EFFECTS OF FEEDING ALKALINE HYDROGEN PEROXIDE-TREATED WHEAT STRAW-BASED DIETS ON INTAKE, DIGESTION, RUMINAL FERMENTATION, AND PRODUCTION RESPONSES BY MID-LACTATION DAIRY COWS

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ABSTRACT

The objective of this experiment was to determine the effects of feeding different levels of alkaline hydrogen peroxide-treated wheat straw (AHP-WS) in the diet on feed intake, nutrient digestion, ruminal fermentation, and production responses in mid-lactation dairy cows. Eight Holstein cows, averaging 147 d postpartum, were used in two replications of a 4 x 4 Latin square design. Complete mixed diets consisted of 70% forage and 30% concentrate (DM basis) with various levels of AHP-WS, alfalfa haylage, and corn silage as forage sources. Treatments contained 0 (control), 20.0, 40.1, or 60.0% AHP-WS in the diet. A quadratic effect ($P = 0.08$) of AHP-WS level on DMI was noted, with values of 21.6, 22.3, 20.8, and 18.9 kg/d for the control, 20.0, 40.1, and 60.0% AHP-WS treatments, respectively. Apparent digestibilities of DM, OM, CP, and ADF were not affected ($P > 0.10$) by replacing haylage and corn silage with increasing amounts of AHP-WS in the diet, but there was a linear increase ($P = 0.03$) in NDF digestibility (44% for control vs 59% for the 60.0% AHP-WS diet) and a parallel decrease ($P < 0.05$) in cell content digestibility (82 vs 70% for these two diets). Yields of milk and 4% fat-corrected milk (FCM) were decreased (quadratic; $P = 0.0001$) as the level of AHP-WS increased in the diet. The addition of AHP-WS to the diet decreased the milk fat percentage from 3.72 to 3.60% (quadratic; $P = 0.05$) and decreased milk protein percentage from 3.27 to 3.13% (linear; $P = 0.0001$). Cows fed the higher levels of AHP-WS had linear increases ($P = 0.0001$) in ruminal concentrations of total VFA (128.0 mM for control vs 136.0 mM for the 60.0% AHP-WS treatment) and molar proportion of acetate, resulting in a quadratic effect ($P < 0.0001$) on the acetate:propionate ratio. These data indicate that feeding the 40.1 and 60.0% AHP-WS diets lowered digestible DM and OM intakes, which resulted in reduced 4% FCM yield as nutrient intakes were decreased compared with cows fed the 20.0% AHP-WS diet or the control diet containing alfalfa haylage and corn silage. Although substituting AHP-WS for haylage and corn silage increased NDF digestibility and tended to increase digestible NDF intake, milk production was depressed because digestible DMI decreased.

Key Words: Straw, Lactation, Intake, Digestibility, Milk Production


Introduction

Roughage of the proper quality, quantity, and physical form is necessary in dairy cow diets to maintain normal milk fat percentage and to minimize nutritionally related metabolic disorders (NRC, 1978). Fibrous feedstuffs, such as corn stover, wheat straw, and soybean residues, account for more than 80% of the...
500 million tons ($5.1 \times 10^8$ Mg) of U.S. farm residue supply (Walker and Kohler, 1981). Crop residues typically are high in cell wall carbohydrates (cellulose, hemicelluloses) and can be incorporated into the diet of dairy cows as a source of energy as well as providing the dietary fiber to ensure normal ruminal function. However, the lower DMI and nutrient digestibility associated with feeding such crop residues, compared with traditional diets containing forages such as alfalfa haylage or corn silage, has limited their level in diets of early- or mid-lactation cows. A treatment process using alkali and hydrogen peroxide (Gould, 1984; 1985) has improved both intake and digestibility of wheat straw (WS) by ruminants (Kerley et al., 1986). The alkaline hydrogen peroxide (AHP) treatment has increased degradation of structural carbohydrates by increasing their rate and extent of digestion in the rumen as well as increasing bacterial colonization and adhesion to fiber particles (Kerley et al., 1985). The objective of this experiment was to determine the effects of various levels of AHP-WS in the diet on feed intake, nutrient digestion, ruminal fermentation, and production in dairy cows during mid-lactation. The control diet consisted of feedstuffs (alfalfa haylage, corn silage, ground shelled corn, and soybean meal) that are typically fed and readily available to dairy producers in the Midwest.

**Materials and Methods**

**Treatment of Wheat Straw.** Approximately 113 kg of WS (ground through a 10-mm screen) was treated in each batch. The native WS contained 92.2% DM, 91.2% OM, 84.8% NDF, 61.0% ADF, and 9.0% ADL. The AHP-WS required for the experiment was prepared using a 3041 Marion Batch Mixer in conjunction with a Toledo 8142 Digital Indicator and load cell system. The Toledo 8142 was programmed to start and stop the appropriate motors and pumps that delivered the WS, water, and chemical reagents into the batch mixer in weighed amounts for mixing. Commercially available hydrogen peroxide (50% H$_2$O$_2$, wt/wt), sodium hydroxide (50% NaOH, wt/wt), and water were pumped into the batch mixer and applied via three spray nozzles. Upon starting the mixing sequence, the system collected WS with a belt conveyor from a forage wagon, conveyed it to the batch mixer, and weighed the allotted amount of WS. Sodium hydroxide was added to the WS at 5.0% of the DM. Both the water and NaOH pumps were started and the solution was sprayed onto the WS until the scale reached a set point. The pumps shut off automatically and mixing continued for 3 min. Upon completion of the mixing, H$_2$O$_2$ was added to the WS at 2.0% of the DM. Water and H$_2$O$_2$ were sprayed onto the WS until the scale reached the final set point, the pumps shut off, mixing continued for 3 min, and the end product was discharged into another forage wagon. The final moisture content of the AHP-WS was 34.2%; this product was stored in an oxygen-limiting silo during the experiment.

**Animals and Diets.** Eight Holstein cows were used in two replications of a 4 x 4 Latin square design. The replicated Latin squares were conducted simultaneously with ruminally cannulated multiparous cows or intact primiparous cows (four cows/replication). The ruminal cannulas were made of soft plastic and were 10.2 cm in diameter. Ruminal surgeries were conducted in the surgical facilities of the Veterinary Medicine Teaching Hospital at the University of Illinois. Paravertebral nerve blocks using 2% lidocaine were done to provide anesthesia to the left paralumbar fossa. After preparation of the surgical area, a circle of skin of the proper size was removed by excision and a grid incision was used to complete entry into the abdominal cavity. The rumen wall was sutured to the muscle to seal the abdominal cavity, then both were sutured to the skin, and the ruminal cannula was inserted into the circular opening. Each replicate contained cows of similar age and stage of lactation. Cows averaged 147 d postpartum (range = 135 to 158) at the beginning of the experiment. Initial BW at the onset of the experiment was 535 kg ± 38 (SD, Replicate 1, ruminally cannulated) and 476 kg ± 15 (SD, Replicate 2). During the trial, cows were housed in conventional stanchions (132 cm x 182 cm) in a well-ventilated barn, fed daily at 1100 and 2200, and allowed to exercise outdoors from 0800 to 1000. The ruminally cannulated cows were not allowed to exercise during the collection phase (last 3 d) of each period.

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3Marion Mixers, Inc, Marion, IA.
4Toledo Scale, Westerville, OH.
TREATED WHEAT STRAW DIGESTION BY COWS

TABLE 1. INGREDIENT AND CHEMICAL COMPOSITION OF DIETS AS A PERCENTAGE OF THE DRY MATTER

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>20.0</th>
<th>40.1</th>
<th>60.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa haylage</td>
<td>37.0</td>
<td>25.9</td>
<td>15.7</td>
<td>5.2</td>
</tr>
<tr>
<td>Corn silage</td>
<td>32.5</td>
<td>23.7</td>
<td>13.9</td>
<td>4.6</td>
</tr>
<tr>
<td>AHP-WS</td>
<td>—</td>
<td>20.0</td>
<td>40.1</td>
<td>60.0</td>
</tr>
<tr>
<td>Concentrate mix</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground shelled corn</td>
<td>20.4</td>
<td>15.2</td>
<td>8.9</td>
<td>2.4</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>8.4</td>
<td>13.8</td>
<td>19.4</td>
<td>24.9</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral/vitamin mix&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.15</td>
<td>.15</td>
<td>.15</td>
<td>.15</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>.64</td>
<td>.76</td>
<td>.89</td>
<td>1.02</td>
</tr>
<tr>
<td>Limestone</td>
<td>—</td>
<td>.09</td>
<td>.35</td>
<td>.63</td>
</tr>
<tr>
<td>Magnesium oxide</td>
<td>.14</td>
<td>.15</td>
<td>.19</td>
<td>.21</td>
</tr>
<tr>
<td>Calcium sulfate</td>
<td>.05</td>
<td>.13</td>
<td>.20</td>
<td>.27</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>.08</td>
<td>.08</td>
<td>.27</td>
<td>.65</td>
</tr>
<tr>
<td>Chemical analyses, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OM</td>
<td>92.2</td>
<td>90.7</td>
<td>88.1</td>
<td>86.3</td>
</tr>
<tr>
<td>CP</td>
<td>17.7</td>
<td>17.8</td>
<td>17.4</td>
<td>16.7</td>
</tr>
<tr>
<td>NDF</td>
<td>34.1</td>
<td>37.4</td>
<td>40.8</td>
<td>43.7</td>
</tr>
<tr>
<td>ADF</td>
<td>20.8</td>
<td>25.1</td>
<td>29.6</td>
<td>34.2</td>
</tr>
</tbody>
</table>

<sup>a</sup>AHP-WS = alkaline hydrogen peroxide-treated wheat straw.

<sup>b</sup>Contains the following: 1) 0.025%; Fe, 2.0%; Zn, 3.0%; Mn, 3.0%; Mg, 5.0%; Cu, 5.0%; Co, 0.04%; Se, 0.015%; S, 10.0%; and K, 7.5%; Vitamin A, 2,200 IU/g; vitamin D<sub>3</sub>, 660 IU/g; and vitamin E, 7.7 IU/g.

All cows were fed a complete mixed diet of 70% forage and 30% concentrate (C) on a DM basis, with various levels of AHP-WS, alfalfa haylage (AH), and corn silage (CS) as the sources of forage. The ratio of AH:CS in each diet was maintained at approximately 1:1. The four completely mixed diets contained the following: 1) 37.0% AH, 32.5% CS, 0% AHP-WS, 30.5% C (control); 2) 25.9% AH, 23.7% CS, 20.0% AHP-WS, 30.4% C (20.0% treatment); 3) 15.7% AH, 13.9% CS, 40.1% AHP-WS, 30.3% C (40.1% treatment); and 4) 5.2% AH, 4.6% CS, 60.0% AHP-WS, 30.2% C (60.0% treatment). The completely mixed diets were available ad libitum, allowing at least 10% orts. Water was available continuously. Ingredients and chemical composition of diets and individual feedstuffs fed to cows are presented in Tables 1 and 2. Minerals and vitamins were added to each diet to meet or exceed NRC (1978) recommendations. Sodium bicarbonate was not included in diets containing AHP-WS because requirements for Na were met by the high concentration of Na present in the AHP-WS (3.42% of DM). Limestone, calcium sulfate, and potassium chloride were increased in the diet as the AHP-WS level was increased because AHP-WS contains little Ca, S, or K. Diets were balanced to contain at least 0.80% Ca and 0.45% P. Percentage of CP varied slightly among diets, ranging from 16.7 to 17.8%. The variation in OM, NDF, and ADF contents among the diets was primarily a result of the various levels of AHP-WS in the diet. The proportions of dietary NDF that came from the AHP-WS were 0, 32.4, 59.6, and 83.0%, respectively, for the control diet and the diets containing 20.0, 40.1, and 60.0% AHP-WS. Alkaline hydrogen peroxide-treated WS is higher in structural carbohydrates than either AH or CS (Table 2). Forages fed during the experiment were of high quality, with AH and CS containing 22.1 and 8.3% CP, respectively (Table 2).

Experimental periods lasted 14 d. The first 3 d of each period were used to gradually change the cows from one diet to another. On d 1 of each period, cows were fed 75% of the diet from the previous period and 25% of the diet from the current period. On d 2, the diets were 50:50; on d 3, 25:75; and, by d 4, cows were fed 100% of the diet for that period. The first 9 d were used for adjustment to diets followed by 5 d of sample and data collection. Fourteen-day periods were used to ensure that
TABLE 2. CHEMICAL COMPOSITION OF FEEDS

<table>
<thead>
<tr>
<th>Ingredient, %</th>
<th>DM&lt;sup&gt;a&lt;/sup&gt;</th>
<th>OM</th>
<th>CP</th>
<th>NDF</th>
<th>ADF</th>
<th>ADL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa haylage</td>
<td>54.5</td>
<td>88.8</td>
<td>22.1</td>
<td>40.9</td>
<td>33.2</td>
<td>7.4</td>
</tr>
<tr>
<td>Corn silage</td>
<td>37.3</td>
<td>95.5</td>
<td>8.3</td>
<td>45.2</td>
<td>22.9</td>
<td>4.2</td>
</tr>
<tr>
<td>AHP-WS&lt;sup&gt;b&lt;/sup&gt;</td>
<td>65.8</td>
<td>86.3</td>
<td>3.4</td>
<td>60.4</td>
<td>47.9</td>
<td>7.5</td>
</tr>
<tr>
<td>Concentrate mix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>85.4</td>
<td>92.7</td>
<td>22.5</td>
<td>12.5</td>
<td>4.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Low</td>
<td>86.3</td>
<td>91.6</td>
<td>30.3</td>
<td>13.1</td>
<td>5.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Medium</td>
<td>87.4</td>
<td>86.5</td>
<td>37.9</td>
<td>12.2</td>
<td>4.5</td>
<td>1.8</td>
</tr>
<tr>
<td>High</td>
<td>88.2</td>
<td>84.0</td>
<td>43.5</td>
<td>10.5</td>
<td>5.7</td>
<td>1.9</td>
</tr>
</tbody>
</table>

<sup>a</sup>DM on as-fed basis for each feed.

<sup>b</sup>AHP-WS = alkaline hydrogen peroxide-treated wheat straw.

the experiment was started and completed during mid-lactation.

Sampling Procedures and Analyses. Dry matter intake was measured daily during d 10 to 14. Samples of forage and feed refusals were obtained on d 10 to 14; samples of concentrate were taken on d 12. Samples were dried at 55°C, ground in a Wiley mill (2-mm screen), and composited at the end of each period. Feed and feed refusals were analyzed for DM and OM (AOAC, 1984). Organic matter (non-NDF) was calculated as the OM fraction minus the NDF fraction. Nitrogen was measured using the Kjeldahl method (AOAC, 1984). Neutral detergent fiber was measured using the alpha-amylase procedure of Robertson and Van Soest (1977). Acid detergent fiber and ADL were measured according to Goering and Van Soest (1970).

Cows were milked at 0600 and 1700; milk weights were recorded daily. Daily morning and afternoon milk samples were taken at each milking on d 11 and 12, composited based on milk yield, and analyzed for milk protein and milk fat using infrared analysis<sup>5</sup>. Milk solids-not-fat (SNF) was determined gravimetrically (Golding, 1959). Body weights were recorded immediately after the morning milking on d 1 and 14 of each period.

On d 12 of each period, approximately 2.3 kg of each as-fed complete mixed diet was marked with 3 g of ytterbium (Yb; 7.32 g of YbAc<sub>3</sub>·4H<sub>2</sub>O) and offered to each ruminally cannulated cow. The Yb was dissolved in 150 ml of distilled water and the resulting solution was sprayed onto and mixed slowly with the 2.3-kg portion of the diet. The ruminally cannulated cows were given approximately 15 min to consume the labeled feed and the uneaten portion was collected and placed in the rumen via the ruminal cannula. Ruminal particulate samples were taken from the rumen at 4, 10, 16, 22, 28, 34, 40, and 46 h following consumption of the Yb-marked meal to determine particulate (Yb) dilution rate. Six ruminal particulate samples were taken from representative areas in the rumen and composited. Approximately 300 g of the composited ruminal particulate sample was dried at 55°C and ground (2-mm screen) before Yb analysis. Ruminal particulate samples were prepared and analyzed for Yb using atomic absorption spectrophotometry<sup>6</sup> as described by Ellis et al. (1982). Particulate dilution rate was the slope of the regression of the natural logarithm of Yb concentration per unit of DM against time.

On d 14 of each period, the ruminally cannulated cows were dosed intraruminally at 0800 with 50 g of Co-EDTA dissolved in 500 ml of water as described by Uden et al. (1980) to determine the ruminal fluid dilution rate. The Co-EDTA solution was placed in several locations in the rumen via a plastic tube attached to a plastic funnel. Ruminal fluid samples (50 ml) were taken hourly for 24 h beginning at 0800 from several locations in the rumen at each sampling time via a suction pump. Ruminal pH measurements were made immediately using a Beckman 31 pH meter<sup>7</sup>. Ruminal fluid samples were strained through eight layers of cheesecloth after sampling and centrifuged at 10,000 × g for 10 min; the
supernatant fraction was acidified with 1 ml of 50% sulfuric acid (pH < 2). Ruminal fluid samples were refrigerated and subsequently analyzed for Co, VFA, and ammonia.

Ruminal fluid ammonia concentrations were determined according to the procedure of Chaney and Marbach (1962). Samples for Co and VFA analyses were prepared by centrifuging the ruminal fluid sample at 18,000 × g for 20 min. Cobalt content of the ruminal fluid was measured using atomic absorption spectrophotometry. Fluid (Co) dilution rate was calculated as the slope of the regression of the natural logarithm of Co concentration per milliliter against time. The amount of Co pulse dosed was divided by the antilogarithm of the y-intercept of Co regression to calculate ruminal fluid volume. Volatile fatty acids in ruminal fluid were prepared for gas chromatographic analysis following the procedure of Erwin et al. (1961). Samples were analyzed for VFA using an automated Hewlett Packard Model 5890 gas chromatograph equipped with a hydrogen flame ionization detector. A glass column (approximately 210 cm long × 8 mm o.d.) packed with Chromosorb WAW (80 to 100 mesh) coated with 1% phosphoric acid was used to separate the individual VFA.

Ruminally cannulated cows were dosed via the ruminal cannula with 10 g of chromic oxide powder twice daily at 1000 and 2200 (12-h intervals) on d 5 to 14 of each period to determine digestibility of the diets. Fecal grab samples were obtained twice daily and 100 g of each sample (wet basis) were composited for each cow during the collection phase and dried at 55°C. Dried fecal samples were ground in a Wiley mill (2-mm screen) and assayed for DM, OM, OM (non-NDF), N, NDF, and ADF as described previously. Chromium concentration of feces was determined by atomic absorption spectrophotometry (Williams et al., 1962).

Statistical Analysis. Data were analyzed by ANOVA for a Latin square arrangement of treatments according to the GLM procedure (SAS, 1982). Model sums of squares for the Latin square included animals, period, and diet effects. Model sums of squares for the replicated Latin square were separated into replication, cow within replication, period, and diet effects. Sums of squares for diet effects were separated further into orthogonal contrasts for linear and quadratic effects of AHP-WS level. Least squares means were calculated for the replicated Latin square design for DMI, change in BW, milk production, and milk composition. Least squares means were calculated for digestible nutrient intake, apparent nutrient digestibility, and ruminal fermentation data for the four ruminally cannulated cows only.

Results and Discussion

Ingredient and chemical composition of diets and individual feedstuffs fed to cows in mid-lactation are presented in Tables 1 and 2. Alkaline hydrogen peroxide-treated WS partially replaced the AH and CS portions of the control diet at 20.0, 40.1, and 60.0%, respectively, in the other three diets. Because AHP-WS supplies mostly energy (it is nearly devoid of protein), its inclusion in the diet required the use of various amounts of ground shelled corn, soybean meal, and minerals to meet NRC (1978) recommendations for CP and some minerals. Crude protein varied from 16.7 to 17.8%, an adequate level of dietary CP for cows in mid-lactation. It is important to supplement AHP-WS diets with CP sources that will establish an optimal N: energy ratio that will meet the requirements of both the host animal and the ruminal microbes. Inclusion of AH and soybean meal in the AHP-WS-based diets should provide ruminally degraded and ruminal escape protein fractions that should maximize ruminal digestion of AHP-WS. In the lactating dairy cow, ruminal escape protein is needed to meet the cow’s high requirement for protein because of insufficient synthesis of microbial protein (NRC, 1988). Percentages of NDF and ADF in the diet increased as the level of AHP-WS in the diet increased. Neutral detergent fiber increased from 34.1% for the control diet to 43.7% for cows fed the 60.0% AHP-WS diet, an increase of 9.6 percentage units. Percentage of ADF increased by 13.4 from the control to the 60.0% AHP-WS diet. Data in Table 2 indicate that the percentage of NDF and ADF in AHP-WS were markedly higher than those for either the AH or CS. Alkaline hydrogen peroxide treatment of WS decreased NDF, ADF, and ADL concentrations by 24, 13, and 1.5 percentage units, respectively, compared with...
the native WS (data not shown). This decrease in structural cell wall components and lignin are consistent with those values reported by other researchers (Kerley et al., 1986; Lewis et al., 1987; Cameron et al., 1988) for treatment of WS with AHP.

Dry Matter Intake. Dry matter intake (kilograms/day) decreased (quadratic; \( P = .08 \)) with inclusion of AHP-WS in the diet (Table 3). Dry matter intake by cows in the replicated Latin square (means for eight cows) was 22.3 kg/d for the 20.0% AHP-WS diet and was lower by .7, 1.5, and 3.4 kg/d for the control, 40.1, and 60.0% AHP-WS diets, respectively. For the four ruminally cannulated cows (Table 4), DMI decreased linearly (\( P = .02 \)) from 23.6 kg/d for cows fed the control diet to 19.3 kg/d for cows fed the 60.0% AHP-WS diet, a change of 4.3 kg/d. Research by Cameron et al. (1990) suggests that the AHP treatment of WS resulted in higher DMI by lactating cows than by cows fed NaOH-treated residues (Greenhalgh et al., 1976; Phipps et al., 1988) or untreated WS (Amir et al., 1970; Blair et al., 1974). Soper et al. (1977) reported that DMI was 18.0 kg/d for cows fed diets containing 12.0 and 23.0% sodium and calcium hydroxide-treated corn cobs; that was similar to the DMI value of 17.1 kg/d for cows fed 12.5 to 37.5% AHP-WS in early lactation (Cameron et al., 1990) but less than DMI values reported in this study. However, Soper et al. (1977) observed a linear decrease in DMI from 20.1 kg/d for cows fed the control diet to 18.0 kg/d for cows fed their treated corn cob diets. In contrast, Cameron et al. (1988) reported that growing wethers fed AHP-WS diets ingested and digested more DM than wethers fed NaOH-WS diets and that the inclusion of \( \text{H}_2\text{O}_2 \) to the NaOH treatment process increased digestible nutrient intake by 15 to 17%.

Consumption of DM, when expressed as a percentage of BW, decreased linearly (\( P = .01 \)) from 3.93% for the control to 3.46% for the 60.0% AHP-WS treatment (Table 3). Body weight change (kilograms) was not altered (\( P > .10 \)) by feeding AHP-WS in the diet. All cows gained BW during the experiment. Changes in gut fill due to diet adjustment between periods make interpretation of BW changes difficult; also, the SEM was relatively high (Table 3). Other researchers (Phipps et al., 1988; Cameron et al., 1990) reported that cows in early lactation fed large amounts of chemically treated straw lost live weight due to tissue mobilization in an attempt to sustain milk production at a slightly lower DMI.
Milk Production and Composition. Feeding the higher levels of AHP-WS in the diet affected milk yield and milk components (Table 3). Milk yield and 4% FCM yield decreased (quadratic; $P = 0.0001$); similar production existed between cows fed the control and 20.0% AHP-WS diets (26.9 kg/d for milk yield and 25.8 kg/d for 4% FCM yield, respectively). Cows fed the 40.1 and 60.0% AHP-WS diets had lower daily milk production (1.0 and 3.4 kg/d decreases) and 4% FCM (1.2 and 3.8 kg/d decreases) than those fed the 20.0% AHP-WS diet. This decrease in milk yield by cows fed the 40.1 and 60.0% AHP-WS diets could be attributed to their lower digestible DM and OM intakes (Table 4), which resulted in lower energy intakes. Milk fat percentage decreased (quadratic; $P = 0.05$) from 3.72% for cows fed the control diet to 3.60% for cows fed the 60.0% AHP-WS diet. This is inconsistent with results of other studies (Blair et al., 1974; Greenhalgh et al., 1976; Ghebriel et al., 1981; Phipps et al., 1988; Cameron et al., 1990) in which inclusion of untreated, NaOH-, or AHP-treated roughage in the diet increased milk fat percentages. The lower milk yield and milk fat percentage for cows fed the 40.1 and 60.0% AHP-WS diets resulted in a decrease (quadratic; $P = 0.0001$) in milk fat yield from 1.0 kg/d for the control to .84 kg/d for the high-AHP-WS diet. Forage in the proper quantity and physical form is necessary to maintain milk fat percentage; grinding or fine chopping of the roughage will lower the effectiveness of the fiber in preventing depressed milk fat percentages (Davis and Brown, 1970). The mean forage particle sizes in this experiment for the AH, CS, and AHP-WS were 2,735, 3,390 and 1,018 μm, respectively. Approximately 50 g of forage were dry-sieved in duplicate on a vibrational sieve shaker as described by Waldo et al. (1971). In this study, the higher amounts of AHP-WS in the diet led to ADF percentages (Table 1) that were greater than NRC (1978) recommendations; however, the small particle size of the fiber may have contributed to the lower milk fat percentage when AHP-WS was fed. Milk fat percentages consistently decrease when forage-containing diets are pelleted (O’Dell et al., 1968; Shaver et al., 1986; Woodford et al., 1986; Woodford and Murphy,
the lower DMI because those cows were under
nate ratios of less than
Ruminal
nate increases (Sutton, 1981).

expected for all diets, which was attributed to
Acetate:propionate ratio 3.64 3.50 3.58 3.81

The inclusion of
were mobiliz-

consuming diets containing adequate fiber

percentage tended to increase from 3.07% for
the control diet to


severe heat stress. Perhaps the cows in early

milk

fat percentage data reported for cows fed
(O’Dell et al., 1968). Such decreases usually
are attributed to alterations in ruminal VFA
patterns; generally, the molar proportion of
acetate and the acetate:propionate ratio
decrease and the molar proportion of propio-
nate increases (Sutton, 1981). Acetate:propio-
nate ratios of less than 2.5 have been
associated with milk fat depression. In the
current experiment, milk fat percentage was
lowered as a result of feeding the higher levels
of AHP-WS (Table 3), even though cows were
consuming diets containing adequate fiber
levels. Both ADF and NDF percentages were
higher than NRC (1988) recommendations.
The inclusion of AHP-WS into the diets resulted in
ruminal VFA patterns that are not
usually associated with decreased milk fat
synthesis because the molar proportion of
acetate and acetate:propionate ratios were
increased (Table 5). This is inconsistent with
milk fat percentage data reported for cows fed
the same AHP-WS during early lactation
(Cameron et al., 1990) because milk fat
percentage tended to increase from 3.07% for
the control diet to 3.32% for the diet containing
37.5% AHP-WS. However, in that experiment,
milk fat percentages were lower than expected
for all diets, which was attributed to the
lower DMI because those cows were under
severe heat stress. Perhaps the cows in early
lactation (Cameron et al., 1990) were mobiliz-
ing fat from body stores and directly incorpo-
rating the long-chain fatty acids into the milk.
Therefore, the milk fat percentage was
increased by both the VFA end products that
favor milk fat synthesis and the mobilization
of body reserves. Woodford et al. (1986)
proposed that a mean forage length of .6 to .8
cm is the minimum for retaining roughage
effective fiber and maintaining milk fat
concentration. In dairy cow nutrition, particle size
will be an important issue should use of
chemically treated roughages become popular.

Milk protein percentage decreased linearly
(P = .0001) as AHP-WS increased, from
3.27% for the control diet to 3.13% for the
60.0% AHP-WS diet. This decrease in milk
protein percentage and the lower milk yield for
cows fed the 40.1 and 60.0% AHP-WS diets
resulted in a decrease (quadratic; P = .0006) in
milk protein yield (Table 3). Numerous re-
searchers (Lofgren and Warner, 1970; Blair et
al., 1974; Soper et al., 1977; Phipps et al.,
1988; Cameron et al., 1990) have reported that
milk protein percentage decreased when addi-
tional crude fiber or ADF was added to the
diet. Emery (1978) concluded that milk protein
decreased by .013 percentage units for each
1% increase in dietary crude fiber and that an
energy intake (DMI) increased, more dietary
protein, or less dietary fiber increased the
milk protein concentration. Perhaps a lower protein
content of milk occurs because energy intake

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*ns least squares means analyzed for Replicate 1 (ruminally cannulated, multiparous cows).

*ns P = .20.
Nutrient Intakes and Digestibilities. Nutrient intakes, apparent digestibilities, and digestible nutrient intakes for the ruminally cannulated cows are presented in Table 4. Intakes of DM (P = .02), OM (P = .006), OM (non-NDF; P = .0005), and CP (P = .02) decreased, whereas ADF intake (P = .005) increased linearly with increasing amounts of AHP-WS in the diet. Organic matter intake was similar for cows fed the control and 20.0% AHP-WS diets, approximately 21.7 kg/d, and decreased by 2.9 and 5.1 kg/d for cows fed the 40.1 and 60.0% AHP-WS diets, respectively. Intake of CP was 22% greater for cows fed the control and 20.0% AHP-WS diets than for those fed the 40.1 and 60.0% AHP-WS diets. Acid detergent fiber intake increased from 4.9 kg/d for the control diet to an average of 6.3 kg/d for cows fed the diets containing AHP-WS. Inclusion of AHP-WS in the diet resulted in an increase (quadratic; P = .16) in NDF intake, and cows fed the 20.0 and 40.1% AHP-WS diets averaged 8.8 kg/d compared with 8.2 kg/d for the control and 60.0% AHP-WS diets.

Digestibilities of DM, CP, and ADF were not affected (P > .10) by increasing AHP-WS in the diet, whereas there was a decrease (quadratic; P = .05) in OM (non-NDF) digestibility. These digestibility values were higher for all diets than those of Soper et al. (1977), who fed dairy cows (past peak lactation) diets containing sodium and calcium hydroxide-treated corn cobs with corn silage. In another lactation study, Cameron et al. (1990) reported similar DM digestibilities, ranging from 62.0 to 65.0%, for cows fed diets containing 12.5, 25.0, and 37.5% AHP-WS. Blair et al. (1974) fed 17.5, 32.5, and 47.5% pelleted untreated-WS diets to lactating cows and reported DM digestibilities of 75.3, 69.4, and 62.6%, respectively. However, their DMI were low, ranging from 14.1 to 16.2 kg/d, and the higher DM digestibility of their pelleted untreated-WS diet probably resulted from their low DMI. Organic matter (non-NDF) digestibility was similar for cows fed the control and 20.0% AHP-WS diets, which averaged 81.6%, but tended to decrease (76.8 and 70.3%) for cows fed the 40.1 and 60.0% AHP-WS diets, respectively. This suggests that the components solubilized during the AHP-WS treatment procedure are not as extensively degraded in the gastrointestinal tract as other cell-soluble components, resulting in the decreased OM (non-NDF) digestibilities for cows fed increasing levels of AHP-WS in the diet. Also, this result could explain the trend for lower OM digestibility with increased AHP-WS levels.

Increasing level of AHP-WS in the diet resulted in a linear increase (P = .03) in NDF digestibility, 44.4% for the control vs 54.6, 56.5, and 59.5% for the 20.0, 40.1, and 60.0% AHP-WS treatments, respectively. Cameron et al. (1990) reported a similar effect for cows in early lactation. This suggests that the NDF fraction of the diets containing AHP-WS was more rapidly and extensively degraded in the gastrointestinal tract than NDF of the fiber sources (AH and CS) in the control diet. This resulted in a linear upward trend (P = .13) in digestible NDF intake as the level of dietary AHP-WS increased, even though digestible DMI decreased when cows were fed the 40.1 and 60.0% AHP-WS diets. It seems that the AHP treatment of WS allows for its extensive microbial fermentation, which increases cell wall component digestion (Kerley et al., 1985). Other studies with AHP-WS (Kerley et al., 1986, 1987; Lewis et al., 1987) have indicated that NDF digestibilities were high, ranging from 61.9 to 85.1%, depending on diet composition. However, those values were achieved with the Type I (Kerley et al., 1985) and Type II (Kerley et al., 1987) AHP-WS products, in which higher concentrations of chemicals are used and the treated WS is washed free of most residual chemicals. The washed products also are dried in a forced-air oven. It is encouraging that high fiber digestibilities continue to be obtained with a product generating no liquid effluent (i.e., all treatment chemicals [water, residual H₂O₂, NaOH] are retained in the product). However, the significant increase in NDF digestibility for the AHP-WS diets compared with the control diet is partially offset by the equally large decrease in OM (non-NDF) digestibilities for these diets, most noticeably for cows fed the 60.0% AHP-WS diet. This suggests that the AHP
treatment of WS increased solubilization of the fiber components but that the solubilized fraction remained partially indigestible. This lowered digestible OM intakes for cows fed the 40.1 and 60.0% AHP-WS diets. A fiber analysis in which soluble fiber components are considered would be more appropriate in those instances in which a chemical treatment modifies cell wall structure such that a portion of the cell wall becomes soluble.

The addition of higher amounts of AHP-WS to the diet resulted in linear decreases in intakes of digestible DM ($P = .08$), OM ($P = .04$), OM (non-NDF; $P = .002$), and CP ($P = .10$) and a trend toward increased digestible ADF intake ($P = .12$). Digestible nutrient intakes for the control and 20.0% AHP-WS treatments averaged 16.2 and 15.2 kg/d for DM and OM, respectively, with noticeable decreases in digestible DM and OM intakes for the 40.1 and 60.0% AHP-WS treatments (Table 4). Digestible OM (non-NDF) intake decreased from 11.3 kg/d for cows fed the control diet to 7.8 and 5.8 kg/d for cows fed the 40.1 and 60.0% AHP-WS diets. This suggests that the decreased milk yield by cows fed the 40.1 and 60.0% AHP-WS diets may be attributed to decreases in digestible nutrient intake, because low energy and protein intakes are the two nutritional factors most likely to limit milk production.

**Ruminal Fermentation.** The effects of dietary AHP-WS on ruminal fluid pH, ruminal VFA patterns, ammonia N concentration, and digesta passage are presented in Table 5 for the ruminally cannulated cows. The level of AHP-WS in the diet had no effect ($P > .10$) on ruminal pH. Ruminal pH was similar among diets during the 24-h sampling period but diurnal variation occurred (ruminal pH tended to be highest from 0100 to 1100 for all diets and was lowest from 1600 to 1800; data not shown). In contrast, Cameron et al. (1990) observed that the substitution of 12.5% AHP-WS in the diet of early-lactation cows decreased ruminal pH to 5.79; this reduction was attributed to a smaller mean roughage particle size in the diet, which probably resulted in decreased saliva production and reduced the buffering capacity in the rumen. Ruminal pH was 6.17 for the AHP-WS diets in the present study, even though the forage particle size of these diets was decreased compared with the control diet. This may be the result of buffering by the residual NaOH in the AHP-WS, which contained approximately 80.1, 60.0, and 2.40% Na (DM basis) for the 20.0, 40.1, and 60.0% AHP-WS diets, respectively. The higher ruminal pH observed for cows when fed the AHP-WS diets in the present study may be attributed to the higher levels of AHP-WS, AH, and CS (70% forage: 30% concentrate) in the diet compared with the level of AHP-WS fed to early-lactation cows (Cameron et al., 1990) for which the diet was 50% forage:50% concentrate. Increasing the forage in the diet should increase both rumination time and saliva production, which enhances buffering capacity and dilution rate of ruminal fluid. Mertens (1979) suggested that maximal fiber degradation occurs between pH 6.7 and 7.1 and that fiber digestion is greatly reduced at a pH below 6.0. Therefore, the ruminal pH values reported in the present study should not greatly inhibit fibrolytic activity in the rumen. This was evident as NDF digestibility increased linearly, resulting in a higher digestible NDF intake as AHP-WS was added to the diet (Table 4).

Feeding higher levels of AHP-WS resulted in a linear increase ($P = .0001$) in total VFA concentration in the ruminal fluid (Table 5). Generally, an increase in total VFA concentration in the ruminal fluid is associated with a reduced ruminal fluid pH. However, the addition of AHP-WS to the diet increased total VFA concentration but resulted in molar proportions of acetate and propionate that were indicative of fiber fermentation end products. The reduced particle size and chemical treatment of the AHP-WS resulted in a rapidly fermented feedstuff that produced the highest concentration of total VFA for the 60.0% AHP-WS treatment (136.0 mM) and the lowest total VFA concentration (128.0 mM) for cows fed the control diet. The reduced particle size of the AHP-WS diets should increase surface area available for attachment of fiber-digesting bacteria and increase the rate of fermentation, which should allow for greater concentrations of total VFA. This agrees with previous research (Cameron et al., 1990) in which total VFA concentrations in the ruminal fluid of cows fed diets containing 12.5 and 25.0% AHP-WS were higher than those in ruminal fluid of cows fed the control diet containing AH and CS as the fiber sources.

Molar proportion acetate in ruminal fluid was increased linearly ($P = .0001$) with the addition of AHP-WS to the diet. Cows fed the
20.0, 40.1, and 60.0% AHP-WS diets had .9, 1.8, and 4.3 percentage units, respectively, greater molar proportions of acetate than cows fed the control diet, which had an acetate value of 64.9 mol/100 mol. Molar proportion of acetate in ruminal fluid was higher and less variable during the 24-h sampling period for cows fed the 60.0% AHP-WS diet, followed by the 40.1% AHP-WS diet, and considerable hourly variation occurred on both the control and 20.0% AHP-WS diets (data not shown). A quadratic effect \( (P = .0001) \) was observed for molar proportion of propionate with increased levels of dietary AHP-WS. The molar proportion of propionate was highest for the cows fed the 20.0 and 40.1% AHP-WS diets and lowest for cows fed the control and 60.0% AHP-WS diets. The shift in molar proportion of acetate can be attributed to a ruminal fermentation associated with increased fiber digestion and is confirmed by the increased NDF digestibilities for the diets containing AHP-WS (Table 4). A quadratic effect \( (P = .001) \) on the acetate to propionate \((A:P)\) ratio in ruminal fluid was observed as AHP-WS increased in the diet. The \( A:P \) ratios were 3.64, 3.50, 3.58, and 3.81 for cows fed the control, 20.0, 40.1, and 60.0% AHP-WS diets, respectively; corresponding milk fat percentages of 3.81, 3.90, 3.79, and 3.74 were noted for these ruminally cannulated cows. This resulted in a quadratic decrease in milk fat percentage (Table 3) as higher amounts of AHP-WS were fed, but this was not expected because lower milk fat percentages tend to occur when the \( A:P \) ratio falls below 2.5:1 (Woodford et al., 1986; Woodford and Murphy, 1988). However, feeding diets containing NaOH-treated sugar cane bagasse (Randel et al., 1972), sodium, and calcium hydroxide-treated corn cobs (Soper et al., 1977) or NaOH-treated alfalfa and orchardgrass hay (Canale et al., 1988) also did not increase milk fat percentage. In contrast, Cameron et al. (1990) reported a linear trend \( (P = .14) \) for greater milk fat percentage for cows in early lactation fed AHP-WS-based diets.

Ruminal ammonia N concentrations decreased linearly \( (P = .0001) \) for cows fed the higher amounts of dietary AHP-WS (Table 5). Ruminal ammonia N concentrations varied throughout the 24-h sampling period, peaking approximately 1 h after each feeding (1200 and 2300); concentrations were lowest and less variable over time for the 60.0% AHP-WS diet (data not shown). The higher ammonia N concentration for the control diet may be explained by the release of ammonia N from the AH, which contained 22.1% CP and was fed as 37.0% of the diet. Perhaps the rapidly fermented AHP-WS provided energy to increase the use of ammonia N for synthesis of microbial protein; a shortage of energy can limit the amount of microbial protein synthesized within the rumen (NRC, 1988). Kerley et al. (1987) reported lower ammonia N concentrations for diets containing AHP-WS when fed to wethers and suggested that ruminal microbes assimilated the greatest amount of ammonia into bacterial protein when provided with a diet that contained a rapidly fermentable carbohydrate such as AHP-WS. Wilkins (1981) reported a similar finding, in which the addition of fermentable carbohydrates to grass silage resulted in reduced ruminal ammonia N concentrations. It seemed that ruminal ammonia N concentrations were adequate in this study for cows fed all diets based on the high fiber digestibilities and digestible fiber intakes. Hungate (1966) concluded that a shortage of ruminal ammonia N may reduce cellulolytic bacterial growth, which could reduce fiber digestion in the rumen.

Fluid and particulate dilution rates \((D)\) responded quadratically \( (P = .02 \text{ and } P = .09, \text{ respectively}) \) as level of AHP-WS in the diet increased. Fluid \( D \) were higher for the AHP-WS-based diets at approximately 15.0%/h, compared with 14.1%/h for the control diet. Particulate \( D \) was 6.69%/h for the control diet and increased to 7.09, 7.29, and 6.92%/h for the 20.0, 40.1, and 60.0% AHP-WS diets, respectively. This is consistent with other studies (Kerley et al., 1986; Cameron et al., 1990) in which feeding AHP-WS increased both fluid and particulate \( D \) in wethers and early-lactation dairy cows. A more rapid reduction in AHP-WS particle size during rumination as well as increased rates and extent of digestion could result in more extensive microbial degradation of the AHP-WS, which could lead to an increased particulate \( D \) from the rumen. Although particulate \( D \) were higher for cows fed the AHP-WS-based diets, no depressions in DM digestibility or increases in DMI were observed among treatments. In contrast, fluid or particulate \( D \) from the rumen were not affected in lactating cows fed NaOH-treated alfalfa and orchardgrass hay (Canale et al., 1988) or in sheep fed NaOH-
treated cotton straw (Ben-Ghedalia et al., 1983). Other reports indicate that feeding (Thomson et al., 1978) or intraruminal infusions (Rogers and Davis, 1982) of mineral salts increased fluid D. Given the high level of sodium in the AHP-WS, one might anticipate increases in fluid and particulate D in cows fed this material. However, other dietary ingredients may have prevented large increases from occurring. Fluid D were similar to those reported by Woodford and Murphy (1988) and higher than those of Shaver et al. (1986) and Woodford et al. (1986), all of whom used traditional forage sources in their diets. In this study, ruminal liquid volume was not altered (P > .20); values ranged from 77.1 liters for cows fed the control diet to 78.7 liters for cows fed the high-AHP-WS diet. The results of this study demonstrate that during mid-lactation, dairy cows fed the 20.0% AHP-WS diet had DMI and milk yields similar to those of cows fed a control diet containing AH and CS as the fiber sources. Cows fed the 60.0% AHP-WS diet had noticeably lower DMI and milk production than those fed the other diets. Milk fat and milk protein percentages decreased when cows were fed the 40.1 and 60.0% levels of AHP-WS in the diet. These AHP-WS diets had greater NDF digestibility and digestible NDF intake than the control diet. Dry matter, OM, and CP digestibilities were not affected by feeding higher amounts of AHP-WS in the diet. Feeding AHP-WS to supply greater than 40% of the dietary DM decreased DMI, milk yield, and certain milk components.

Implications

The alkaline hydrogen peroxide treatment of wheat straw results in a product that when used in reasonably high quantities in diets, can provide a relatively large amount of the energy required by dairy cows in mid-lactation. Intake-limiting components in native wheat straw are modified so that cows are able to ingest larger quantities of feed. Ruminal fermentation criteria were not negatively affected by the inclusion of treated wheat straw in the diet; milk yield and composition remained within acceptable ranges for mid-lactation dairy cows when up to 60% of the roughage (alfalfa haylage and corn silage) was replaced by treated straw.

Literature Cited


