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Digestibility, Nitrogen Utilization, and Voluntary Intake of Ensiled Crab Waste-Wheat Straw Mixtures Fed to Sheep[1]

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ABSTRACT: Crab waste and wheat (*Triticum aestivum* L.) straw mixtures, ensiled with different additives, were evaluated in metabolism and palatability trials. Crab waste and straw were mixed in proportions of 1:1, wet basis, with 20% water and different additives, and ensiled in 210-L metal drums double-lined with polyethylene bags. Thirty crossbred wethers (40 kg initial BW) were fed a 1) basal diet consisting of 75% orchardgrass (*Dactylis glomerata* L.) hay and 25% concentrate, 2) ensiled crab waste-wheat straw, with 16% (vol/wt) added glacial acetic acid, 3) crab waste-wheat straw ensiled with 20% dry molasses, 4) crab waste-wheat straw ensiled with 20% dry molasses and a microbial inoculant, and 5) ensiled wheat straw supplemented with urea. Apparent digestibility of DM and CP was lower ($P < .05$) for acetic acid-treated silages than for silages containing molasses. Nitrogen retention was higher ($P < .05$) for molasses-inoculant-treated silage than for the molasses-treated silage (5.4 vs 3.9 g/d). Ruminal NH_3 N and blood urea N were higher ($P < .05$) for lambs fed the molasses-treated silages than for those receiving the acetic acid-treated crab waste mixture. Among the wethers fed crab waste silages, intake was lower ($P < .01$) for wethers receiving the acetic acid-treated silage than for those fed the molasses-treated mixtures. Treatment of crab waste-straw mixtures with molasses produced a palatable silage that was efficiently utilized by wethers.

Key Words: Crab Waste, Molasses, Acetic Acid, Digestibility, Palatability

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Introduction

The total catch of crabs in the United States is approximately 149,000 t (NMFS, 1975). Waste from crab processing amounts to 85% by weight of the amount processed (Brinsfield, 1980). The small size of most of the crab processing plants is a deterrent to processing the waste into crab meal. Furthermore, substantial fossil fuel is required to produce crab meal. The high moisture content and perishability of the waste precludes transportation for long distances for processing. Ensiling has been shown to be effective in preservation and subsequent utilization by ruminants of various types of animal wastes (Fontenot et al., 1971). Ensiling is effective in destroying coliforms (Caswell et al., 1975), salmonella (Creger et al., 1973), and staphylococci (McCaskey and Anthony, 1975).

Crop residues represent another potential source of feed for ruminants if they are properly supplemented (Klopfenstein, 1978). Samuels et al. (1991a) reported that mixtures of crab waste preserved satisfactorily with addition of 16% glacial acetic acid, but it is questionable whether this practice would be economically feasible. However, addition of moderate amounts of dry sugarcane molasses resulted in satisfactory ensiling (Abazinge et al., 1993). This experiment was conducted to determine the nutritional value and voluntary intake of crab waste and wheat straw ensiled with different additives fed to wethers.

Materials and Methods

Metabolism and palatability trials were conducted with wethers to evaluate crab processing waste (obtained from Graham and Rollins, Hampton, VA) ensiled with ground wheat straw in 210-L metal drums double-lined with .08-mm polyethylene bags. Five silos were prepared per treatment. Detailed procedures for ensiling were given by Abazinge et al.

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(1993). Briefly, crab waste and wheat straw were ensiled in proportions of 1:1, wet basis, with the following additives: 1) 16% (vol/wt) glacial acetic acid, 2) 20% (wt/wt) dry sugarcane molasses, and 3) 20% (wt/wt) dry molasses plus silage inoculant (Pioneer® Silage Inoculant, obtained from Pioneer Hi-Bred International, Des Moines, IA). The inoculant was a blend of *Streptococcus faecium* and *Lactobacillus plantarum*. Water was added at 20% to all mixtures. Thus, the final mixtures contained 13% acetic acid or 16% dry molasses. In addition, wheat straw was ensiled alone with 40% added water. The mixtures were packed by trampling, and the bags were individually sealed after expelling air. The mixtures were ensiled for a minimum of 42 d before the trials were initiated.

Metabolism Trial. Thirty crossbred wethers, averaging 40 kg, were blocked by weight and allotted at random to the following diets: 1) basal diet, 2) crab waste-wheat straw ensiled with acetic acid, 3) crab waste-wheat straw ensiled with dry molasses, 4) crab waste-wheat straw ensiled with dry molasses and a microbial inoculant, and 5) ensiled wheat straw supplemented with urea. Urea was supplemented to the wheat straw silage to raise the CP level to approximately 10%, DM basis. The basal diet consisted of 75% orchardgrass hay, 20% ground corn grain, 4.5% soybean meal, and .5% ground limestone.

All wethers were treated for internal parasites and administered 5×10^5 IU of vitamin A and 75×10^3 IU of vitamin D by intramuscular injection before the start of the trial. The wethers were fed 700 g of DM plus 10 g of iodized salt daily in equal portions during 2-h feeding periods at 12-h intervals. Water was available at all times except during the 2-h feeding periods.

The wethers were placed in false-bottomed metabolism stalls similar to those of Briggs and Gallup (1949), which permitted separate collection of urine and feces. A 2-d adaptation period to the stalls and a 5-d transition to the experimental diets were followed by a 10-d preliminary period and a 10-d period during which urine and feces were collected. The experimental diets were sampled and refusals (if any) were collected at each feeding 2 d before the start until 2 d before the end of the collection period.

Feces were collected once daily, dried in a forced-draft oven at a maximum of 60°C for 24 h, and composited by animal in metal cans with loosely fitted lids. At the end of the trial, fecal composites were weighed, mixed, and subsampled. Procedures for collecting and handling the urine were similar to those described by Bhattacharya and Fontenot (1965).

Duplicate 200-g samples of the diets were dried in a forced-draft oven at a maximum of 60°C for 48 h for DM determination. These samples were allowed to air-equilibrate. Feed, refusal, and fecal samples were ground in a Wiley mill through a 1-mm screen and analyzed for DM and ash (AOAC, 1980), NDF (Van Soest and Wine, 1967), ADF (Van Soest, 1963), and cellulose (Van Soest and Wine, 1968). Hemicellulose was determined by difference. Nitrogen (AOAC, 1980) was determined on the feeds, refusals, feces, and urine.

At the end of the trial, ruminal fluid samples were taken via stomach tube with a strainer 2 h after feeding. The samples were strained through four layers of cheesecloth and the pH was determined electrometrically. The ruminal fluid was analyzed for NH_3 N (Beecher and Whitten, 1970) and VFA (Varian 6000 gas-liquid chromatograph, column packed with 10% SP-1200/1% H3PO4 on 80/100 chromosorb WAW). Blood samples were taken 6 h after feeding by jugular puncture and analyzed for urea N (Coulombe and Favreau, 1963).

Palatability Trial. Thirty crossbred wethers with an average BW of 40 kg were blocked by weight and allotted at random within blocks to the five diets used in the metabolism trial. The wethers were placed in individual 1.2-m × 4-m stalls in a semi-enclosed barn. The wethers were provided fresh feed every 12 h at approximately 10% in excess of intake, and water continuously.

The trial consisted of a 2-d adaptation period to the stalls, a 5-d transition to the experimental diets, a 7-d preliminary, and a 7-d measurement period. Refusals were collected once daily during the measurement period and dried at 100°C in a forced-draft oven. Samples of the diets were taken during the trial, frozen, and later composited, subsampled, and analyzed for DM. The average of the BW taken before the start and at the end of the trial was used to determine metabolic size.

Statistical Analyses. Statistical analyses were performed using analyses of variance by the GLM procedures of SAS (1982). The model included treatment and blocks for the metabolism and the palatability trials. Differences among treatments were tested using the following orthogonal contrasts: 1) basal vs silages, 2) straw silage vs crab waste-straw silages, 3) acetic acid-treated vs molasses-treated silages, and 4) molasses vs molasses plus inoculant-treated crab waste-straw silages.

Results and Discussion

Chemical Composition. The DM of the basal diet was 91.6%, and the CP averaged 12.6% on a DM basis (Table 1). The CP content of the basal diet was lower than that reported by Samuels et al. (1991b). Average DM and CP values for the crab waste-straw mixtures were 57.5 and 13.0%, respectively, which are similar to the values reported by Samuels et al. (1991a) for the 40:60 crab waste:straw mixtures. Neutral detergent fiber and hemicellulose were higher and ash was

Table 1. Chemical composition of basal diet and silages fed wethers in the metabolism and palatability trials

Component	Basal	Additives to mixtures[a] 16% acetic acid	20% molasses	20% molasses + .1% inoculant[b]	Ensiled wheat straw	SEM
Dry matter, %	91.6	56.6	58.4	57.6	52.9	1.2
Crude protein[c]	12.6	12.1	13.4	13.5	12.8[d]	1.1
Neutral detergent fiber[c]	69.0	55.8	59.3	60.3	84.7	.9
Acid detergent fiber[c]	40.5	40.6	44.7	45.5	59.7	1.1
Cellulose[c]	29.7	28.9	32.8	33.6	41.9	1.2
Hemicellulose[c]	28.5	15.3	14.6	14.8	25.0	1.1
Lignin[c]	10.4	9.4	10.6	11.5	16.7	1.3
Ash[c]	6.9	21.0	16.9	16.8	5.3	1.0

[a]Crab waste and wheat straw (1:1, wet basis).
[b]Obtained from Pioneer Hi-Bred International (*S. faecium* and *L. plantarum*).
[c]DM basis.
[d]Included supplemental urea.

lower in the basal than in the crab waste-straw silages. Mixtures containing added molasses alone or with inoculant and straw ensiled alone decreased in pH after ensiling. These values averaged 5.28, 4.70, and 4.75, respectively. There was no change in pH for mixtures containing acetic acid, indicating that fermentation was inhibited. Appreciable amounts of lactic acid were produced in mixtures containing added molasses alone or with inoculant, averaging 10.8 and 12.8%, respectively. A high level of acetic acid (34.68%, DM basis) was observed only for the mixture with added acetic acid.

Apparent Digestibility. Apparent digestibility of DM was highest ($P < .01$) for the basal diet (Table 2). Apparent digestibility of CP was similar ($P > .05$) for the basal diet and silages. Digestibility of DM and CP was lower ($P < .01$) for the acetic acid-treated than for the molasses-treated mixtures. Although differences were small, digestibility of DM and CP was higher ($P < .05$) for the molasses-inoculant-treated silage than for the molasses-treated silage. Digestibilities of both DM and CP were lower ($P < .05$) for the wheat straw-urea diet than for the crab waste silages. The DM digestibility of the acetic acid-treated silage was higher than the value calculated by difference by Samuels et al. (1991b) for silage with proportions of crab waste and straw similar to those in the present experiment. Digestibility of DM for the crab waste mixtures was slightly lower than values reported by Patton et al. (1975) when 10 and 20% crab meal were included in the diet of ruminating calves.

The digestibilities of NDF and hemicellulose followed trends similar to that of DM digestibility. The digestibility of cellulose tended to be lower for the crab waste-straw silages than for the basal and wheat straw silage diets. Adding molasses before ensiling increased ($P < .01$) the digestibility of all the cell wall components except cellulose, compared with adding

Table 2. Apparent digestibility of diets by wethers

Component	Basal	Additives to mixtures[a] 16% acetic acid	20% molasses	20% molasses + .1% inoculant[b]	Ensiled wheat straw	SEM
			%			
Dry matter[cdef]	62.0	51.1	54.2	57.7	44.4	1.1
Crude protein[def]	70.2	64.8	70.3	74.4	66.9	1.2
Neutral detergent fiber[cdef]	59.8	39.5	42.1	49.1	49.7	1.8
Acid detergent fiber[cde]	60.1	41.7	47.3	53.8	55.7	3.3
Cellulose	54.6	46.8	45.5	52.6	53.3	2.8
Hemicellulose[cdef]	59.3	17.0	26.0	34.6	35.3	2.9

[a]Crab waste and wheat straw (1:1, wet basis).
[b]*S. faecium* and *L. plantarum*.
[c]Basal diet and silages differ ($P < .01$).
[d]Acetic acid treatment and molasses plus inoculant treatments differ ($P < .01$).
[e]Molasses treatment and molasses plus inoculant treatment differ ($P < .05$).
[f]Wheat straw and crab waste silages differ ($P < .05$).

acetic acid. Use of the silage inoculant resulted in a further increase in digestibility of ADF, NDF, and hemicellulose. Higher digestibility of the cell wall fractions of the crab waste silages than of those calculated by Samuels et al. (1991b) may be due partly to the fact that in the present experiment the silages were fed alone and not as part of a basal diet, or to the associative effects of added molasses. The digestibilities of DM, CP, and cell wall fractions of the ensiled wheat straw diet were higher than values reported by Samuels et al. (1991b).

Nitrogen Utilization. Nitrogen intake was similar for all wethers (Table 3). Utilization of N was not significantly different between wethers fed the basal diet and those fed the crab waste-straw silages. Fecal N excretion was higher ($P < .05$) for sheep fed the acetic acid-treated crab waste silage than for those fed the molasses-treated crab waste silages. Excretion of fecal and urinary N was lower than that reported by Samuels et al. (1991b). These workers also reported higher levels of N intake, and divergences from results of the present experiment may reflect excretion of excess dietary N. Urinary N excretion was highest for wethers fed the wheat straw silage, perhaps a reflection of the lower efficiency of N utilization from urea than from crab waste and soybean meal. This could also be due to the lower energy value of the straw silage. Fecal and urinary N excretions were lower ($P < .05$) and N retention was higher ($P < .05$) for the molasses-inoculant-treated silage than for the silage treated with molasses alone. Retention of N, expressed as grams/day, percentage of intake or percentage of absorbed, was higher ($P < .05$) for wethers fed the molasses-treated silages than for wethers fed acetic acid-treated silage. The improvement in N utilization for the molasses-treated silages compared with the acetic acid-treated silage may be partly due to availability of energy and also to the high quality of microbial protein in the fermented mass of the molasses-treated silages.

Ruminal and Blood Parameters. Ruminal fluid pH was lower ($P < .01$) for lambs fed the basal diet than for those fed the silages (Table 4), possibly due to the high ash content of the crab waste-straw silages and high concentrations of ruminal NH_3 for wethers fed the urea-supplemented ensiled straw diet. The major component of the ash in crab waste is $CaCO_3$ (Cantor, 1980), which may have buffered the ruminal contents of wethers fed the crab waste-straw silages. Ruminal fluid pH of wethers fed the acetic acid-treated crab waste silage was lower ($P < .05$) than that of wethers receiving molasses-treated crab waste silages, probably a reflection of appreciable amounts of acetic acid added to the initial mixture.

Ruminal fluid NH_3 N was higher ($P < .01$) for wethers fed the silages than for those receiving the basal diet. This high concentration of NH_3 for wethers fed the crab waste-straw silages may have contributed to buffer the ruminal contents of wethers receiving these silages. The ruminal NH_3 N concentrations reported here are similar to those noted by Samuels et al. (1991b), even though there were differences in CP intake. Ruminal fluid NH_3 N was lower ($P < .05$) for wethers that were fed the acetic acid-treated crab waste silage than for those on molasses-treated crab waste silages. The slightly acid condition for wethers fed the acetic acid-treated silage may have been beneficial in reducing/retarding ruminal degradation and(or) deamination. This is consistent with the study by Raa and Gilberg (1982), who showed that

Table 3. Nitrogen utilization by wethers fed a basal diet and crab waste and wheat straw silages

	Diet[a]					
		Additives to mixtures[b]				
Item	Basal	16% acetic acid	20% molasses	20% molasses + .1% inoculant[c]	Ensiled wheat straw	SEM
Intake, g/d	14.28	14.70	15.40	15.19	14.63	.38
Excretion, g/d						
Fecal[de]	4.26	5.18	4.57	3.89	4.84	.36
Urinary[ef]	5.89	6.90	6.90	5.87	7.64	.36
Total	10.15	12.08	11.47	9.76	12.48	.30
Retention						
g/d[def]	4.13	2.62	3.93	5.43	2.15	.41
% of Intake[def]	28.9	17.8	25.6	35.8	14.7	2.8
% of Absorbed[def]	41.2	27.0	36.4	48.1	21.8	4.0

[a]Each values represents the average of six wethers.
[b]Crab waste and wheat straw (1:1, wet basis).
[c]*S. faecium* and *L. plantarum*.
[d]Acetic acid treatment and molasses treatments differ ($P < .05$).
[e]Molasses alone and with inoculant treatments differ ($P < .05$).
[f]Wheat straw and crab waste silages differ ($P < .05$).

Table 4. Ruminal pH, ammonia nitrogen, and blood urea nitrogen of wethers fed a basal diet and crab waste and wheat straw silages

	Diet[a]					
		Additives to mixtures[b]				
Item	Basal	16% acetic acid	20% molasses	20% molasses + .1% inoculant[c]	Ensiled wheat straw	SEM
Ruminal fluid pH[de]	6.76	6.86	7.29	7.08	6.99	.08
Ruminal fluid NH_3 N, mg/dL[def]	26.9	28.7	34.4	30.9	42.3	1.3
Blood urea N, mg/dL[def]	24.3	25.4	32.1	28.8	40.5	1.5

[a]Each value represents the average of six wethers.
[b]Crab waste and wheat straw (1:1, wet basis).
[c]*S. faecium* and *L. plantarum*.
[d]Basal and silages differ ($P < .01$).
[e]Acetic acid treatment and 20% molasses and inoculant treatments differ ($P < .05$).
[f]Wheat straw and crab waste silages differ ($P < .01$).

deamination is suppressed under acid conditions. In the present study, the highest ($P < .01$) level of ruminal NH_3 N was observed for wethers fed the wheat straw silage supplemented with urea, reflecting the rapid ruminal degradation of urea to ammonia, which was likely responsible for low efficiency of N utilization (Table 3). Blood urea N followed a trend similar to that of the ruminal NH_3 N. The high levels of blood urea N may be a reflection of N intake (Preston et al., 1965) and suppressed recycling to the rumen due to a high level of ruminal NH_3. Plasma urea enters the rumen either via saliva or by diffusion through the ruminal wall. The amount of N recycled is reduced when NH_3 concentration in the rumen is high.

Total ruminal fluid VFA was higher ($P < .05$) for wethers fed crab waste-straw silages than for those fed wheat straw silage or the basal diet (Table 5). Total VFA tended to be higher for wethers receiving the acetic acid-treated crab waste silage than for those receiving the molasses-treated silages. This level of VFA probably contributed to the lower ruminal pH observed for wethers fed the acetic acid-treated silage. Acetic acid concentration was higher ($P < .01$) for wethers fed the acetic acid-treated silage than for those fed the molasses-treated silages, undoubtedly a reflection of the large difference in acetic acid in the silage. Acetic and propionic acid concentrations were not significantly different for wethers fed the crab waste-straw mixtures and for those on the wheat straw silage diet. Propionic acid was more than twice as high ($P < .01$) for wethers fed the molasses-treated crab waste silages than for those fed the acetic acid-treated silage. Chappell and Fontenot (1968) reported a tendency for total VFA concentration in the rumen

Table 5. Ruminal fluid volatile acid concentrations, metabolism trial

	Diet[a]					
		Additives to mixtures[b]				
Volatile fatty acids	Basal	16% acetic acid	20% molasses	20% molasses + .1% inoculant[c]	Ensiled wheat straw	SEM
Total, μmol/mL[de]	73.4	97.2	89.9	92.1	74.6	7.8
			mol/100 mol			
Acetic[f]	65.3	81.9	57.5	60.1	67.7	1.6
Propionic[f]	23.6	12.5	30.4	29.0	23.0	1.3
Isobutyric[f]	1.3	.6	1.3	1.0	1.1	.1
Butyric[f]	7.7	4.0	7.2	7.3	6.3	.6
Isovaleric[fg]	1.5	.6	1.7	1.2	1.3	.1
Valeric[defg]	.8	.5	1.8	1.4	.6	.1

[a]Each value represents the average of six wethers.
[b]Crab waste and wheat straw (1:1, wet basis).
[c]*S. faecium* and *L. plantarum*.
[d]Straw and crab waste silages differ ($P < .05$).
[e]Basal and silages differ ($P < .05$).
[f]Acetic acid treatment and molasses treated silages differ ($P < .01$).
[g]20% molasses treatment and inoculant treatment differ ($P < .01$).

Table 6. Dry matter intake of wethers fed a basal diet, crab waste, and wheat straw silages

	Diet[a]					
		Additives to mixtures[b]				
Measurement	Basal	16% acetic acid	20% molasses	20% molasses + .1% inoculant[c]	Ensiled wheat straw	SEM
g/d[de]	908	779	936	955	709	19
$g/W_{kg}^{.75}/d$[de]	56.1	47.1	56.1	58.0	42.3	1.1

[a]Each value represents the average of six animals.
[b]Crab waste and wheat straw (1:1, wet basis).
[c]*S. faecium* and *L. plantarum*.
[d]Wheat straw and crab waste silages differ ($P < .01$).
[e]Acetic acid treatment differs from molasses treated silages ($P < .01$).

to be higher when readily available carbohydrate sources were fed, and the increase was due primarily to increased levels of propionate and butyrate. In the present experiment, this trend was observed for the molasses-treated crab waste silages. The predominant ruminal VFA for wethers fed ensiled straw were acetic and propionic acids, a trend also observed by Samuels et al. (1991b).

Isobutyric acid tended to be higher and isovaleric and valeric acids were higher ($P < .05$) for wethers fed the molasses-treated crab waste mixture alone than for those fed the molasses-inoculant-treated crab waste silage. Leng (1973) reported that the branched-chain fatty acids are indicative of proteolysis and(or) deamination. He also indicated that decreased production of isobutyrate and isovalerate in fermentations is indicative of reduced proteolysis and(or) deamination. This may be one reason for the higher N retention observed for the lambs fed the molasses-inoculant-treated crab-waste silage than for those receiving the molasses-treated silage. However, this theory does not seem to apply to the acetic acid-treated crab waste silage, which had lower isobutyric and isovaleric acid levels but lower N retention. Apparently, other biological factors are involved in determining N retention. Digestibility of N and total VFA for the molasses-inoculant-treated crab waste silage was higher, suggesting that microbial protein synthesis was enhanced. This may partly explain the improved N retention for the molasses-inoculant treatment, because microbial protein may be more digestible than crab waste protein.

Palatability Trial. Dry matter intake, expressed as grams per day or per unit of metabolic size, was similar for wethers fed the basal and crab-waste silages and higher than for wethers fed the acetic acid-treated silages (Table 6). The value for the acetic acid-treated silage is lower than those reported by Samuels et al. (1991b). Presumably, this difference is due to the fact that in the present experiment the wethers were fed acetic acid-treated silage alone; hence, they were exposed to a higher concentration of acetic acid in the diet, whereas Samuels et al. (1991b) fed the silage as 50% of the diet on a DM basis. Wilkins et al. (1971) and Brown and Radcliffe (1972) reported low voluntary DM intake and poor performance in wethers fed silages with acetic acid as the additive. Dry matter intake was higher ($P < .01$) for wethers fed the crab waste silages than for those fed the straw silage diet. Wethers fed the molasses-treated crab waste silages consumed more ($P < .01$) DM than those fed the acetic acid-treated crab waste silage. Intake of DM expressed per unit of metabolic size followed the same trends as intake per day.

Implications

Ensiling crab processing waste, wheat straw, and molasses resulted in a feed with desirable fermentation characteristics and palatability. Dry matter digestibility indicates that the nutrients are largely recovered in the resultant silage, and that the silage could be fed to ruminants at low levels of production without supplementation. However, for ruminants at high levels of production, a crab waste-straw silage could form part of the complete diet, supplying both protein supplement and roughage in the diet.

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