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Effects of Corn Processing and Dietary Fiber Source on Feedlot Performance, Visceral Organ Weight, Diet Digestibility, and Nitrogen Metabolism in Lambs^{1,2}

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ABSTRACT: In Exp. 1, early-weaned Targhee and Polypay crossbred lambs (60 ewes and 66 rams; initial BW 24 ± 1.0 kg) were used in a 2×3 factorial experiment to determine the effects of corn processing (whole shelled corn [WSC] or ground and pelleted corn [GC]) in combination with supplemental fiber (none [control]; soybean hulls, SBH [highly digestible]; or peanut hulls, PH [highly indigestible]) on DMI, ADG, feed efficiency, and visceral organ weight. For the total trial, WSC resulted in a 4% increase ($P < .01$) in ADG vs GC, and supplemental fiber resulted in increased ($P < .01$) DMI and ADG vs the control diet. Experiment 2 was conducted using 12 Targhee and Polypay crossbred wether lambs (initial BW 25 ± 7 kg) to determine the effects of corn processing and

fiber source in high-concentrate diets on diet digestibility and N retention using the same diets as in Exp. 1. Lambs fed WSC had greater ($P < .001$) apparent N digestion, true N digestion, and N retention ($P < .01$) than those fed GC. The apparent digestibilities of DM, OM, and NDF were greater ($P < .001$) for WSC than for GC diets. Peanut hulls resulted in decreased ($P < .01$) DM, OM, and NDF apparent digestibilities compared with the control and SBH diets. Starch digestion was not affected ($P > .10$) by diet. Whole corn resulted in improved DM, OM, NDF, and N digestibility compared with GC. Overall, both the SBH and PH diets resulted in greater DMI and ADG than the control diet, which lacked supplemental fiber.

Key Words: Maize, Fiber, Digestibility, Growth

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Introduction

In cattle, reducing the particle size of dry corn increases the proportion of starch digestion that occurs in the rumen (Hale, 1973; Galyean et al., 1979). Therefore, Galyean et al. (1979) concluded that alteration of corn kernels beyond that provided by mastication was necessary to maximize starch digestion in cattle. However, sheep masticate their feed more completely than cattle. As a result, sheep do not benefit as much as cattle from grain processing (Hale, 1973). Predigestive behaviors such as sorting, time spent chewing, DMI, saliva flow, and duration of

mastication are contributing factors in the overall digestion of feed grains by sheep. There are no reports of lamb feedlot experiments in the literature that have examined the effects of corn processing in high-concentrate diets as influenced by highly digestible vs relatively indigestible fiber sources.

The objectives of these experiments were to determine the effects of feeding high-concentrate diets containing either whole or ground and pelleted corn with either no supplemental dietary fiber, a highly digestible fiber source (soybean hulls), or a relatively indigestible dietary fiber source (peanut hulls) on lamb performance, visceral organ weight, carcass characteristics, nutrient digestibility, and N metabolism.

Experimental Procedures

Experiment 1. Early-weaned Targhee and Polypay lambs (60 ewes and 66 rams; initial BW $24 \text{ kg} \pm 1 \text{ kg}$) were used in a 2×3 factorial experiment to determine the effects of corn processing (whole shelled corn

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[WSC] vs ground and pelleted corn [GC]) and dietary fiber source (none [control], soybean hulls [SBH], or peanut hulls [PH]) on animal performance, visceral organ weight and daily accretion rate, and carcass characteristics. Because replacement breeding males for the OARDC flock were selected and removed from the group at weaning, which occurred immediately prior to the initiation of this experiment, ram lambs were used in the experiment. Castration at that time was deemed unnecessary, because it would have resulted in an added stress without any benefit because the ram lambs were slaughtered at 4 to 4.5 mo of age, prior to reaching sexual maturity. Therefore, no negative carcass characteristics were expected. The experiment began in March and ended in July 1995. Diets were formulated to meet the dietary nutrient requirements during two feeding periods (NRC, 1985). Period 1 diets were fed until the lambs in a treatment group achieved an average weight of 36 kg. At that time, the treatment group was switched to the Period 2 diet, which was fed until the lambs reached their respective terminal weight ranges (45.5 to 50 kg for ewes and 47.5 to 52 kg for rams). Diets were formulated to provide equal daily intakes of

vitamins, minerals, urea, ammonium chloride, and lasalocid (Hoffman-La Roche, Paramus, NJ) across treatments (Tables 1 and 2). The GC diets were fed as a complete pelleted feed with the fiber source included in the pellet. In the WSC diets, supplements containing ground corn, protein, vitamins, minerals, and supplemental fiber were pelleted and fed with WSC. Unfortunately, the corn used in the experiment was not sampled and analyzed at the time the diets were pelleted. In the WSC diets, the corn was mixed with the pelleted supplement and bagged immediately after the pellets were manufactured. The composite feed was sampled every 14 d, dried in a forced-air oven at 55°C, ground with a Wiley Mill to pass a 1-mm screen, and analyzed for DM (AOAC, 1984), NDF according to Procedure A (Van Soest et al., 1991), and N using the macro-Kjeldahl technique (AOAC, 1984).

Initial and final weights were determined using the average of weights taken on two consecutive days, and 14-d intermediate weights were taken prior to feeding at 0800. Average daily gain, DMI, feed efficiency (gain/feed), and days required to reach the terminal weight were determined for all lambs. Lambs were

Table 1. Composition of diets fed during Period 1 (up to 36 kg)

Item	Whole corn, no fiber	Pelleted corn, no fiber	Whole corn, peanut hulls	Pelleted corn, peanut hulls	Whole corn, soybean hulls	Pelleted corn, soybean hulls
	% , DM basis					
Whole corn	70.00	—	60.00	—	70.00	—
Ground corn	15.64	85.64	15.21	75.21	6.01	76.01
Peanut hulls	—	—	10.00	10.00	—	—
Soybean hulls	—	—	—	—	10.00	10.00
Soybean meal	5.70	5.70	5.84	5.84	5.44	5.44
Blood meal	2.85	2.85	2.92	2.92	2.72	2.72
Corn gluten meal	2.85	2.85	2.92	2.92	2.72	2.72
Urea	.40	.40	.40	.40	.40	.40
Limestone	1.30	1.30	1.30	1.30	1.30	1.30
Dicalcium phosphate	.25	.25	.25	.25	.25	.25
Monosodium phosphate	—	—	.15	.15	.15	.15
Trace mineral salt ^a	.45	.45	.45	.45	.45	.45
Vitamin A, 30,000 IU/g	.01	.01	.01	.01	.01	.01
Vitamin D, 3,000 IU/g	.01	.01	.01	.01	.01	.01
Vitamin E, 44 IU/g	.03	.03	.03	.03	.03	.03
Selenium, 201 ppm	.09	.09	.09	.09	.09	.09
Ammonium chloride	.40	.40	.40	.40	.40	.40
Lasalocid, 150 g/kg	.019	.019	.019	.019	.019	.019
Calculated composition						
Crude protein, %	17.03	17.03	17.02	17.02	17.01	17.01
Calcium, %	.55	.55	.57	.57	.59	.59
Phosphorus, %	.41	.41	.42	.42	.43	.43
NE _m , Mcal/kg	2.08	2.08	1.86	1.86	1.98	1.98
NE _g , Mcal/kg	1.43	1.43	1.28	1.28	1.34	1.34
Analyzed composition						
Crude protein, %	15.67	15.38	16.79	15.14	18.13	16.87
NDF, %	16.45	13.36	22.22	19.73	18.88	16.98
Starch, %	60.27	58.21	56.08	51.93	54.60	56.94

^aContained > 93% NaCl, .35% Zn, .28% Mn, .175% Fe, .035% Cu, .007% I, and .007% Co.

removed from the trial on an individual basis as they reached the predetermined final weight range.

Three Polypay and three Targhee ram lambs were slaughtered at the onset of the trial (baseline control animals) to estimate initial visceral organ weight. The remaining 120 lambs were allotted randomly by weight (within sex and breed) to the six dietary treatments. There were five lambs per replicate pen and four replicate pens for each of the six treatments. Therefore, each dietary treatment had one pen of each of the following breed \times sex combinations: Polypay rams, Targhee rams, Polypay ewes, and Targhee ewes. The pens (1.5 \times 4.9 m) were constructed using expanded metal floors, with metal gates on three sides and a wooden fence line feed bunk (1.5 m long) on the fourth side. Therefore, each lamb had access to at least .3 m of feed bunk space. Each pen had an automatic water cup, so water was available at all times.

Ewe lambs were not slaughtered when they reached the terminal weight range. Therefore, they were not accounted for in the carcass and visceral organ measurements. All 60 ram lambs were slaughtered when they reached the predefined terminal weight

range to determine final visceral organ weight and accretion rates and final carcass measurements. Lambs were selected for slaughter in such a manner as to achieve equal carcass weights across treatments. Lambs were slaughtered at a commercial abattoir. The visceral organs were removed from each lamb, flushed with water, allowed to drip-dry, and weighed. The heart, kidney, liver, rumen-reticulum, omasum, abomasum, small intestine, cecum, and colon were weighed. Visceral organ accretion rates were determined (within breed) by calculating the percentage of live weight that each individual organ and visceral fat represented in the initial baseline control animals. The initial weight of the organs and visceral fat was then calculated for each of the 60 lambs that were in the performance portion of the experiment by multiplying the respective organ's percentage of live weight by the lamb's initial weight. The estimated initial organ weight for each lamb was subtracted from the actual organ weight at slaughter to determine the estimated total accretion in weight. Daily organ accretion rate was then calculated by dividing the estimated total organ accretion weight by the number of days that the lamb was on the experiment.

Table 2. Composition of diets fed during Period 2 (36 kg to final weight)

Item	Whole corn, no fiber	Pelleted corn, no fiber	Whole corn, peanut hulls	Pelleted corn, peanut hulls	Whole corn, soybean hulls	Pelleted corn, soybean hulls
	% , DM basis					
Whole corn	70.00	—	60.00	—	70.00	—
Ground corn	19.04	89.04	18.61	78.61	9.37	79.37
Peanut hulls	—	—	10.00	10.00	—	—
Soybean hulls	—	—	—	—	10.00	10.00
Soybean meal	4.00	4.00	4.14	4.14	3.76	3.76
Blood meal	2.00	2.00	2.07	2.07	1.88	1.88
Corn gluten meal	2.00	2.00	2.07	2.07	1.88	1.88
Urea	.40	.40	.40	.40	.40	.40
Limestone	1.30	1.30	1.30	1.30	1.30	1.30
Dicalcium phosphate	.25	.25	.25	.25	.25	.25
Monosodium phosphate	—	—	.15	.15	.15	.15
Trace mineral salt ^a	.45	.45	.45	.45	.45	.45
Vitamin A, 30,000 IU/g	.01	.01	.01	.01	.01	.01
Vitamin D, 3,000 IU/g	.01	.01	.01	.01	.01	.01
Vitamin E, 44 IU/g	.03	.03	.03	.03	.03	.03
Selenium, 201 ppm	.09	.09	.09	.09	.09	.09
Ammonium chloride	.40	.40	.40	.40	.40	.40
Lasalacid, 150 g/kg	.019	.019	.019	.019	.019	.019
Calculated composition						
Crude protein, %	15.16	15.16	15.15	15.15	15.16	15.16
Calcium, %	.54	.54	.56	.56	.58	.58
Phosphorus, %	.40	.40	.41	.41	.42	.42
NE _m , Mcal/kg	2.08	2.08	1.87	1.87	1.98	1.98
NE _g , Mcal/kg	1.43	1.43	1.28	1.28	1.34	1.34
Analyzed composition						
Crude protein, %	14.91	14.95	14.62	14.76	15.95	15.41
NDF, %	17.56	16.12	24.54	21.25	24.14	21.04
Starch, %	56.76	63.20	48.38	59.53	49.88	54.68

^aContained > 93% NaCl, .35% Zn, .28% Mn, .175% Fe, .035% Cu, .007% I, and .007% Co.

Chilled carcasses were weighed 48 h after slaughter. In addition, the backfat, internal fat, and loin eye area were measured.

Statistical analysis was performed using the GLM procedure of SAS (1988) for a 2×3 factorial experiment blocked by breed and sex. Performance data within each period and for the total trial were analyzed using a model that included effects due to block, corn processing, dietary fiber source, and the corn processing \times dietary fiber source interaction. Pen was used as the experimental unit for lamb performance data. For visceral organ and carcass data, the model contained effects due to breed, corn processing, dietary fiber source, and the corn processing \times dietary fiber source interaction. Individual lamb served as the experimental unit for carcass and visceral organ data. Treatment means were compared with Fisher's protected LSD using the PDIFF statement of SAS (1988) when protected by a significant ($P < .07$) F-value.

Experiment 2. A 2×3 factorial experiment was conducted to determine the effects of feeding high-concentrate diets composed primarily of corn (WSC vs GC) in combination with supplemental fiber (none, SBH, or PH) on diet digestibility and N retention. Twelve white-faced (Targhee and Polypay) crossbred wether lambs (initial BW $24 \text{ kg} \pm 1 \text{ kg}$) of moderate growth potential were used in a total collection (urine and feces) metabolism trial. Composition of diets is shown in Table 1; however, because Exp. 2 was not conducted concurrently with Exp. 1, the corn had a different origin and the analyzed CP composition of the diets differed. The actual analyzed CP composition of the diets used in Exp. 2 were as follows: WSC-no supplemental fiber, 17.87% CP; GC-no supplemental fiber, 18.03% CP; WSC-PH, 16.73% CP; GC-PH, 16.15% CP; WSC-SBH, 17.01% CP; and GC-SBH, 15.06% CP. Diets were formulated to provide equal daily intakes of N, vitamins, minerals, urea, ammonium chloride, and lasalocid (Hoffman-La Roche) across treatments and were formulated to meet nutrient requirements (NRC, 1985). Diets were fed once daily at 0800, and lambs were allowed ad libitum access to feed and fresh water.

The trial consisted of two 14-d periods during which lambs were placed in metabolism crates (1.6 m \times .53 m) designed to allow for separation and collection of feces and urine. Lambs were allowed 7 d to adapt to the crates before initiation of the experiment and were housed in the crates throughout the experiment. The assignment of lambs to Period 2 was random, with the restriction that no lamb received the same diet in both periods.

Each 14-d experimental period consisted of 9 d of adaptation and 5 d for total collection of feces and urine. Feed and orts were sampled and collected daily from d 10 to 14 of the experimental period. Total feces were collected and weighed, and a 10% aliquot was retained and composited for each lamb within each

period. Feces were stored frozen during the collection period. Urine was collected into containers with sufficient 6 N HCl added to maintain a pH below 3.0. A 5% aliquot of urine was retained daily and composited for each lamb within each period.

Feed and fecal samples were dried in a forced-air oven at 55°C , ground with a Wiley Mill to pass a 1-mm screen, and analyzed for DM, OM, N (AOAC, 1984), NDF according to Procedure A (Van Soest et al., 1991), and starch by the use of enzymatic hydrolysis and glucose oxidase (Fleming and Reichert, 1980). Urine was analyzed for N using the macro-Kjeldahl technique (AOAC, 1984). Digestibilities and N retention were calculated by difference.

Statistical analysis was performed using the GLM procedure of SAS (1988) for a 2×3 factorial experiment blocked by initial weight of the lambs into light and heavy groups. The model contained effects due to block, period, corn processing, fiber source, and the corn processing \times fiber source interaction. Animal served as the experimental unit. Treatment means were compared using the PDIFF statement of SAS (1988) when protected by a significant ($P < .05$) F-value.

For all trials, research protocols concerning animal care followed guidelines recommended in the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (Consortium, 1988).

Results and Discussion

Experiment 1. Dry matter intake was greater for the lambs fed diets containing supplemental fiber (soybean hulls or peanut hulls) than for those fed the control (none) diet during Periods 1 ($P < .01$) and 2 ($P < .001$) (Table 3). In addition, the overall DMI was greater ($P < .001$) for lambs fed fiber-supplemented diets than for lambs fed the control diet, which lacked supplemental fiber. Average daily gain was greater ($P < .05$) during Periods 1 and 2 when PH were fed compared with the control diet.

There was a corn type \times fiber source interaction ($P < .05$) for overall ADG. When GC was fed, there were no differences ($P > .26$) in ADG when the control, SBH, or PH fiber sources were fed (307, 312, and 318 g/d, respectively). However, when WSC was fed, the control diet produced a lower ($P < .01$) ADG than did the diets containing SBH or PH (296, 331, and 347 g/d, respectively). Overall, SBH and PH resulted in a greater ($P < .01$) ADG than diets containing no supplemental fiber. Furthermore, diets containing PH resulted in fewer ($P < .05$) days on feed for lambs to reach market weight than did the control diet. For the entire trial, WSC resulted in a greater ($P < .01$) ADG than did GC. The increase in ADG with WSC compared with GC may be due to differences in

ruminal energy output due to corn type. Sharp et al. (1982) reported that the ruminal output of energy as VFA equaled 60% of consumed energy with WSC and only 43% of consumed energy with GC.

For the entire trial, there was a corn type \times fiber source interaction for feed efficiency. When GC was fed, there were no differences ($P > .16$) in feed efficiency when the control, SBH, or PH fiber sources were fed (.28, .27, and .27, respectively). However, when WSC was fed, the control diet lacking supplemental fiber had a lower ($P < .01$) feed efficiency than the PH diet (.26 vs .29), and the SBH diet, with a feed efficiency of .28, approached being different ($P < .07$) from the control diet.

There is very little information concerning dietary fiber source in high-concentrate diets that have been fed to lambs. Galyean et al. (1979) reported that cattle required comminution of corn kernels beyond that provided by mastication to maximize starch digestion in cattle. However, sheep masticate their feed more completely than cattle. As a result, sheep do not benefit from grain processing to the same extent as cattle (Hale, 1973).

High-concentrate diets that either lack supplemental fiber or have highly processed fiber have been associated with metabolic disorders such as acidosis and liver abscesses in cattle (Gill et al., 1979; Burrin et al., 1988). Furthermore, feeding all-concentrate diets has been shown to result in greater ruminal papillae clumping and greater foreign matter accumulation than does feeding diets containing added fiber,

with the exception that whole shelled corn was reported to have a roughage effect on ruminal papillae compared with crimped corn (Vance et al., 1972).

Table 4 presents performance and carcass data of the finished ram lambs. There were no interactions of corn type \times fiber source on carcass characteristics. Ground corn resulted in a greater ($P < .05$) 12th rib fat depth than did whole shelled corn. Quality grade; leg conformation; percentage kidney, pelvic, and heart fat (**KPH**); and dressing percentage did not differ ($P > .10$) with diet. Rams fed the WSC diets had carcasses with lower ($P < .05$) yield grade than rams fed the GC diets. Fiber source did not affect ($P > .10$) carcass characteristics.

The rumen-reticulum was heavier ($P < .01$) in lambs fed GC than it was in lambs fed WSC (Table 5). However, there is no obvious reason for this difference. Corn type effects on visceral organ accretion rates followed the same trend as visceral weight (Table 6). Daily accretion rate of the rumen-reticulum was greater ($P < .05$) when GC was fed than when WSC was fed (Table 6). Fiber source had no effect ($P > .10$) on visceral organ weights or daily accretion rates of organ weight.

Experiment 2. The apparent digestibilities of DM, OM, and NDF were greater ($P < .001$) for WSC than for GC (Table 7). Conversely, Hart and Glimp (1991) found no differences in DM, starch, or CP digestibilities of either a 90% concentrate, pelleted diet or a 100% concentrate, whole shelled corn diet when they were fed to lambs at restricted intakes (92.5 or 85% of

Table 3. Main effects of corn type and fiber source on lamb performance

Item	Corn type		SEM	Fiber source			SEM
	GC ^a	WSC ^a		None	SBH ^b	PH ^b	
Period 1							
DMI, g/d	965	974	6	943 ^c	980 ^d	984 ^d	8
ADG, g/d	294	300	6	285 ^e	297 ^{ef}	310 ^f	7
Gain/feed, g/g	.31	.31	.01	.30	.30	.31	.01
Days on feed	42.6	40.8	1.1	43.7	42.0	39.4	1.4
Period 2							
DMI, g/d	1,334	1,361	17	1,261 ^g	1,397 ^h	1,388 ^h	20
ADG, g/d	337	359	8	327 ^e	356 ^{ef}	360 ^f	9
Gain/feed, g/g	.25	.25	.01	.25	.25	.26	.01
Days on feed	34.8	34.2	1.5	35.3	33.8	34.4	1.9
Overall							
Initial wt, kg	24.2	24.2	.1	24.1	24.3	24.2	.1
DMI, g/d	1,134	1,152	7	1,089 ^g	1,170 ^h	1,175 ^h	9
ADG, g/d	313 ^c	325 ^d	4	302 ^c	322 ^d	332 ^d	5
Gain/feed, g/g	.27	.28	.004	.27	.27	.28	.005
Days on feed	77.4	75.1	1.2	79.0 ^e	75.8 ^f	73.8 ^f	1.4
Final wt, kg	48.7	48.8	.1	48.5	48.8	48.9	.2

^aGC = ground and pelleted corn; WSC = whole shelled corn.

^bSBH = soybean hulls; PH = peanut hulls.

^{c,d}Means within a row and main effect with different superscripts differ ($P < .01$).

^{e,h}Means within a row and main effect with different superscript differ ($P < .05$).

^{g,h}Means within a row and main effect with different superscripts differ ($P < .001$).

Table 4. Main effects of corn type and fiber source on ram lamb performance and carcass characteristics

Item	Corn type			Fiber source			SEM
	GC ^a	WSC ^a	SEM	None	SBH ^b	PH ^b	
Initial wt, kg	24.6	24.7	.6	24.9	24.4	24.7	.7
Intermediate wt, kg	37.2	37.1	.8	38.0	36.6	36.9	1.0
End wt, kg	51.6	51.7	.3	51.4	51.8	51.7	.3
Period 1, d	38.3	38.4	.6	40.0	38.5	36.6	.7
Period 2, d	38.9	37.3	2.3	37.5	39.7	37.1	2.9
On test, d	77.2	75.6	2.2	77.5	78.2	73.7	2.8
Period 1 ADG, g/d	327	322	9	331	313	331	14
Period 2 ADG, g/d	381	404	9	367	399	408	14
Overall ADG, g/d	354	363	9	349	354	372	9
Hot carcass wt, kg	26.0	26.3	.3	26.2	26.3	26.0	.3
Chilled carcass wt, kg	25.2	25.5	.2	25.5	25.5	25.1	.3
Fat depth, mm ^c	7.1	5.8	.5	6.4	7.1	6.1	.8
KPH, % ^d	3.8	3.6	.1	3.6	3.8	3.6	.1
Leg conformation ^e	11.3	10.8	.2	10.9	11.1	11.2	.3
Quality grade ^e	11.2	11.1	.2	11.0	11.5	11.0	.2
Dressing, %	50.3	50.8	.4	50.9	50.6	50.2	.5
Yield grade ^{cf}	3.9	3.5	.1	3.7	3.9	3.6	.2
REA, cm ²	14.2	15.2	.4	14.5	14.7	15.0	.5

^aGC = ground and pelleted corn; WSC = whole shelled corn.

^bSBH = soybean hulls; PH = peanut hulls.

^cCorn type effect ($P < .05$).

^dKidney, pelvic, and heart fat.

^e9 = Good+, 10 = Choice-, 11 = Choice, 12 = Choice+.

^fYield grade = $1.66 - (.05 \times \text{leg conformation grade code}) + (.25 \times \text{percentage kidney and pelvic fat}) + (6.66 \times \text{adjusted fat thickness, inches})$.

ad libitum intake). Murphy et al. (1994) fed steers an all-concentrate diet using two dry corn processing methods (whole vs rolled) at either ad libitum or 70% of ad libitum intake. The ad libitum and 70% of ad libitum intake levels provided steers with 2.0 and 1.3 times their daily maintenance energy requirements, respectively. The whole corn diet resulted in higher DM and OM digestibilities than the rolled corn diet when steers were offered feed for ad libitum consumption. However, when intake was at the 70% of ad libitum level, rolled corn resulted in improved DM,

OM, N, and starch digestibilities compared with whole corn. Therefore, intake level may greatly influence the results of digestibility studies with high-concentrate diets and explain some of the differences in findings between the present study and those of Hart and Glimp (1991).

Diets containing PH decreased ($P < .01$) DM, OM, and NDF digestibilities compared with the control and SBH diets (Table 7). Dry matter intake and starch digestibility were not different ($P > .10$) among the dietary treatments.

Table 5. Main effects of corn type and fiber source on organ and viscera weights of ram lambs

Item	Corn type			Fiber source			SEM
	GC ^a	WSC ^a	SEM	None	SBH ^b	PH ^b	
Heart, g	197	207	5	201	204	202	6
Liver, g	1,096	1,143	21	1,086	1,141	1,133	26
Kidney, g	145	146	3	139	149	148	4
Rumen-reticulum, g ^c	1,313	1,202	28	1,259	1,242	1,270	35
Omasum, g	97	96	3	99	97	93	4
Abomasum, g	194	214	8	204	207	202	10
Small intestine, g	928	924	20	889	956	933	25
Cecum, g	66	63	2	63	66	67	3
Large intestine, g	472	443	15	445	465	463	19
Visceral fat, g	1,408	1,445	54	1,454	1,434	1,391	68

^aGC = ground and pelleted corn; WSC = whole shelled corn.

^bSBH = soybean hulls; PH = peanut hulls.

^cCorn type effect ($P < .01$).

Table 6. Main effects of corn type and fiber source on organ and viscera accretion of ram lambs

Item	Corn type		SEM	Fiber source			SEM
	GC ^a	WSC ^a		None	SBH ^b	PH ^b	
	Accretion, g/d						
Liver	5.77	6.47	.33	5.51	6.27	6.58	.41
Kidney	.40	.43	.06	.31	.46	.47	.07
Rumen-reticulum ^c	8.70	7.33	.41	8.03	7.72	8.29	.52
Omasum	.53	.54	.04	.55	.55	.52	.05
Abomasum	.90	1.20	.11	1.01	1.08	1.06	.14
Small intestine	-.80	-.89	.39	-1.46	-.35	-.74	.49
Cecum	.18	.13	.03	.11	.17	.17	.04
Large intestine	1.96	1.60	.20	1.55	1.90	1.89	.25
Mesenteric fat	12.63	13.50	.77	13.37	12.81	13.01	.96

^aGC = ground and pelleted corn; WSC = whole shelled corn.

^bSBH = soybean hulls; PH = peanut hulls.

^cCorn type effect ($P < .05$).

Nitrogen intake was greater for lambs consuming WSC ($P < .05$) than for those fed GC (Table 8). Additionally, there was a corn type \times fiber source interaction ($P < .01$) for N intake. When GC was fed, the control fiber source diet produced a greater ($P < .01$) N intake than did the diets containing SBH or PH (27.4, 21.6, and 23.8 g/d, respectively). However, when WSC was fed there were no differences ($P > .15$) in N intake due to fiber source (25.9, 26.4, and 24.8 g/d for the control, SBH, and PH diets, respectively). Fecal N was greater ($P < .001$) as a result of GC diets compared with WSC diets. Urinary N, conversely, was greater ($P < .05$) as a result of WSC compared with GC diets. Lambs consuming the WSC diets had greater apparent N digestion, true N digestion ($P < .001$), N retention ($P < .01$), N retention as a percentage of N intake ($P < .01$), and N retention as a percentage of N digested ($P < .05$) than did lambs consuming GC diets. Additionally, the control (no supplemental fiber) diet resulted in a greater ($P < .01$) N intake than did SBH and PH. There were no other differences ($P > .10$) in N metabolism due to dietary fiber. Anderson et al. (1988) suggested that due to the smaller particle size of a ground feedstuff it

would have a greater surface area and potentially increased digestibility than would an unprocessed feed. However, the results of the present study and those of Murphy et al. (1994) indicate that other factors are also involved. Whole corn is known to have a "roughage factor" effect on ruminal papillae, which can lead to greater surface area for absorption of VFA compared with processed corn due to less papillae clumping and hair accumulation (Vance et al., 1972). The effect is the result of physical stimulation of the papillae, similar to what is observed when animals are fed forage diets. This roughage factor could be responsible for the results of Hart and Glimp (1991), who reported greater DM and starch digestibilities with lambs consuming a WSC diet than with those consuming a pelleted, high-concentrate diet. Ruminal pH was higher and fluctuated less for lambs fed the WSC diet; the authors suggested that WSC results in a more stable fermentation that should reduce the risk of acidosis compared with a pelleted, high-concentrate diet.

Selective consumption of feed particles may be characteristic of the dietary patterns of certain spe-

Table 7. Main effects of corn type and fiber source on apparent diet digestibility

Item	Corn type		SEM	Fiber source			SEM
	GC ^a	WSC ^a		None	SBH ^b	PH ^b	
DMI, g/d	921	934	16	927	933	924	20
Apparent digestibility, %							
Dry matter	74.8 ^c	85.1 ^d	.8	82.7 ^e	80.4 ^e	76.8 ^f	1.0
Organic matter	76.1 ^c	86.1 ^d	.8	83.8 ^e	81.7 ^e	77.9 ^f	1.0
NDF	15.6 ^c	66.5 ^d	2.8	45.9 ^e	46.8 ^e	30.4 ^f	3.4
Starch	96.2	97.4	.9	97.9	95.9	96.5	1.1

^aGC = ground and pelleted corn; WSC = whole shelled corn.

^bSBH = soybean hulls; PH = peanut hulls.

^{c,d}Means within a row and main effect with different superscripts differ ($P < .001$).

^{e,f}Means within a row and main effect with different superscripts differ ($P < .01$).

Table 8. Main effects of corn type and fiber source on nitrogen metabolism by lambs fed diets varying in corn type and fiber source

Item	Corn type		SEM	Fiber source			SEM
	GC ^a	WSC ^a		None	SBH ^b	PH ^b	
N intake, g/d	24.3 ^c	25.7 ^d	.4	26.7 ^e	24.0 ^f	24.3 ^f	.5
Fecal N, g/d	8.2 ^g	5.0 ^h	.4	6.4	6.9	6.5	.4
Apparent N digestion, %	65.1 ^g	80.6 ^h	1.6	75.9	70.1	72.5	1.9
True N digestion, %	86.2 ^g	100.6 ^h	1.6	95.0	91.6	93.5	1.9
Urinary N, g/d	11.1 ^c	12.6 ^d	.5	12.8	11.4	11.3	.6
N retention, g/d	4.9 ^e	8.2 ^f	.6	7.5	5.7	6.4	.7
% of N intake	20.3 ^e	32.1 ^f	2.1	28.6	23.5	26.6	2.6
% of N digested	31.0 ^c	40.0 ^d	2.5	37.7	32.6	36.2	3.1

^aGC = ground and pelleted corn; WSC = whole shelled corn.

^bSBH = soybean hulls; PH = peanut hulls.

^{c,d}Means within a row and main effect with different superscripts differ ($P < .05$).

^{e,f}Means within a row and main effect with different superscripts differ ($P < .01$).

^{g,h}Means within a row and main effect with different superscripts differ ($P < .001$).

cies. For example, Hale (1973) suggested that cattle and sheep digest and utilize grains differently, and that sheep are better able to digest unprocessed grains. The larger particle size of the WSC diet than of the GC diet requires that sheep spend more time chewing in order to break down the feed to a suitable size for swallowing. It is quite possible that an increase in saliva production in lambs results from an increased time spent chewing the feed particles. Church (1988) noted that saliva production was lower with processed diets (pelleted form) due to the rapid rate of feed consumption and, possibly, the physical form of the feed. The saliva produced serves to buffer ruminal pH conditions during digestion. Beauchemin (1991) reported a rapid decrease in ruminal fluid pH postprandially in cattle fed processed grains. However, Beauchemin et al. (1994) reported that cattle fed whole corn had sufficient salivary buffering capacity to control the effects of acid production from fermentation, even though the corn underwent substantial particle size reduction during mastication. Likewise, Hart and Glimp (1991) observed more stable ruminal pH values and VFA concentrations with lambs fed WSC compared with lambs fed a ground and pelleted corn diet. The findings of Hart and Glimp (1991) can be partially explained by those of Sharp et al. (1982) that ruminal liquid dilution rate and outflow rate were greater when steers were fed WSC rather than GC, reflecting greater salivary production with WSC. Therefore, a more stable ruminal environment could have been responsible for the enhanced bacterial fermentation in the rumen of the lambs consuming WSC compared with lambs consuming GC in the present study, and could have resulted in the greater DM, OM, NDF, and N digestibilities when WSC was fed. Thus, if WSC diets are fed to feedlot lambs, financial and energy costs associated with mechanical processing methods can be avoided (Cole et al., 1976; Beauchemin et al., 1994).

Implications

High-concentrate diets containing whole shelled corn can improve nutrient utilization, N retention, and lamb performance compared with diets containing primarily ground, pelleted corn. Additionally, adding some supplemental fiber such as soybean hulls or peanut hulls can improve intake and daily gain compared with high-concentrate diets lacking supplemental fiber, even if the supplemental fiber is ground and pelleted. Processing corn may not optimize performance when high-concentrate diets are fed to lambs.

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