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The Effect of Forage Source and Particle Size on Finishing Yearling Steer Performance and Ruminal Metabolism[1]

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ABSTRACT: Two finishing trials and a metabolism trial were conducted to evaluate the effect of forage source and particle size in dry-rolled corn finishing diets. In Exp. 1, 224 crossbred yearling steers (BW = 342 ± 11 kg) were used in a randomized complete block design consisting of seven treatments. Treatments were an all-concentrate diet or diets containing equal NDF levels provided by alfalfa hay or wheat straw (three treatments each) with each forage source ground to pass through a .95-, 7.6-, or 12.7-cm screen. Steers fed diets containing forage had greater ($P < .05$) DMI than steers fed an all-concentrate diet. Steers fed alfalfa diets gained faster ($P < .05$) with a greater ($P < .05$) concentrate efficiency than steers fed either all-concentrate or straw diets. In Exp. 2, 120 crossbred yearling steers (BW = 307 ± 2 kg) were used in a completely randomized design and fed dry-rolled corn diets containing 10% alfalfa ground to pass through either a .95- or 7.6-cm screen. Alfalfa particle size had no effect on performance or carcass measurements. In Exp. 3, six ruminally fistulated steers (BW = 508 ± 34 kg) were used in a 6 × 6 Latin square design and fed an all-concentrate diet or diets containing equal NDF levels provided by alfalfa hay, wheat straw, or ground corncobs with alfalfa and straw ground to pass through either a 2.54- or 12.7-cm screen. Steers fed straw diets spent more time ($P < .10$) chewing than those receiving the other diets. In conclusion, forage particle size had no effect on finishing cattle performance or ruminal metabolism data. However, cattle consuming different forage sources in dry-rolled corn finishing diets may not respond similarly in animal performance.

Key Words: Cattle, Forage, Particle Size

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Introduction

Forage in high-concentrate finishing diets helps maintain rumen function, reduces acidosis, improves intake (Gill et al., 1981; Brandt et al., 1987; Stock et al., 1990), stimulates chewing and rumination (Sudweeks et al., 1975), and may increase rate of passage of grain (Goetsch et al., 1984). In addition, Woodford et al. (1986) indicated that normal rumen function is dependent on both qualitative (physical form) and quantitative (dietary concentration) aspects of dietary fiber. If the "effectiveness" of dietary fiber in reducing acidosis depends solely on the amount of NDF provided by the forage, then high-concentrate finishing diets containing equal levels of NDF from different forage sources should elicit similar responses in animal performance.

Chewing is associated with increased saliva output (Balch, 1958), which plays a role in buffering acids produced during ruminal fermentation. If the purpose of adding forage to a high-concentrate diet is to help reduce acidosis, then any dietary alteration that reduces chewing and(or) rumination time may negatively influence animal performance by reducing buffering capacity. However, there is limited information evaluating the effect of forage particle size on animal performance and ruminal metabolism in beef cattle finishing diets. The objectives of this research were to evaluate the effect of different forage sources and forage particle size on animal performance, ruminal metabolism, and chewing activity in beef cattle finishing diets.

Materials and Methods

Finishing Trial 1

British-breed, crossbred yearling steers (n = 224; mean BW = 342 ± 11 kg) were used to evaluate the

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effect of different forage sources and forage particle size in finishing diets. Steers were purchased as calves the previous fall from commercial buyers, processed according to McCoy et al. (1998), and grown in an extensive production system consisting of grazed cornstalks, supplemental feed, and summer grass pasture. Therefore, no additional receiving treatments were implemented prior to the start of this trial. Steers were blocked by weight into four groups and randomly allotted within block to one of seven treatments. Each treatment contained four replicates (pen) with eight steers per pen. Treatments consisted of cattle receiving an all-concentrate dry-rolled corn diet or diets containing alfalfa hay or wheat straw with each forage ground to pass through a .95-, 7.6-, or 12.7-cm screen. Diets containing forage were balanced to provide equal NDF (Van Soest et al., 1991) concentrations and contained (DM basis) 10% alfalfa hay (42.8% NDF) or 5.2% wheat straw (82.0% NDF). All diets were formulated (DM basis) to contain a minimum of 12% CP, .7% Ca, .35% P, .7% K, 27.5 mg/kg monensin (Elanco Animal Health, Indianapolis, IN), and 11 mg/kg tylosin (Elanco Animal Health, Table 1). All diets contained dry-rolled corn as the concentrate source and urea as supplemental protein source. The all-concentrate treatment was included as a negative control, no forage treatment.

Steers were fed common adaptation diets of dry-rolled corn, alfalfa hay, and corn silage while adjusting to the final treatment diets. Dietary treatments were implemented following a 28-d, five-step grain adaptation period. Corn silage was not included in the final treatment diets. Corn was dry-rolled in an attempt to break the kernel into quarters and to minimize fine particles.

Steers were offered a sufficient quantity of feed to allow ad libitum consumption. Diets were fed once daily in outdoor pens (bunk space = 95 cm/animal; pen space = 42 m^2), and the final diets were fed for an average of 76 d. Refused feed was collected when feed was determined out of condition (i.e., heated, molded, or signs of secondary fermentation) and dried for 24 h at 55°C for DM determination to calculate actual DMI. Weekly composites of dry-rolled corn samples were analyzed for starch (Herrera-Saldana and Huber, 1989) to calculate total starch intake. Steers were implanted with Compudose (Elanco Animal Health) at the start of the trial and Finaplix-S (Hoechst-Roussel, Somerville, NJ) on d 28. Steers were weighed initially on two consecutive days after being fed a 50% alfalfa hay:50% corn silage diet for 5 d at 2% of BW (DM basis) to reduce fill differences. Daily gain for treatments was calculated based on average initial weight and final weight at harvesting. Final weight was based on hot carcass weight adjusted to a common 62% dressing percentage. Steers were processed by replication (block) when they appeared to grade 70% Choice. Hot carcass weights and liver scores were recorded at processing. Livers were scored for abscesses according to Brink et al. (1990). Fat thickness (12th rib) and quality and yield grade were obtained after carcasses were chilled for 48 h.

Table 1. Measured composition of diets fed in Trial 1[a]

	Diets		
Ingredient	All-concentrate	Alfalfa	Straw
Dry-rolled corn	90	80	84.8
Forage[b]	—	10	5.2
Molasses	5	5	5
Dry supplement			
Finely ground corn	1.46	2.32	1.61
Urea	.92	.67	.99
Tallow	.10	.10	.10
Limestone	1.61	1.24	1.53
Potassium chloride	.43	.16	.32
Sodium chloride	.30	.30	.30
Dicalcium phosphate	.08	.11	.15
Premix[c]	.10	.10	.10
Dietary CP, % of DM[d]	10.6	10.9	10.5

[a]%, DM basis.
[b]Alfalfa hay or wheat straw, each particle size fed at same percentage within forage type.
[c]Premix included: .05% trace mineral premix containing 10% Mg, 6% Zn, 2% Mn, 4% Fe, .5% Cu, .3% I, and .05% Co; .02% vitamin premix containing 15,000 IU of vitamin A per g, 3,000 IU of vitamin D per g, and 3.75 IU of vitamin E per g; .02% rumensin premix containing 176 g monensin per kg premix, and .01% tylan premix containing 88 g tylosin per kg premix.
[d]Based on actual CP values for corn, alfalfa, and wheat straw.

Data for animal performance and carcass traits were analyzed as a randomized complete block design as outlined by Steel and Torrie (1980). The model included block and treatment with residual used as the error term. Pen was used as the experimental unit. Forage type × particle size interaction was tested using orthogonal contrasts. If no interaction existed, data were pooled and the means for main effects were computed and comparisons made using the least squares means procedures of SAS (1989).

Finishing Trial 2

Crossbred yearling steers (n = 120; mean BW = 307 ± 2 kg) were used to evaluate the effect of alfalfa hay particle size in finishing diets. Steers were randomly allotted to one of two treatments. Each treatment consisted of six replications (pens) with 10 steers per replicate. Final treatment diets consisted (DM basis) of 80% dry-rolled corn, 10% alfalfa hay (ground to pass through either a .95- or 7.6-cm screen), 5% molasses, and 5% dry supplement. Supplement composition was described in Trial 1 (Table 1).

Steers were adapted to final diets using a 28-d, five-step grain adaptation period. Alfalfa hay, used in the adaptation diets, was the same particle size as used for the final treatment diets. Steers were offered a sufficient quantity of feed to allow ad libitum consumption. Diets were fed once daily in outdoor pens (bunk space = 49 cm/animal; pen = 28 m^2) for

136 d (28-d adaptation and 108-d final). Steers were implanted with Revalor-S (Hoechst-Roussel) at the start of the trial. Weighing procedures and carcass measurements were the same as in Trial 1.

Data for animal performance and carcass traits were analyzed as a completely randomized design using the GLM procedure of SAS (1989). The model included replication and treatment, with residual used as the error term. Means were computed and treatment comparisons were made using the least squares means procedure of SAS (1989). Pen was used as the experimental unit.

Metabolism Trial

Ruminally fistulated steers (n = 6; mean BW = 508 ± 34 kg) were used in a 6 × 6 Latin square design to evaluate the effect of forage type and particle size on chewing activity and ruminal characteristics. Treatments consisted of cattle receiving an all-concentrate dry-rolled corn diet or dry-rolled corn diets containing either alfalfa hay, wheat straw, or corncobs. Corn was processed the same as in Trial 1. Alfalfa hay and wheat straw were ground to pass through either a 2.5- or 12.7-cm screen with corncobs ground to pass through a .95-cm screen. All diets were formulated (DM basis) to contain a minimum of 12% CP, .7% Ca, .35% P, .7% K, 27.5 mg/kg monensin and 11 mg/kg tylosin (Table 2). Diets containing forage were balanced to provide equal NDF (Van Soest et al., 1991) concentrations and contained (DM basis) 10% alfalfa hay (48.5% NDF), 5.6% wheat straw (86.6% NDF), or 5.4% corncobs (90.0% NDF). All diets contained dry-rolled corn as the concentrate source and urea as supplemental protein source. Surgical procedures and postsurgical care were the same as outlined by Stock et al. (1991), and all procedures had been reviewed and accepted by the University of Nebraska Institutional Animal Care Program. Steers were housed in 1.5-m × 2.4-m individual slotted floor pens in a 25°C temperature-controlled room.

Steers were adapted to treatment diets using grain adaptation diets similar to those used in Trial 1. Steers were fed once daily at 0800 but were offered a sufficient quantity of feed to allow ad libitum consumption, with free access to water. Each period consisted of 11 d for diet adaptation, 2 d for measurement of chewing activity, and 1 d for collection of ruminal samples. Chewing activity was recorded for 15 sec every 5 min during 48 h for each steer to determine time spent eating, ruminating, and resting (no chewing activity). The visual observation method for determining chewing activity has been considered very reliable when short time intervals, such as 5 min, are used between observations (Woodford and Murphy, 1988). At 0800 on d 13, steers were pulse dosed, via the rumen cannula, with 500 g (DM basis) of erbium-labeled corn, 200 mL of Cr-EDTA, and 200 g (DM basis) of ytterbium-labeled forage. Erbium, ytterbium, and Cr-EDTA have been shown to be reliable external markers for corn, forage, and liquids, respectively, when used in high concentrate diets (Sindt et al., 1993). Labeling procedures for corn and forage were the same as outlined by Sindt et al. (1993). Samples of ruminal fluid and particulate matter were taken at 0 h and at 6-h intervals for 24 h following dosing using the suction strainer technique (Raun and Burroughs, 1962). Particulate matter samples were a composite of samples taken

Table 2. Measured composition of diets fed in Trial 3[a]

	Diets			
Ingredient	All concentrate	Alfalfa hay	Wheat straw	Corncobs
Dry-rolled corn	89	79	83.4	83.6
Forage[b]	—	10	5.6	5.4
Molasses	5	5	5	5
Dry supplement				
Finely ground corn	1.10	3.51	.40	.20
Soybean meal	1.91	—	2.77	2.91
Urea	.61	.61	.61	.61
Limestone	1.61	1.22	1.51	1.52
Potassium chloride	.34	.15	.20	.25
Sodium chloride	.30	.30	.30	.30
Dicalcium phosphate	.03	.11	.11	.11
Premix[c]	.10	.10	.10	.10
Dietary CP, % of DM[d]	11.0	11.5	11.0	11.1

[a]%, DM basis.
[b]Alfalfa hay or wheat straw, each particle size fed at same percentage within forage type.
[c]Premix included: .05% trace mineral premix containing 10% Mg, 6% Zn, 2% Mn, 4% Fe, .5% Cu, .3% I, and .05% Co; .02% vitamin premix containing 15,000 IU of vitamin A per g, 3,000 IU of vitamin D per g, and 3.75 IU of vitamin E per g; .02% rumensin premix containing 176 g monensin per kg premix, and .01% tylan premix containing 88 g tylosin per kg premix.
[d]Based on actual CP values for corn, alfalfa, wheat straw, and corncobs.

from the cranial and caudal areas of the dorsal and ventral sacs of the rumen. After the last collection of ruminal fluid, rumen contents were evacuated, weighed, mixed thoroughly, and subsampled. Ruminal contents were placed back into steers, and steers started the next period.

Ruminal fluid collected (200 mL) was immediately measured for pH with a combination electrode, subsampled, and then frozen (–20°C) for further analysis. A subsample of ruminal fluid was deproteinized with 1/4 volume of 20% *m*-phosphoric acid (Erwin et al., 1961) containing 25 m*M* 2-ethyl butyrate added as an internal standard for VFA analysis. Ruminal VFA were separated and quantified by GLC (Hewlett-Packard, Avondale, PA) containing a packed (10% SP1200/1% H_3PO_4 on Chromosorb W/AW; Supelco, Bellefonte, PA) glass column and equipped with a flame ionization detector. Ruminal fluid samples collected during the last 24 h of each period were used to determine average ruminal pH and VFA. Samples of ruminal particulate matter, diets, and refused feed were dried in a forced-air oven for 24 h at 55°C for DM determination. Ruminal particulate matter samples were ground to pass through a 1-mm screen and analyzed for Yb and Er concentration as outlined by Hart and Polan (1984) by atomic absorption spectroscopy using a nitrous oxide-acetylene flame. Marker concentration of Er and Yb was used to determine ruminal passage rates for dry-rolled corn and forage, respectively.

Particle size distribution of forages was measured using seven sieves on a vertically oscillating sieve shaker (W. S. Tyler, Inc., Mentor, OH). A 400-mL volume of forage was placed on the top sieve, and the sample was sieved for 15 min. Particle distributions were recorded and geometric mean diameter of each forage was calculated (Waldo et al., 1971). Forage effective NDF (eNDF) was determined by NDF analysis of material remaining on each sieve screen according to NRC (1996).

Data were analyzed as a 6 × 6 Latin square design using the GLM procedures of SAS (1989). Main effects of treatment, steer, and period were included in the model with steer × period × treatment used as the error term. Means were computed and treatment comparisons were made using the least squares means procedure of SAS (1989).

Results

Finishing Trial 1. No forage source × forage particle size interaction ($P > .10$) was observed; therefore, data were pooled and main effects of forage source and forage particle size were compared. Dry matter intakes for steers fed diets containing alfalfa or straw were greater ($P < .05$) than steers fed an all-concentrate diet (Table 3). However, steers fed straw diets consumed more concentrate ($P < .05$) than steers fed all-concentrate or alfalfa diets. Steers fed straw diets consumed more ($P < .05$) starch than steers fed alfalfa or all-concentrate diets, and steers fed alfalfa diets consumed more ($P < .05$) starch than steers fed the all-concentrate diet.

Steers fed diets containing alfalfa hay gained faster ($P < .05$) than steers fed the all-concentrate diet or diets containing straw. Steers fed alfalfa diets were more efficient ($P < .05$) than steers fed straw diets. However, feed efficiency for steers fed the all-concentrate diet was intermediate to steers fed diets

Table 3. Effect of forage source on finishing steer performance and carcass characteristics in Trial 1[a]

	Forage Source			
Item	All concentrate	Alfalfa hay	Wheat straw	SEM
Intake, kg DM/d				
Total	10.43[b]	11.59[c]	11.66[c]	.15
Concentrate	9.84[b]	10.03[b]	10.39[c]	.13
Starch intake, kg	5.74[b]	6.21[c]	6.46[d]	.08
Daily gain, kg	1.52[b]	1.74[c]	1.61[b]	.04
Gain/feed				
Complete	.146[bc]	.150[b]	.138[c]	.003
Concentrate	.155[b]	.173[c]	.155[b]	.003
Hot carcass wt., kg	308[b]	321[c]	314[b]	3
12th-rib fat depth, cm	.71[b]	.89[c]	.81[bc]	.05
Liver abscess score[e]	.16	.05	.06	.04
Quality grade[f]	18.1	18.1	18.0	.2
Yield grade	2.0	2.2	2.1	.1

[a]No forage source × particle size interactions were observed; particle size data are presented in Table 5.
[b,c,d]Means within a row lacking a common superscript letter differ ($P < .05$).
[e]0 = healthy liver; 1 = one or two small abscesses; 2 = two to four active abscesses; 3 = one or more large abscesses; 4 = adherence of abscesses to diaphragm or digestive tract.
[f]High select = 18, low choice = 19.

Table 4. Effect of forage particle size on finishing steer performance and carcass characteristics in finishing Trial 1[a]

Item	Screen size, cm .95	7.6	12.7	SEM
Intake, kg DM/d				
Total	11.67	11.79	11.41	.14
Concentrate	10.25	10.36	10.02	.14
Daily gain, kg	1.70	1.69	1.63	.04
Gain/feed				
Complete	.146	.143	.143	.003
Concentrate	.166	.163	.163	.004
Starch intake, kg	6.36	6.43	6.22	.09
Hot carcass wt, kg	319	319	314	3
12th rib fat depth, cm	.87	.85	.83	.03
Liver abscess score[b]	.09	.03	.05	.03
Quality grade[c]	18.2	18.0	18.0	.2
Yield grade	2.1	2.2	2.2	.1

[a]No forage source × particle size interactions were observed; forage source data are presented in Table 3.
[b]0 = healthy liver; 1 = one or two small abscesses; 2 = two to four active abscesses; 3 = one or more large abscesses; 4 = adherence of abscesses to diaphragm or digestive tract.
[c]High select = 18, low choice = 19.

containing either alfalfa or straw. In addition, concentrate efficiency was greatest ($P < .05$) for steers fed diets containing alfalfa when compared with steers fed either the all-concentrate or straw diets. No difference in concentrate efficiency was noted between steers fed the all-concentrate or straw containing diets.

The greater daily gain for steers fed diets containing alfalfa resulted in heavier hot carcass weights ($P < .05$) than for steers fed all-concentrate or straw diets. No other differences in hot carcass weights were noted among treatments. Fat depths, measured at the 12th rib, for steers fed straw diets were similar to steers fed the all-concentrate or alfalfa diets. However, steers fed alfalfa diets had greater fat depths ($P < .05$) than steers fed the all-concentrate diet. No differences were noted in liver abscess score, or quality or yield grade among treatments.

Altering forage particle size had no effect ($P > .10$) on daily intake, starch intake, daily gain, complete feed or concentrate efficiency, or carcass measurements among diets containing different particle size forages (Table 4).

Finishing Trial 2

Results obtained in Trial 1 indicated that steers fed diets containing alfalfa hay ground to pass through a .95-cm screen were 5.5% more efficient ($P = .09$) than steers fed diets containing alfalfa hay ground to pass through a 7.6-cm screen (data not shown). Therefore, Trial 2 was conducted to determine whether the improved efficiency noted in Trial 1 exists by increasing the number of replications to each treatment. However, in Trial 2, no differences in DMI, daily gain, or feed efficiency were observed between steers fed diets containing alfalfa hay ground to pass through either a .95- or 7.6-cm screen (Table 5). In addition, no differences in carcass measurements were observed between treatments.

Metabolism Trial

Steers fed large particle size alfalfa diets consumed more DM ($P < .10$) than steers fed diets containing corncobs and steers fed small particle size straw diets consumed more DM ($P < .10$) than steers fed all-concentrate or corncob diets (Table 6). Mean ruminal pH for steers fed large particle size straw diets was higher ($P < .10$), and steers fed the small particle size straw diet tended to have higher pH values when compared with steers fed all-concentrate, large particle size alfalfa, or corncob diets. Percentage dry matter of ruminal contents was greater ($P < .10$) for steers fed all-concentrate or corncob diets when compared with other treatments. Amount of ruminal dry matter

Table 5. Effect of alfalfa hay particle size on finishing steer performance and carcass characteristics in Trial 2

Item	Screen size, cm .95	7.6	SEM
Daily feed intake, kg	10.55	10.75	.09
Daily gain, kg	1.65	1.68	.03
Gain/feed	.156	.156	.002
Hot carcass wt, kg	329	331	3
12th rib fat depth, cm	1.11	1.17	.07
Quality grade[a]	18.0	18.3	.3
Yield grade	2.5	2.6	.1

[a]High select = 18, low choice = 19.

Table 6. Effects of forage source and particle size on dry matter intake, digesta passage, ruminal fill, pH, and VFA concentration, and rate of ruminal starch digestion in the metabolism trial

Item	AC[a]	Alfalfa hay screen size, cm 2.54	Alfalfa hay screen size, cm 12.7	Wheat straw screen size, cm 2.54	Wheat straw screen size, cm 12.7	CC[a]	SEM
Intake, kg DM/d	9.38^{bc}	9.92^{bcd}	10.33^{bd}	10.57^{d}	9.83^{bcd}	9.21^{c}	.42
Ruminal pH	5.66^{b}	5.73^{bc}	5.65^{b}	5.87^{bc}	5.92^{c}	5.67^{b}	.10
Ruminal DM, %	22.78^{b}	17.36^{c}	19.34^{c}	17.81^{c}	16.98^{c}	23.28^{b}	1.26
Ruminal fill, DM kg	7.87^{bc}	6.51^{bd}	7.26^{b}	7.05^{bd}	5.69^{d}	8.86^{c}	.58
Total VFA, m*M*	120^{bc}	116^{bcd}	122^{c}	110^{d}	107^{d}	111^{bd}	4
Molar proportions, %							
Acetate	45.2^{b}	49.9^{c}	46.7^{b}	53.2^{c}	51.7^{c}	44.2^{b}	2.1
Propionate	41.1^{b}	36.9^{bc}	38.6^{b}	31.7^{c}	34.8^{bc}	41.2^{b}	2.7
Butyrate	9.6	8.8	11.1	8.4	7.6	9.1	1.3
Acetate:propionate	1.2^{b}	1.4^{bc}	1.3^{bd}	1.8^{c}	1.6^{cd}	1.1^{b}	.2
Ruminal Passage, %/h							
Liquid	11.65	9.95	11.11	10.45	11.09	9.94	1.28
Yb-labeled corn	2.87	3.82	3.06	4.12	3.15	3.29	.61
Er-labeled forage	—	4.29	3.59	4.88	3.17	3.68	.83
Rate of ruminal starch disappearance, %/h	2.85	3.40	3.13	3.27	3.19	3.08	.31

[a]AC = All-concentrate diet; CC = corncob diet, corncobs ground to pass a .95 cm screen.
[b,c,d]Means within a row lacking a common superscript differ ($P < .10$).

was greatest ($P < .10$) for steers fed corncob diets compared with diets containing either alfalfa or straw.

Total VFA concentration was greatest ($P < .10$) for steers fed large particle size alfalfa diets compared with steers fed straw or corncob diets and was greater ($P < .10$) for steers fed all-concentrate diets compared with steers fed straw diets. Molar proportions of acetate were greater ($P < .10$) for steers fed small particle size alfalfa or straw diets compared with other treatments. In addition, steers fed small particle size straw diets had the lowest ($P < .10$) molar proportion of propionate compared with steers fed all-concentrate, large particle size alfalfa, or corncob diets. No differences in the molar proportion of butyrate were noted among treatments. Steers fed straw diets had higher ($P < .10$) acetate:propionate ratios compared with steers fed either all-concentrate or corncob diets. No differences in ruminal passage rates (liquid, Yb-labeled corn, or Er-labeled forage) were observed among treatments. However, the addition of forage numerically increased passage rate of corn particles when compared with all-concentrate diets.

Forage particle size sieving (Table 7) and NDF analysis of forages for each sieve screen (Table 8) were used to calculate eNDF and were used in the NRC (1996) model to predict ruminal pH, DIP balance, and bacterial N balance. Including only eNDF derived from forages resulted in ruminal pH predictions below observed values for all treatments (Table 9). Adding eNDF derived from dry-rolled corn (9% NDF, 60% eNDF; NRC, 1996) to the eNDF from forages resulted in ruminal pH predictions closer to observed measurements of ruminal pH. A paired T test (SAS, 1989) indicated that the addition of eNDF derived from dry-rolled corn improved the model's pH prediction ability for all-concentrate, small particle size alfalfa, and wheat straw containing diets (Table 10). However, addition of both forage and corn eNDF overpredicted ruminal pH for the large particle size alfalfa and corncob diets with no improvement in prediction ability compared with using only forage eNDF in the model. In addition, when using both forage and dry-rolled corn eNDF values in diets containing wheat straw, the model still underestimated ruminal pH compared with observed measurements.

Steers fed all-concentrate diets spent less total time eating and ruminating and more time resting (no chewing activity), during a 24-h period, compared with other treatments ($P < .10$; Table 11). Steers fed the small particle size alfalfa or straw diets spent more time eating ($P < .10$) compared with steers fed similar diets containing the large particle size forage. Steers fed corncob diets spent less time eating ($P < .10$) than steers fed small particle size alfalfa or straw diets. Steers fed large particle size straw diets spent more time ruminating ($P < .10$) than steers fed alfalfa or corncob diets. Steers fed small particle size straw diets spent more time ruminating ($P < .10$) than steers fed large particle size alfalfa or corncob diets. Total time spent chewing, both eating and ruminating, was greatest ($P < .10$) for steers fed straw diets, intermediate for steers fed alfalfa and corncob diets, and lowest for steers fed the all-concentrate diet. No differences in the number of eating events occurring during a 24-h period were noted among treatments. The number of ruminating events during a 24-h period was greater ($P < .10$) for steers fed alfalfa or straw diets compared with steers fed all-concen-

Table 7. Geometric mean diameter and effective neutral detergent fiber for corncobs and alfalfa hay or wheat straw ground to pass through different screen sizes used in Trial 3

Forage:	Alfalfa	Alfalfa	Straw	Straw	Corncobs
Screen size, cm:	2.54	12.7	2.54	12.7	.95
	Forage retained/screen, g				
Sieve screen size, mm					
9.5	—	2.60	—	6.45	—
6.3	—	2.19	—	3.62	—
4.75	1.05	—	2.69	—	5.14
3.35	1.95	7.14	1.66	12.02	12.19
2.38	—	5.59	—	8.74	—
1.7	9.73	—	14.60	—	11.67
1.18	8.83	16.07	5.59	9.12	5.19
.85	—	8.81	—	2.66	—
.60	13.33	4.78	6.15	.85	8.44
.425	5.46	—	2.84	—	3.21
.212	6.27	—	1.53	—	3.15
pan	3.73	13.46	.53	.67	1.47
GMD, mm[a]	.97	1.63	1.62	3.56	1.79
eNDF[b]	50.1	61.2	70.2	91.4	68.3

[a]Geometric mean diameter (Waldo et al., 1971).
[b]Effective NDF (% of NDF). Calculated as percentage forage NDF remaining on screen ≥ 1.18 mm.

trate or corncob diets. Steers fed small particle size alfalfa or straw spent more time eating per event ($P < .10$) than other treatments. In addition, steers fed large particle size straw spent more time eating per event than all-concentrate fed steers. Steers fed all-concentrate diets spent less time ruminating per event ($P < .10$) compared with diets containing forage. Steers fed large particle size straw diets spent more time ruminating per event ($P < .10$) than steers fed all-concentrate diets or diets containing alfalfa or corncobs.

Forage Particle Size

Forage samples collected during Trial 1 for use in particle size determination were inadvertently discarded. Therefore, particle size measurements for the alfalfa hay and wheat straw used in this trial are not available. However, no differences among particle sizes within a forage type were noted for animal performance or carcass measurements, indicating that forage particle size had no influence in Trial 1. The geometric mean diameter and calculated eNDF (%

Table 8. Neutral detergent fiber analysis for sieved corncobs, alfalfa hay, or wheat straw ground to pass through different screen sizes used in Trial 3

Forage:	Alfalfa	Alfalfa	Straw	Straw	Corncobs
Screen size, cm:	2.54	12.7	2.54	12.7	.95
	% NDF retained/screen				
Sieve screen size, mm					
9.5	—	5.30	—	14.87	—
6.3	—	4.26	—	8.42	—
4.75	2.52	—	7.71	—	10.48
3.35	4.49	13.13	4.83	27.20	24.11
2.38	—	10.46	—	20.25	—
1.7	22.51	—	41.69	—	23.45
1.18	20.59	28.04	15.96	20.67	10.25
.85	—	15.70	—	5.31	—
.60	26.22	7.08	17.06	1.88	16.71
.425	9.75	—	7.45	—	6.34
.212	9.06	—	3.98	—	6.08
pan	4.88	16.03	1.33	1.40	2.57
eNDF[a]	50.1	61.2	70.2	91.4	68.3

[a]Effective NDF (% of NDF). Calculated as percentage forage NDF remaining on screen ≥ 1.18 mm.

Table 9. Paired comparisons of actual ruminal pH and predicted ruminal pH using the NRC model with and without the eNDF derived from dry-rolled corn

	Ruminal pH			$P > \|T\|$	
Forage source	Actual	Forage eNDF[a]	Forage and corn eNDF[b]	Actual vs forage eNDF[c]	Actual vs forage and corn eNDF[d]
All-concentrate	5.66	5.43	5.63	.078	.795
Small particle size alfalfa	5.73	5.53	5.72	.166	.929
Large particle size alfalfa	5.65	5.55	5.74	.505	.519
Small particle size straw	5.87	5.57	5.76	.03	.334
Large particle size straw	5.92	5.62	5.81	.075	.462
Corncobs	5.67	5.57	5.76	.141	.152

[a]NRC model, Level 1. Model inputs used listed in Table 10.
[b]Calculated using eNDF values obtained for forages in the NRC (1996) model.
[c]Calculated using eNDF values obtained for forages and 9% NDF and 60% eNDF for dry-rolled corn in the NRC (1996) model.
[d]Paired T test comparison (SAS, 1989) of actual ruminal pH versus NRC model prediction using only eNDF for forages in the model.
[e]Paired T test comparison (SAS, 1989) of actual ruminal pH versus NRC model prediction using eNDF for forages and dry-rolled corn in the model.

NDF remaining on screens 1.18 mm) for the different particle size alfalfa hays used in Trial 2 were .77- and 3.43-mm, and 50 and 62% eNDF, for alfalfa ground to pass through a .95- or 7.6-cm screen, respectively.

Discussion

Finishing Trials

The addition of either alfalfa hay or wheat straw increased DMI, which is consistent with other research (Gill et al., 1981; Brandt et al., 1987; Stock et al., 1990; Willms et al., 1991). In contrast, Freeman et al. (1991) found that with finishing diets based on high-moisture corn or steam-flaked corn, DMI increased when either 6 or 10% wheat straw was added to the diet compared with 6 or 10% alfalfa hay. However, increased intake due to forage addition in high-concentrate diets may be related to rate of ruminal starch digestion (Stock et al., 1990). Therefore, comparisons of diets using different grain sources may differ in their intake response to added forage.

The increased daily gain in steers fed diets containing alfalfa hay agrees with Stock et al. (1990) and Huffman et al. (1992) who both reported that forage addition improved daily gain. However, the addition of wheat straw did not improve gain compared with all-concentrate fed steers. The addition of forage to high-concentrate diets has been shown to reduce feed efficiency (Stock et al., 1987). However, feed efficiency in Trial 1 was not different among steers fed all-concentrate diets compared with diets containing alfalfa or straw. Goetsch et al. (1984) indicated that forage addition to diets containing slowly fermented grains, such as dry-rolled corn, may be detrimental to cattle performance by increasing passage rate and(or) diluting the energy density of the diet. However, Stock et al. (1990) postulated that forage addition to diets containing a rapidly digested grain source may help reduce acidosis by diluting concentrate intake and stimulating salivation. Even though the ruminal digestion of dry-rolled corn is not considered to be rapid, steers fed the all-concentrate dry-rolled corn diets were possibly experiencing acidosis to some degree. Acidosis and a reduction in passage rate may explain the reduced daily gains, starch intake, and concentrate efficiency noted in steers fed all-concentrate diets compared with steers fed diets containing alfalfa.

Table 10. NRC model input variables used to predict ruminal pH in Trial 3[a]

	Input variables, %				Screen size, eNDF			
Feed	CP	NDF	DIP	eNDF	.95	2.5	7.6	12.7
Alfalfa hay	22.1	48.5	72	—	—	50.1	—	61.2
Wheat straw	3.65	86.6	28	—	—	70.2	—	91.4
Corncobs	3.2	90.0	22	—	68.3	—	—	—
Dry rolled corn	8.8	9.0	40	60	—	—	—	—

[a]Values for CP, NDF, and eNDF for different screen sizes are calculated. Other values were obtained from NRC (1996).

Table 11. Effects of dietary forage source and particle size on chewing activity in Trial 3

Item	AC[a]	Alfalfa hay screen size, cm 2.54	Alfalfa hay screen size, cm 12.7	Wheat straw screen size, cm 2.54	Wheat straw screen size, cm 12.7	CC[a]	SEM
	min/24 h						
No. Observations	6	6	6	6	6	6	
Eating	88[b]	120[c]	105[d]	139[e]	118[cd]	105[d]	6
Ruminating	89[b]	196[cd]	184[ce]	229[df]	240[f]	153[e]	17
Total chewing	177[b]	316[c]	289[cd]	368[e]	358[e]	258[d]	20
No chewing	1,263[b]	1,124[cd]	1,150[d]	1,072[e]	1,082[ce]	1,183[d]	20
	events/24 h						
Eating	8.0	7.9	8.4	8.2	9.2	8.4	.5
Ruminating	7.0[b]	11.6[c]	11.0[c]	12.3[c]	12.1[c]	8.8[b]	1.0
	min/event						
Eating	11.0[b]	16.3[c]	12.8[bd]	17.8[c]	13.5[d]	12.9[bd]	1.0
Ruminating	12.8[b]	17.0[c]	17.3[c]	19.3[cd]	20.4[e]	17.2[c]	1.1

[a]AC = All-concentrate diet; CC=corncob diet, corncobs ground to pass a .95 cm screen.
[b,c,d,e,f]Means within a row lacking a common superscript differ ($P < .10$).

An explanation for the lower daily gains and reduced efficiencies for steers fed straw diets compared with steers fed alfalfa diets is not clear. Freeman et al. (1991) found that 10% wheat straw depressed feed conversion when compared to 10% alfalfa hay in high-moisture corn or steam-flaked corn diets. However, comparing forages fed at equal percentages of the diet may be misleading because a wide range in fiber (NDF) content of different forages exists. Concentrate and starch intakes for steers fed diets containing straw were greater than diets containing alfalfa; therefore, energy intake was not a limiting factor.

Forage particle size plays a major role in determining ruminal retention time (Welch, 1982). In these trials, we hypothesized that reducing forage particle size may increase passage rate from the rumen, reduce the dilution effect obtained by feeding forages, and reduce the effectiveness of the fiber in maintaining normal rumen function, therefore providing little benefit in reducing acidosis. Conversely, if forage particle size is too large, total intake and energy consumed may decrease due to an increased ruminal retention time. Sniffen et al. (1992) indicated reducing forage particle size reduces eNDF of forage. In addition, Pitt et al. (1996) indicated that in diets containing less than 30% eNDF, as level of eNDF decreases, ruminal pH decreases. However, results from Trials 1 and 2 indicate that particle size within forage type had no influence on DMI, daily gain, or feed efficiency. This indicates that altering eNDF by altering forage particle size had no effect. When compared to the all-concentrate diet, differences obtained in animal performance due to altering forage particle size within a forage source are apparently due to different forage sources rather than particle size.

Metabolism Trial

Addition of forage to a dry-rolled corn finishing diet did not seem to alter ruminal passage rate of liquid, corn, or forage in the diet, as suggested by some research (Goetsch et al., 1984). However, the rate of corn passage in steers fed the all-concentrate diet was numerically lower when compared with diets containing forage. A large amount of variation, as indicated by the standard error of the mean, was noted in measuring corn passage rates among treatments. This variation would reduce the likelihood of detecting any significant differences.

Marshall et al. (1992) found that rate and extent of ruminal starch digestion was similar in finishing diets using different forage sources of either long stem grass hay, pelleted alfalfa, or ground corncobs. Reducing forage particle size within diets containing either alfalfa or straw did not influence the rate of corn or forage passage. However, passage rates for corn and forage in diets containing small forage particles were numerically faster, as suggested by Welch (1982). The numerically greater pH values for steers fed diets containing straw is possibly due to an increased buffering capacity from increased saliva production due to more total time spent chewing, which was observed for these treatments. Oltjen et al. (1965) found that buffering capacity was directly related to salivary flow, and Welch (1982) indicated that increasing chewing activity increases saliva flow.

The addition of either alfalfa hay, wheat straw, or corncobs increased time spent eating and ruminating compared with all-concentrate diets, and this is consistent with the findings of Bines and Davey (1970). The increased total chewing time for steers fed straw diets was unexpected, because total cell wall content from forages was formulated to be equal across forage fed diets. Welch and Smith (1970)

indicated that rumination time increases as forage quality decreases; however, rumination time per unit of cell wall content was similar. Sudweeks (1977) found that diets that increase chewing time and saliva flow have lower concentrations of VFA due to a dilution effect and increased acetate:propionate ratios. In addition, Latham et al. (1974) suggested that the buffering action of saliva increases rumen pH, thereby favoring the synthesis of acetate over propionate. Our results tend to support these conclusions. Steers fed diets containing straw spent more time chewing and had numerically lower total ruminal VFA concentrations and numerically higher acetate:propionate ratios. However, it is not clear why steers fed corncob diets spent less time chewing but had similar ruminal VFA concentrations and lower acetate:propionate ratios compared with steers fed straw diets.

In the metabolism trial, steers fed the all-concentrate diet may not have experienced acidosis to the same extent as steers fed the all-concentrate diets in Trial 1 because acidosis may be more easily controlled when feeding individual animals. Steers fed straw diets in Trial 1 consumed more starch than steers fed alfalfa diets. However, steers fed straw diets gained slower and less efficiently than steers fed alfalfa diets. Therefore, the addition of straw must have altered starch digestibility and(or) utilization. The reduced total VFA production and subsequent increase in acetate and decrease in propionate production observed in straw-fed steers in the metabolism trial indicates that starch utilization was altered. Fahey and Berger (1988) indicated that increasing the acetate:propionate ratio may result in greater amounts of energy lost as methane, thereby reducing metabolizable energy available for animal performance. In addition, the reduced bacterial N balance noted for steers fed diets containing either straw or corncobs possibly reduced microbial protein synthesis with a subsequent decrease in ruminal digestion.

The reduced daily gains and feed efficiency observed for steers fed straw diets compared with steers fed alfalfa diets in Trial 1 may be related to several factors. The lower amounts of available DIP for microbial protein synthesis, combined with slightly higher levels of eNDF, may have reduced microbial production, thereby reducing ruminal digestion. Increasing total chewing time and the subsequent increase in saliva production may have altered ruminal VFA production. A reduction in propionate synthesis would increase energy lost as methane, thereby reducing the energy level of the diet.

Within the NRC (1996) model, as level of eNDF in the diet decreases, predicted ruminal pH decreases (Pitt et al., 1996). The addition of straw or corncobs increased the total amount of dietary eNDF provided, compared with alfalfa. However, model predictions (NRC, 1996) using eNDF values for both forage and dry-rolled corn underestimated ruminal pH for straw diets and overestimated ruminal pH for diets containing large particle size alfalfa or corncobs. Apparently, wheat straw has a higher eNDF value than predicted by particle sieving, and, therefore, the eNDF of this forage may be more accurately predicted by its ability to stimulate chewing activity.

The eNDF values for the alfalfa hay ground to pass through a 2.54- or 12.7-cm screen were lower than values reported by Sniffen et al. (1992). This difference may help explain why the use of only forage eNDF in the model led to predicted pH values for alfalfa hay diets that were lower than observed pH measurements. In addition, Sniffen et al. (1992) reported a 56% eNDF value for ground corncobs, which is lower than the eNDF (68.3) obtained for corncobs in this study. Even though the NRC model (1996) seems to more accurately predict ruminal pH when the eNDF of both forage and dry-rolled corn are included in the model, correlation coefficients (r) indicate that using forage eNDF alone or in combination with dry-rolled corn eNDF give similar results (r = .637, P = .17, NRC model using only forage eNDF; r = .649, P = .16, NRC model using both forage and corn eNDF).

The relationship of total chewing time to pH was better (r = .8) than the relationship of eNDF to pH (r = .67). This suggests that the use of particle size alone is not sufficient to define eNDF. Further, it is difficult to determine whether the NDF in corn grain is "effective." The relationship of eNDF to pH described in Pitt et al. (1996) and used in NRC (1996) was developed with metabolism studies such as the one reported herein. Our relationship of eNDF to pH (r = .67) was similar to that (r = .72) reported by Pitt et al. (1996). However, cattle in our metabolism study consumed about 14% less diet than those in the feedlot, which is typical of metabolism studies. Without appropriate techniques to measure pH or microbial CP production in feedlot studies, we cannot validate the eNDF equation in NRC (1996) for use in production situations. Inclusion of eNDF for corn increases predicted pH by about .2 pH units, and this has a large impact on predicted microbial CP synthesis. This may be offset in production settings by the higher intakes.

Results from these trials indicate that using wheat straw in high-concentrate finishing diets may not elicit a similar response in animal performance compared with alfalfa hay. Calculating eNDF using particle size distributions may not be accurate for wheat straw. Therefore, eNDF values for wheat straw may be more accurately predicted by its ability to stimulate chewing activity. Increasing the level of dietary eNDF, by using a forage source containing a high level of NDF, may require additional DIP to satisfy microbial N requirements for maximal microbial protein synthesis and ruminal digestion.

Implications

A major goal in using forages in high-concentrate finishing diets is to help reduce acidosis. The addition of forage to high-concentrate finishing diets may

improve dry matter intake. However, the response in daily gain and feed efficiency when using different forage sources may not be similar. In addition, altering forage particle size may provide limited benefits in improving animal performance. Therefore, other factors, such as ease of handling and processing cost, should be considered when processing dry forages.

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