen kurang daripada nilai yang dijangkakan tanpa memberi kesan terhadap kecekapan pertumbuhan mikrob sebagaimana yang disyorkan oleh pihak NRC (1996).

Abstract

Six steers fitted with ruminal and duodenal cannulas were used in a replicated 3 x 3 Latin square. Ruminal digestion and efficiency of microbial protein synthesis were measured. Three corn based diets were formulated to contain the following percentages of cottonseed hulls (CSH) and effective neutral detergent fiber (eNDF): a) 18% CSH and 10.4% (eNDF), b) 18% CSH (ground) and 6.1% (eNDF) and c) 25% CSH and 14.1% (eNDF). Mean ruminal pH values increased as eNDF content of the diet was increased. Ruminal NH_3-N, peptide-N, and amino acid-N were similar among treatments averaging 96.4, 1.56, and 2.56 mg/L. The efficiency of microbial protein synthesis in the rumen was unaffected by the concentration of eNDF, and averaged 13.67 g of microbial N/kg of organic matter (OM) digested for all treatments. Increasing eNDF increased true ruminal

*Livestock Research Division, MARDI Headquarters, P.O. Box 12301, 50774 Kuala Lumpur, Malaysia
**E (kika) de la Garza Institute for Goat Research, Langston University, Langston, P.O. Box 730, Langston, OK 73050 USA
***Optimum Quality Grains, L. L. C., 10700 Justin Drive, Des Moines, IA 50322 USA
Authors' full names: Yusof Hamali Ahmad, Richard Pucala and Frederick N. Owens

OM and starch digestion in the rumen. Grinding CSH reduced ruminal starch digestion. Reducing the eNDF content of the diet depressed rumen pH less than expected and did not reduce efficiency of microbial growth to the degree proposed by NRC (1996).

Introduction

The current beef NRC (1996) employs a model that uses effective neutral detergent fiber (eNDF) concentrations of dietary ingredients to predict ruminal pH which is used to estimate fiber digestion and efficiency of microbial protein synthesis. Prediction equation predicts that microbial growth, and fiber digestion rate both decline linearly with pH as pH falls below 6.2. This equation is currently a component of the Cornell Net Carbohydrate and Protein model (NRC 1996). Effective NDF is defined as the proportion of NDF that remains on a 1.18 mm screen after dry sieving and presumably represents that fraction of the diet that will stimulate rumination.

Fine grinding and pelleting will reduce the eNDF level in forage diet and thereby would be expected to decrease the quantity of microbial N as well as the proportion of microbial N that reaches the duodenum. In most cases, net microbial production is unaffected or slightly decreased when ground and pelleted forages are fed although it has been increased in some studies (Rode et al. 1985) due to grinding.

The rumen sub-model for predicting the effect of eNDF on microbial growth efficiency in the beef NRC (1996) is based on continuous culture data. Extrapolating from chemostatic condition to the rumen condition can be erroneous because apart from eNDF, other factors (e.g., grain form, grain intake, starch digestion rate) can influence ruminal pH. The objective of this experiment was to determine the effect of form and dietary level of cottonseed hulls on ruminal digestion and efficiency of microbial protein synthesis in the rumen of steers fed high corn diets.

Materials and methods

Animals and treatments

Six crossbred steers averaging 363 kg in body weight were used in the experiment. Each was equipped with rumen fistula and duodenal re-entrant cannula in the duodenum proximal to the bile duct. The steers were randomly allotted to individual pen (3 x 5 m) and had continuous free access to water. The steers were assigned to three dietary treatments in two identical 3 x 3 Latin squares experiment. Dietary treatments consist of: a) 10.4% eNDF-ground corn + 18% cottonseed hulls plus supplements (CSH18), b) 6.1% eNDF-ground corn + 18% ground cottonseed hulls plus supplements (CSH18g) or c) 14.1% eNDF-ground corn + 25% cottonseed hulls plus supplements (CSH25). Cottonseed hulls (CSH) for diet "b" were ground through a 2-mm screen. Ingredients and chemical composition were analysed and computed *(Table 1).*

Diets were fed twice daily at 0800 h and 1600 h in equal portions. Feed dry matter was provided at a rate of 1.8% of body weight daily. Chromium oxide (Cr: 0.2% of the total diet) was used as a nonabsorbable marker for measurement of digesta flow and was mixed with the supplements for all diets.

Sampling procedures

Before the start of the experiment, the steers were given the diet "a" for 3 weeks for adaptation. Each experimental period lasted 21 days, with 16 days for adjustment and 5 days for sampling. On day 17 through 19, approximately 250 mL of duodenal digesta and 200 g of wet faeces were collected at 2 h and 8 h after feeding. On day 20, approximately 1 000 mL of strained rumen fluid were collected at 2 h and 8 h after

Table 1. Composition of diets

Ingredient	(% of dry matter) in diets		
	CSH18[2]	CSH18g[1]	CSH25[2]
Ground corn	74.4	74.4	67.4
Molasses	3.59	3.59	3.59
Chromic oxide	0.2	0.2	0.2
Supplement			
Cottonseed hulls	18.0	18.0	25.0
Urea	1.4	1.4	1.4
Dicalcium phosphate	1.4	1.4	1.4
Limestone (38%)	0.7	0.7	0.7
Trace mineralized salt	0.3	0.3	0.3
Vitamin A	0.01	0.01	0.01
Crude protein (%)	12.1	12.1	11.7
Starch (%)	52.3	52.3	50.3
NDF (%)	24.1	24.1	29.5
eNDF (% of NDF)[3]	43.3	25.3	47.9
eNDF (% of diet D.M)	10.4	6.1	14.1
ADF (%)	13.9	13.9	18.3

[1]CSH ground through 2-mm screen
[2]CSH non-ground
[3]Calculated from data of Fox et al. (1990)

feeding and frozen for bacteria isolation. On day 21, approximately 250 mL of rumen fluid were withdrawn at 1, 2, 4 and 8 h after feeding and were frozen for ammonia and peptides analyses. Rumen fluid collected was strained through four layers of cheesecloth and the pH was measured immediately. Before freezing, all rumen samples were acidified with 1 mL of 20% v/v sulphuric acid per 50 mL strained fluid to stop microbial activity.

Feed samples were obtained before each sampling day and composited within each diet and period. All samples were ground in Wiley Mill fitted with a 2-mm screen and stored for analysis.

Laboratory analyses and calculations

Feed, duodenal and faecal samples were analysed for dry matter (DM), organic matter (OM), ash (AOAC 1984), starch (Herrera-Saldana and Huber 1989) and chromium (Cr) (Fenton and Fenton 1979). The nitrogen (N) content of feed, duodenal digesta, bacterial composites, and faeces were analysed by macro-Kjeldahl analysis (AOAC 1984). Acid detergent fiber (ADF) and neutral detergent fiber (NDF) in feed, duodenal and faecal samples were analysed using procedures described by Goering and Van Soest (1970).

Rumen NH_3-N was analysed colorimetrically using a spectrophotometer (UV-VIS Spectrophotometer, Gilford-Respond Series, 1987) following the procedures of Broderick and Kang (1980). Bacteria were isolated from the ruminal fluid using the procedures of Weakley and Owens (1983). Dried duodenal and bacterial samples were analysed for nucleic acid-N by the procedure of Zinn and Owens (1986). To improve recovery of RNA pellets after precipitation with silver chloride, the RNA pellets were washed with a solution (100 mL) that consisted of 5 mL solution containing 12.5% $HCLO_4$ in 0.0285 *M* $NH_4H_2PO_4$ + 5 mL of 0.4 *M* $AgNO_3$ + 90 mL of 0.2 *M* $NH_4H_2PO_4$. Rumen fluid samples for peptide-N analysis were prepared using the procedures described by Chen et al. (1987). Prehydrolysed and hydrolysed rumen fluid samples were

analysed colorimetrically at 570 nm using a spectrophotometer (UV-VIS Spectrophotometer, Gilford-Respond Series, 1987).

The concentrations of ninhydrin reactive material in hydrolysed and unhydrolysed form were measured and leucine was used as a standard (Moore and Stein 1954; Moore 1968). The concentration of peptide-associated α-amino N was calculated as the difference between the α-amino N content of hydrolysed and the unhydrolysed samples. The concentrations of α-amino N in the hydrolysed and unhydrolysed form were corrected for NH_3-N in samples and ninhydrin (by subtracting NH_3-N concentrations in the samples and ninhydrin from α-amino N concentrations in the hydrolysed and unhyrolysed samples).

Flows of DM at the duodenum were calculated by dividing daily Cr intake (grammes) by Cr concentration (g/kg) in duodenal digesta. Nutrient flows were calculated by multiplying DM flow by the concentration of the given nutrient in duodenal DM. Bacterial N flow (g/d) at the duodenum was calculated by multiplying daily N flows at the duodenum by the proportion of bacterial N in the duodenal N. This proportion was calculated by dividing the bacterial N:purine ratio of ruminal bacteria isolated from each steer in each period.

Daily amounts of non-microbial DM and N flowing past the duodenal cannula were calculated by subtracting the microbial contributions from the total. Bacterial DM was determined by oven drying the freeze-dried bacteria samples (ground) at 60 °C for 24 h. Daily duodenal organic matter (OM) flow, corrected for microbial contributions, was calculated from the corrected duodenal DM flow multiplied by duodenal OM percentage.

Statistical analysis

Variables measured were analysed as replicated 3 x 3 Latin square with animal (6), period (2) and dietary treatment (2) as factors (SAS 1988). Differences between treatments were determined using a multiple comparison test (SAS 1988). Statistical significance was considered to exist where $p < 0.05$, whereas a trend was considered to exist if $0.05 \leq p \leq 0.10$. Simple correlations also were calculated across all observations. Contrast was utilized to make specific treatments comparison i.e., 1) between CSH18 and CSH18g, 2) between CSH18 and CSH25. All values presented in tables are least square means.

Results and discussion

Feed DM intake for CSH25, CSH18g and CSH18 averaged 6.76, 6.51 and 6.51 kg/d, respectively. Ruminal pH was lower ($p < 0.01$) for steers fed CSH18g diet than CSH18 diet *(Table 2)*. But the pH was higher ($p < 0.06$) for steers fed the CSH25 than CSH18 diets. The lower level of fiber in diet CSH18 as compared to diet CSH25 appeared to lower the rumen fluid pH. Lower ruminal pH for steers fed ground CSH than non-ground CSH was probably due to the smaller particle size of ground CSH that presumably decreased salivary input during chewing and rumination. This reduction in pH would be expected to reduce activity of fiber degrading bacteria. Cattle fed all diets had a lower pH at 1–2 h after feeding presumably due to rapid fermentation of starch to volatile fatty acids, but 4–6 h after feeding, the ruminal pH had rebounded.

No differences ($p > 0.05$) were noted for rumen NH_3-N among diets; the mean NH_3-N concentration for all treatments was 9.64 mg/dL. This concentration is well above the value (5 mg/dL) suggested by Satter and Slater (1974) for supporting maximal microbial growth. Reduction in percentage of eNDF (25.3%) *(Table 1)* in CSH18g diet did not affect the levels of rumen NH_3-N but tended to lower ruminal pH when compared to other diets with higher percentage of eNDF. The ruminal pH values for steers fed CSH18g was still above 6.0 probably because the percent of eNDF

Table 2. Mean rumen pH, ammonia, peptide-N, amino-N and microbial synthesis in the rumen of steers fed ground corn based supplemented with different forms and levels of cottonseed hulls

	Diet				Contrast	
	CSH18[2]	CSH18g[1]	CSH25[2]	SEM	CSH18g[1] vs. CSH18[2]	CSH18[2] vs. CSH25[2]
pH	6.20a	6.11b	6.31b	0.02	0.01	0.06
NH_3-N (mg/dL)	9.53	10.00	9.40	0.41	0.41	0.86
Amino acid-N (mg/L)[3]	2.43	2.36	2.39	0.01	0.16	0.37
Peptide-N (mg/L)[4]	1.59	1.53	1.57	0.02	0.37	0.20
Microbial efficiency[5]	13.50	13.03	14.47	0.37	0.47	0.13

Means in a same row with different letters differ significantly (p <0.05)
[1]CSH ground through 2-mm screen
[2]CSH non-ground
[3]Prehydrolysed fluid
[4]Hydrolysed fluid
[5]g microbial N per kg OM fermented

used in this experiment was slightly higher than the 20% minimum value suggested by NRC (1996).

Forms and level of CSH did not affect concentrations of peptide-N or amino acid-N in the rumen since all treatments received corn and urea as N source. The correlation coefficient between rumen peptide-N concentration and MOEFF is low and positive (r = 0.27; p <0.48). Ludden and Cecava (1995) in their studies using steers fed a high corn diet (81% cracked corn) supplemented with urea (1.5%) reported that the rumen peptide concentration was 14.6 mM that is ten fold higher than measured in this experiment. William and Cockburn (1991) reported a rumen peptide concentration of 2.4 mg/L for steers fed barley straw plus tapioca supplemented with casein.

Ruminal amino acid-N and peptide-N concentrations among treatments were similar averaging 2.56 and 1.56 mg/L, respectively. Effect of sampling time on ruminal concentrations of peptide-N and amino acid-N showed that both of these N-compounds presumably had increased slightly after feeding because they were higher at 1 h than later, but decreased thereafter. This agrees with others (Chen et al. 1987; Broderick and Wallace 1988; William and Cockburn 1991) who reported that peptides accumulate in rumen fluid transiently after feeding, and thereafter their concentrations decline. Concentrations of peptide-N and amino acid-N were only 1–2% of the concentration of NH_3-N with all treatments; thus their contribution to the N supply of ruminal microbes in this study should be low.

Efficiency of microbial protein synthesis (MOEFF) tended to be highest (14.5 g) for steers supplemented with CSH25 and to be lowest for steers fed with CSH18g (13.03 g) but the differences among treatments were not significant (p >0.05). Non-ground CSH diet, the diet that had higher percentage of eNDF tended to give a slightly higher MOEFF than the ground CSH diet that had less eNDF. Firkins et al. (1986) also detected no significant difference (p >0.05) in MOEFF for steers fed ground versus non-ground hay. However, Rode et al. (1985) observed that MOEFF was higher in lactating cows receiving ground hay than those fed non-ground hay which was directly related to ruminal solids turnover rate but inversely related to liquid dilution rate.

Although the amounts of N entering the duodenum were not significantly different (p >0.05), steers fed CSH25 and CSH18 had values 5.6% higher than steers fed diet CSH18g. Steers fed CSH18g had

Table 3. Nitrogen (N) digestion in steers fed a ground corn-based diet supplemented with different forms and levels of cottonseed hulls

	Diet				Contrast	
	CSH18[2]	CSH18g[1]	CSH25[2]	SEM	CSH18g[1] vs. CSH18[2]	CSH18[2] vs. CSH25[2]
Nitrogen intake (g/d)	125.5	125.5	126.6	–	–	–
Entering duodenum (g/d)	117.6	112.0	119.7	1.8	0.08	0.15
Microbial N (g/d)	56.7	50.4	60.7	3.1	0.27	0.14
NANMN (g/d)[3]	54.1	53.6	52.9	4.4	0.52	0.72
Ruminal digestion, (%)						
Unadjusted	6.3a	10.8b	5.6a	0.1	0.01	0.01
Adjusted[4]	56.9	57.4	57.8	0.4	0.49	0.52
Faecal N (g/d)	31.0	32.1	30.8	1.4	0.57	0.63
ATT digestion (%)[5]	75.5	74.3	75.7	1.1	0.48	0.55

Means in a same row with different letters differ significantly (p <0.05)
[1]CSH ground through 2-mm screen
[2]CSH non-ground
[3]Non-ammonia non-microbial nitrogen
[4]Adjusted for microbial and ammonia nitrogen
[5]Apparent Total Tract digestibility

lower (p <0.15) N entering the duodenum than steers fed CSH18 suggesting that less N was utilized for microbial growth in the rumen *(Table 3)*. Supplementation with different physical forms and levels of CSH had very limited influence on microbial N and NANMN flow to duodenum. Average quantities of microbial N entering the duodenum were 60.7, 50.4 and 56.7 g N/d for diets CSH25, CSH18 and CSH18g, respectively with microbial N flow for the non-ground CSH diet averaging 14.5% higher but not significantly different (p >0.05) than for the ground CSH diet. Feeding more CSH (25 vs 18%) also did not significantly (p >0.05) influence microbial N entering the duodenum. Grams of NANMN flow to duodenum were slightly higher for steers fed CSH18 than for steers fed CSH18g (54.1 vs. 53.6 g/d). This trend was similar to other reports on NANMN flow to the duodenum in steers fed ground versus non-ground hay (Rode et al. 1985; Firkins et al. 1986). Adjusted ruminal N digestion and apparent total tract N digestibilities were similar between diets averaging 57.4% and 75.2%, respectively indicating that level and form of CSH did not influence ruminal and post-ruminal N digestion.

Level of eNDF in the diet (25.3% for CSH18g vs 43.3% for CSH18) did not appear to affect N digestion and MOEFF in this experiment. Even though mean rumen pH in steers fed CSH18g was lower (6.11) than rumen pH of steers fed CSH18 (6.20) and CSH25 (6.31), MOEFF for CSH18g was similar to the other dietary treatments. The in vitro data of Russell et al. (1992) and Pitt et al. (1996) indicated that when rumen pH fell below 6.2, microbial protein production decreased linearly with pH; this conflicts with our in vivo results. Ludden and Cecava (1995) studied the effect of feeding high corn diet (81% cracked corn) supplemented with urea (1.5%) showed that MOEFF was high (21 g N/kg true OM digested) even though ruminal pH (6.13) was low. A summary of two studies by Weakley and Owens (1983) involving steers fed corn diets demonstrated that efficiency of microbial synthesis was quite variable and not related to ruminal pH across a pH range from 5.8 to 6.7.

Organic matter intake *(Table 4)* was higher for steers fed CSH25 than for steers

Table 4. Organic matter (OM) and starch digestion by steers fed ground corn-based diet supplemented with different forms and levels of cottonseed hulls

	Diet				Contrast	
	CSH18[2]	CSH18g[1]	CSH25[2]	SEM	CSH18g[1] vs. CSH18[2]	CSH18[2] vs. CSH25[2]
OM intake (g/d)	6209.0	6209.0	6433.0	–	–	–
OM flow at duodenum (g/d)	2852.4	2969.3	2889.0	41.9	0.19	0.60
Ruminal digestion,						
Apparent (g/d)	3356.6a	3239.7ab	3544.0b	36.6	0.08	0.10
% of intake	54.4a	51.1b	55.3a	0.4	0.02	0.33
True (g/d)	3956.3a	3734.3ab	4143.8a	65.4	0.09	0.11
% of intake[3]	63.1	60.7	64.2	0.8	0.08	0.13
Faecal OM (g/d)	1291.5a	1390.8b	1361.5b	19.0	0.14	0.05
ATTOMD (%)[4]	79.2	77.6	78.8	0.3	0.47	0.13
Starch intake (g/d)	3411.0	3411.2	3406.0	–		
Flow at duodenum (g/d)	1510.8ab	1577.0b	1446.7a	17.9	0.12	0.13
Ruminal digestion,						
Apparent (g/d)	1900.2a	1834.2b	1959.3a	9.8	0.01	0.02
% of intake	55.7a	53.8b	57.5	0.5	0.04	0.11
Faecal starch (g/d)	143.0	186.1	144.4	16.4	0.21	0.21
ATTSD (%)[5]	95.3	94.5	95.8	0.3	0.28	0.41

Means in a same row with different letters differ significantly (p <0.05)
[1] CSH ground through 2-mm screen
[2] CSH non-ground
[3] Adjusted for microbial OM
[4] Apparent Total Tract OM digestibility
[5] Apparent Total Tract Starch digestibility

fed either CSH18g or CSH18. Organic matter flows to duodenum were similar among diets averaging 2 903 g/d. Apparent and true ruminal OM digestibilities percentages were higher (p <0.02, p <0.13) in the rumen of steers fed CSH18 than that of steers fed CSH18g, but values were similar to those for steers fed CSH25. These results are similar to data from Lessard and Fisher (1980) who fed dairy cows long and ground alfalfa hay and showed that apparent and true ruminal OM digestibility was lower than ground alfalfa hay. Non-ground CSH were probably retained in the rumen longer for digestion than ground CSH although the greater surface area per g DM of ground CSH should have allowed more rapid colonization by ruminal microbes. Beever et al. (1972) also observed less OM digested in the rumen of sheep fed pelleted than ground grass.

The correlation coefficient between ruminal organic matter digestibility and MOEFF in this experiment was low and not significant (r = 0.14, p = 0.72). Feeding a higher percentage of cottonseed hulls in the diet (25 vs 18%) increased (p <0.05) faecal output and tended to decrease (p <0.08) diet digestibility. Replacing corn by cottonseed hulls at a rate of 7% dry matter of diet increased adjusted duodenal OM flow by only 1.1% and 0.4% faecal output. If the ground corn had a digestibility of 88% (TDN from NRC, 1996), ruminal and total tract digestibility of added CSH were 82% and 93%, respectively. These values greatly exceeded the NRC (1996) estimate of 42% TDN for cottonseed hulls. Similar values contrasting CSH25 with CSH18g revealed that CSH had true ruminal and total tract digestibilities of 43% and 81%, respectively. These values suggest that added CSH had a

Table 5. NDF and ADF digestion in steers fed ground corn-based diet Supplemented with different forms and levels of cottonseed hulls

	Diet				Contrast	
	CSH18[2]	CSH18g[1]	CSH25[2]	SEM	CSH18g[1] vs. CSH18[2]	CSH18[2] vs. CSH25[2]
NDF intake (g/d)	1 569.0	1 569.0	1 993.0	–	–	–
Entering duodenum (g/d)	790.0a	827.3a	981.6b	10.0	0.12	0.01
Ruminal digestion (g/d)	779.0a	741.7a	1 011.4b	9.6	0.11	0.002
As % of intake	49.6ab	47.3b	50.7a	0.5	0.04	0.09
Faecal NDF (g/d)	752.6a	787.2a	945.7b	10.5	0.14	0.01
ATTNDFD (%)[3]	52.0	49.8	52.5	0.6	0.08	0.12
Expected digestion, % of maximum based on pH[4]	95.8	88.0	92.5			
ADF intake (g/d)	905.0	905.0	1 237.0	–	–	–
Entering duodenum (g/d)	489.6a	499.3a	663.8b	11.2	0.57	0.01
Ruminal digestion (g/d)	415.4a	407.7a	573.2b	11.1	0.55	0.01
As % of intake	45.9	45.0	46.3	1.08	0.51	0.42
Faecal NDF (g/d)	466.6a	478.7a	645.1b	11.2	0.40	0.01
ATTNDFD (%)[5]	48.4	47.1	47.8	1.1	0.29	0.35

Means in a same row with different letters differ significantly (p <0.05)
[1]CSH ground through 2-mm screen
[2]CSH non-ground
[3]Apparent Total Tract NDF digestibility
[4]Pitt et al. 1996
[5]Apparent Total Tract ADF digestibility

positive associative effect on OM digestion with these diets. Post ruminal digestion of ground CSH compensated for two-thirds of the depression in ruminal digestion noted from grinding the cottonseed hulls.

Starch intakes were similar for all diets *(Table 4).* There were no significant differences (p >0.05) in starch duodenal flow attributable to grinding CSH or adding more CSH to the diet. However, ruminal starch digestibility tended to increase (p <0.08) with addition of CSH to the diet and to be decreased (p <0.02) by grinding of CSH. This may reflect increased chewing or rumination of grain with higher amounts or larger particle size of CSH. Total tract digestion values were similar among dietary treatments averaging 95.2%. The correlation coefficient between ruminal starch digestion and MOEFF was r = 0.27 (p <0.48) but the correlation of ruminal starch digestion and dietary NDF and eNDF was considerably greater (r = 0.86; r = 0.99).

Intakes, duodenal flows, and faecal output of NDF and ADF *(Table 5)* all were higher with the CSH25 diet than the CSH18 diet because of higher DMI and the higher percentage of cottonseed hulls in the diet. Yet, ruminal and total tract ADF and NDF digestion percentages were not altered by level of cottonseed hulls in the diet. Grinding CSH tended to reduce ruminal and total tract digestibilities of NDF and ADF. Rode et al. (1985) studying the effect of hay particle size in cows reported that digestibility of ADF was lower with ground than with non-ground hay.

Conclusion

Increasing the amount of cottonseed hulls in a corn-based diet from 18% to 25% increased ruminal pH and ruminal starch digestion but tended to decrease total tract organic matter digestibility. Grinding the cottonseed hulls to decrease effective NDF concentration, tended to decrease ruminal

pH and ruminal digestion of organic matter, starch, and NDF in ruminal fluid. Increasing the effective NDF content of the diet from 6% to 10%, and 14% dry matter of diet increased ruminal pH, ruminal and total tract starch digestibility but had little effect on NDF or ADF digestion or efficiency of microbial growth in the rumen.

References

AOAC. (1984). *Official Methods of Analysis* (14th ed.). Washington, DC: Association of Official Analytical Chemists

Beever, D. E., Harrison, D. G. and Thomson, D. J. (1972). Determination of the quantities of food and microbial nitrogen in duodenal digesta. *Proc. Nutr. Soc.* ***31:*** 61A

Broderick, G. A. and Kang, J. H. (1980). Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and *in vitro* media. *J. Dairy Sci.* ***63:*** 64

Broderick, G. A. and Wallace, R. J. (1988). Effects of dietary nitrogen source on concentrations of ammonia, free amino acids and flourescamine-reactive peptides in the sheep rumen. *J. Anim. Sci.* ***66:*** 2233

Chen, G., Russell, J. B. and Sniffen, C. J. (1987). A procedure for measuring peptides in the rumen fluid and evidence that peptide uptake can be a rate-limiting step in the ruminal protein degradation. *J Dairy Sci.* ***70:*** 121

Fenton, T. W. and Fenton, M. (1979). An improved procedure for the determination of chromic oxide in feed and feces. *Can. J. Anim. Sci.* ***59:*** 631

Firkins, J. L., Berger, L. L., Merchen, N. R. and Fahey Jr., G. C. (1986). Effects of forage particle size, level of feed intake and supplemental protein degradability on microbial protein synthesis and site of nutrient digestion in steers. *J. Anim. Sci.* ***62:*** 1081

Fox, D. G., Sniffen, C. J., O'Conner, J. D., Russell, J. B. and Van Soest, P. J. (1990). The Cornell net carbohydrate and protein system for evaluating cattle diets. Search: Agric., Cornell Univ. Agric. Exp. Stn. No. 34, Ithaca, NY

Goering, H. K. and Van Soest, P. J. (1970). Forage fiber analysis. Agriculture Handbook No. 397. ARS/USDA

Herrera-Saldana, R. and Huber, J. T. (1989). Influence of varying protein and starch degradations on performance of lactating cows. *J. Dairy. Sci.* ***72:*** 1477

Lessard, J. R. and Fisher, L. J. (1980). Alfalfa fed as formic acid-treated silage, dehydrated pellets or hay in mixed rations with corn silage for lactating cows. *Can. J. Anim. Sci.* ***60:*** 945

Ludden, P. A. and Cecava, M. J. (1995). Supplemental protein sources for steers fed Corn-based diets. 1. Ruminal characteristics and intestinal amino acids flow. *J. Anim. Sci.* ***73:*** 1466

Moore, S. (1968). Amino acid analysis: Aqueous dimethylsulfoxide a solvent for ninhydrin reaction. *J. Biol. Chem.* ***243:*** 6281

Moore, S. and Stein, W. H. (1954). A modified ninhydrin reagent for the photometric determination of amino acids and related compounds. *J. Biol. Chem.* ***211:*** 907

NRC. (1996). Nutrient requirements of Beef Cattle (7th ed.). Washington DC: National Academy Press

Pitt, R. E., Van Kessel, J. S., Fox, D. G., Barry, M. C. and Van Soest, P. J. (1996). Prediction of ruminal volatile fatty acids and pH within the net carbohydrate and protein system. *J. Anim. Sci.* ***74:*** 226

Rode, L. M., Weakley, D. C. and Satter, L. D. (1985). Effect of forage amount and particle size in diets of lactating dairy cows on sote of digestion and microbial protein synthesis. *Can. J. Anim. Sci.* ***65:*** 10

Russell, J. B., Connors, J. D., Fox, D. G., Van Soest, P. J. and Sniffen, C. J. (1992). A net carbohydrate and protein system for evaluating cattle diets: 1. Ruminal fermentation. *J. Anim. Sci.* ***70:*** 3551

SAS. (1988). SAS user's guide: Statistics. SAS. Institute Inc., Cary. N.C.

Satter, L. D. and Slater, L. L. (1974). Effect of ammonia concentration on rumen microbial protein production in vitro. *Br. J. Nutr.* ***32:*** 199

Weakley, D. C. and Owens, F. N. (1983). Influence of roughage level on soybean meal protein degradation and microbial protein synthesis in the rumen. Chapter III. Ph. D. Thesis. Oklahoma State University, Stillwater

William, A. P. and Cockburn, J. E. (1991). Effect of slowly and rapidly degraded protein sources on the concentration of amino acids and peptides in the rumen of steers. *J. Sci. Food Agric.* ***56:*** 303

Zinn, R. A. and Owens, F. N. (1986). A rapid measurement for purine measurement and its use for estimating net ruminal protein synthesis. *Can. J. Anim. Sci.* ***66:*** 157

Accepted for publication on 16 May 2001