Feeding Value of Acid Hydrolyzed Wood Pulp for Ruminants

Aboubacar S. N'diaye

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FEEDING VALUE OF ACID HYDROLYZED
WOOD PULP FOR RUMINANTS

BY

ABOUBACAR S. N'DIAYE

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science
Major in Animal Science
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1986
This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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Appreciation is expressed to Dr. L. D. Kamstra and C. W. Carlson for their advice to correctly accomplish this work.

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Special appreciation is due to my wife, Binette, my daughter, Eva, for their understanding, love and support; to my parents, Djiby and Hady N'Diaye, for their encouragement over the past thirty-two years and my entire life, all of whom have made this possible.

A. S. N.
INTRODUCTION

Wood and wood residues provide a potential source of energy for ruminants because they contain 70 to 80% carbohydrates. In the United States alone, the quantities of low quality wood and non utilized residues may total more than 100 million tons annually. These wood residues have not been used successfully as ruminant feed supplement because of the poor digestibility of their carbohydrate components.

Interest has been generated in identifying roughage substitutes which can be readily obtained at low cost, are uniform in chemical and physical characteristics, can be blended in complete rations and yet maintain normal rumen function and animal health. Materials such as corn cobs and cottonseed hulls have been successfully used although it is sometimes difficult to maintain an adequate supply at reasonable cost. Oyster shells, rice hulls and flax shives have also been used with varying degrees of success. Such feeding programs minimize the nutritive contribution of roughages and focus attention on those non nutritive factors which maintain rumen function and feed intake while preventing abnormalities of the gastro-intestinal tract and liver.

During World War II, Scandinavian and European countries investigated the utilization of delignified wood as a feed component for ruminants. The practice was discontinued after the war because of
the high cost of delignifying the product. An economical means of increasing the digestibility of these materials would provide a significant source of new "forage" materials containing more than 75% available carbohydrates.
Chemical Characterization of Wood Materials

The major components of lignocellulosic materials such as wood pulp and sawdust are lignin, cellulose and hemicellulose (Baumgardt, 1969; Feist et al., 1969; Donifer et al., 1969).

Cellulose is the most abundant and insoluble polysaccharide of the cell wall constituents. It is a polymer of glucose units in which the degree of polymerization varies within and between sources of cellulose (Pidgen and Heaney, 1969). Availability to the rumen microflora ranges from 25 to 90%, making it a potential source of energy for ruminants (Feist et al., 1969; Williams et al., 1969; Van Soest, 1969, 1982; Jurgens, 1982).

Hemicellulose consists of short chains of glucan, polymers of xylose, mannose and galactose plus a mixture of sugars and uronic acid polymers (Williams et al., 1969; Van Soest, 1969, 1982).

Lignin is an aromatic compound that is indigestible and is of no nutritive value to mammals. Its main function is to supply strength and rigidity to the plant material. The nutritional significance of lignin lies in its indigestible nature and subsequent effects of acting as a physical barrier impeding the microbial breakdown of hemicellulose and cellulose.

Williams et al. (1969) indicated that the high level of lignocellulosic components in wood and wood by-products is also
associated with relatively low levels of potassium, calcium and some trace minerals that may limit microbial fermentation.

The association between lignin and the other major fiber constituents appears to limit bacterial and enzymatic access to the carbohydrates of the cell wall, leaving wood and wood residues essentially unavailable to ruminants (Van Soest, 1969, 1982; Baker, 1973; Butterbaugh and Johnson, 1974). Pidgen and Heaney (1969) and Van Soest (1982) have concluded that the chemical composition of lignocellulose and availability in the rumen depend on the stage of maturity of the plants and the digestibility of the hemicellulose component. There is a decrease in cell content as plants mature due to increased lignification which encrusts and protects the cell wall from bacterial attack. In later stages of maturity, xylan and uronic acid which are the major components of hemicellulose are highly indigestible.

The existence of a chemical bond between the soluble carbohydrate fractions and lignin has been identified (Feist and Tarkov, 1969; Van Soest, 1969, 1982; Movat, 1980; Crosthwaite et al., 1984). They also concluded that the high xylan content of hemicellulose and lignin contributed to the depression of digestibility of carbohydrates observed in mature grass and wood by-products.

In spite of the nutritionally limiting factors of these lignocellulosic materials, their advantage is to provide the tactile stimulation necessary to rumen function (Baumgardt, 1969). The
modification of these materials to delignify the product would release
the cellulose fraction from the lignin-carbohydrate fraction and
provide an additional source of energy. The most frequently used
modification procedures involve chemical treatment (Mellenberg et al.,
1970; Anthony et al., 1968; Feist et al., 1969; Baker, 1973; Movat,

Chemical Treatment of Fiberous Feeds

The effect of sodium hydroxide or other alkali treatments such
as liquid ammonia is to saponify ester linkages in the fiber allowing
swelling and water uptake. Swelling of wood and wood residues in
water following treatment with dilute alkali is a result of cleavage
of ester bonds on xylan chains that act as cross linkages that
normally maintain structure (William et al., 1969). Alkali treatment
liberates the carboxyl group on the glucuronic acid attached to the
lignin and hemicellulose. The diffusion rate of water soluble
materials through the cell wall is increased several times by
treatment which increases the swelling capacity of the fiber (Tarkov
and Feist, 1969).

Increasing the amount of free carboxyl groups improves
digestibility. Feist et al. (1969) found that the amount of NaOH
required to maximize digestibility appears to be independent of plant
species and is 5 to 6 g of NaOH/100 g of wood. Alkaline
delignification has been shown to increase in vitro digestibility of
some wood species (William et al., 1969; Pidgen and Heaney, 1969;
Feist et al., 1970). Baumgardt (1969) indicated that treatment of
wheat straw with 6% alkali increased digestible energy content from 35 to 65% but above 9% NaOH no further increases were observed. Millet et al. (1970) indicated that digestibility of aspen wood pulp was 32% before treatment and 50% after treatment with 1% NaOH.

Terashima (1984) demonstrated that ammonia treatment (5%) slightly increased the concentration of free carboxyl groups in rice straw but not in rice hulls. Feist and Tarkov (1969) determined that the N content as ammonium and amides in ammonia treated wood pulp (2.5%) was 0.36gN/100g wood or 2.5 MeqN/100 g treated wood. Millet et al. (1970) observed a 50% increase in digestibility of aspen wood when the material was treated with ammonia. Feist et al. (1969) used NH₄OH as the alkali treatment and proposed that ammonium acetate resulting from the neutralization of the excess alkali could serve as an extra source of nitrogen in the treated straw.

Crosthwaite et al. (1984) using 1.1% HCl as vapour and H₂SO₄ in dilute aqueous solution showed that bagasse, rice straw and oat hulls were more digestible in in vitro rumen fluid fermentations and cellulose enzyme degradation was more extensive. Improvements up to 4-fold for 1.1% HCl in oat hulls were observed. The effects were attributed to acid hydrolysis especially of hemicellulose and perhaps to some extent of lignin - carbohydrate linkages (Butterbaugh and Johnson, 1974). Klopfenstein et al. (1967) using in vitro digestibility to make comparisons of the feeding value of wheat straw and corn cobs found that treatment with .5% HCl increased dry matter digestibility by 16 and 13% for wheat straw and corn cobs,
respectively. Treatment with 4% hydrogen peroxide (H$_2$O$_2$) enhanced dry matter digestibility by 21 and 22% for wheat straw and corn cobs respectively. The cell wall content of both roughages were reduced by treatment with H$_2$O$_2$ and HCl. Lignin content was reduced by treatment with H$_2$O$_2$ but not with HCl.

Butterbaugh and Johnson (1974) indicated that a 75% low acid hydrolyzed wood pulp (LA-HWP) diet treated by .8% H$_2$SO$_4$ was consumed well by growing lambs. There were no significant differences in weight gain of lambs fed 25 or 50% LA-HWP rations compared to lambs fed the basal diet composed of alfalfa. Dry matter intake/kg gain significantly increased as the level of LA-HWP increased over 25% in the diet. Supplementation of the 75% LA-HWP ration with soybean meal reduced the dry matter/kg gain requirement (P < .05). Low acid-hydrolyzed wood pulp dry matter digestibility was 32%. Palatability factors limited the utilization of high acid-hydrolyzed wood-pulp (HA - HWP) treated by 2.3% H$_2$SO$_4$ at more than 35% of the ration. Incorporation of HA - HWP at 20 or 35% of the diet decreased weight gain (P < .05) and dry matter digestibility (P < .05) compared to the basal ration.

Physical treatment has also been used to modify the chemical composition of roughage substitutes. Heller et al. (1977) indicated that there was 20% less hemicellulose in wheat straw ground through a 60 mesh screen than in samples ground through a 20 mesh screen. Shaking wheat bran for 24 hours at 25°C solubilized 17% hemicellulose
at pH 11.5 and 9% at pH 2.2. Refluxing for 60 min reduced hemicellulose by 62 and 52% at pH 11.5 and 2.2 according to the same researchers. Ali et al. (1977) showed that variation in particle sizes by physical treatments may change apparent fiber composition.

**Intake and Rumen Osmolarity: Effect of Salt**

The use of alkali treatments such as NaOH to improve the efficiency of utilization of roughage substitutes has as second effect to provide more salt in the diet (Feist et al., 1969). The role of salts in improving palatability and feed consumption has been known for a long time. Supplementation of salts in a basal diet of barley fed to calves increases feed intake and growth rate before weaning (Feist et al., 1969). These workers also observed a linear increase in feed intake and growth rate with up to 20g Na/kg dry matter as NaHCO₃ after the weaning period.

With NaCl, the threshold has been shown to be 11g Na/kg DM. Above that value, there is a sharp increase in water intake. Kronfeld (1979) showed that the supply of salts provides the animal with elements helpful to the kidney in combating a high load of exogenous acids which is especially important in ruminants fed high proportions of grain.

Animal performance is affected by the type of salts present in the diet. Schneider et al. (1984) found that 7.5% NaHCO₃ increased feed intake and milk production in lactating cows receiving a corn silage basal diet but feed intake and milk yield were depressed if
KHCO₃ was used. These effects became more pronounced when the K content of the diet reached 1.5%.

Hale (1979) showed that salts in the diet increased the turnover rate of the fluid phase in the rumen and raised the osmolarity of rumen liquor which in turn increased absorption from the rumen.

Kronfeld (1979) showed that ammonium sulfate included at .5 to 2% of the diet can be used as a source of NPN for ruminants. It may lead to renal acidosis, calcium loss and osteoporosis at higher concentrations. Its tendency to acidify the urine also helps protect against urolithiasis. Ammonium sulfate has also been used to correct metabolic alkalosis caused by exaggerated bicarbonate excretion (Hale, 1979). Hale (1979) also found that up to .5% (NH₄)₂SO₄ may be beneficial in diets containing abundant soluble carbohydrates and less than optimal protein.

**Effect of Non-protein Nitrogen Supplementation**

The utilization of low quality roughages and crop residue feeds by ruminants is limited by low nutrient content and poor digestibility (Pritchard, 1983). Protein is one of the most limiting nutrients in these feedstuffs. Supplementation is necessary to meet animal protein requirements and to maximize ruminal fermentation. Ammonia availability in the rumen is important to meet N requirements of cellulolytic bacteria (Bryant and Robinson, 1963). Concentrations of ruminal ammonia (NH₃ - N) required for maximum growth have been
determined but these values cover a wide range from 5 mg/dl (Satter and Slyter, 1974) to 23.5 mg/dl (Merhez et al., 1977).

Delayed digestion of diets high in cellulose may compound the problem of optimum ruminal $\text{NH}_3 - \text{N}$ levels. Many protein and NPN sources are rapidly deaminated or hydrolyzed in the rumen, with peak $\text{NH}_3 - \text{N}$ levels reached 1.5 to 4 hours after feeding which then steadily decline (Davis and Stallcup, 1967). The maximum rate of cellulose digestion may not occur for another 4 to 8 hours (Sutton, 1971). Declining ruminal $\text{NH}_3 - \text{N}$ may limit activity of cellulolytic bacteria in these instances.

Zyviens et al. (1977) indicated that the treatment of wood by-products with ammonia will increase $\text{NH}_3$ production in the rumen. Digestibility of crude protein was found to increase to 64% with ammoniated beet pulp fed to cows compared to 60% with untreated dried sugar pulp. Graham et al. (1976) made an evaluation of ammonium sulfate as potential NPN source for ruminants. They found that sheep fed concentrates and given 15 g N as urea died with classic signs of ammonia poisoning whereas no sheep died when fed 15 g N as $(\text{NH}_4)_2\text{SO}_4$. Blood ammonia .5 and 1.5 hours after treatment was higher ($P < .05$) when urea was administered.

Briggs (1967) demonstrated that sulfur in the sulfate form is used by the rumen micro-organisms to synthesize sulfur containing amino-acids. Radioactive sulfur was found in cysteine and methionine after being fed as $(\text{NH}_4)_2^{35}\text{SO}_4$ to growing lambs. With diets low in sulfur, the addition of $(\text{NH}_4)_2\text{SO}_4$ may improve nitrogen retention in
cattle. Donifer et al. (1969) found that bacterial protein synthesized in the rumen was deficient in methionine. The rate of synthesis of sulfur containing amino acids is limited and may be alleviated by feeding supplemental sulfur. Sheep requirements for sulfur appear to be more critical than in cattle because of wool production (Van Soest, 1969, 1982; Jurgens, 1982).

Among all the other NPN (urea derivatives, amides, creatine, ammonium salts), the ammonium salts are the best sources of N for bacterial growth and subsequent cellulose digestion (Briggs, 1967). Garanch (1979) showed that with ammonium salts, the utilization rate of N was higher than that noted when feeding urea. The same worker, in a comparative study of the effect of feeding urea, ammonium acetate and ammonium sulfate on nitrogen metabolism in lactating cows found that the diets supplemented with ammonium salts resulted in more rumino-hepatic circulation of nitrogen than the basal diet alone. The ammonia levels from these compounds and the N utilization were comparable with that obtained with urea.

Feeding Value of Wood-Residues.

Muhamed (1982) fed sheep 300 g of corn grain and 400 g of low quality cellulose or wood residues and found that crude fiber digestibility was 64% and 63% respectively for the two fiberous products. Both roughages decreased protein digestibility of the basal ration. Sorokin (1982) noted that when wood hydrolysate and beet molasses were added to diets fed to rams there was a decrease in the
concentration of ammonia in the rumen and an improvement of the efficiency of dietary N utilization.

According to Muhamedyanov (1982), the product obtained after treating wood residues with $\text{H}_2\text{SO}_4$ contained .5 to 1.0% nitrogen, 33 to 54% crude fiber, .9 to 2.1% fat and 10.8 to 12.2% reducing substances. Young bulls given a daily ration of hay and barley with or without 2.9 kg of wood product replacing barley showed no difference in average daily gain. Staroddubstev (1981) found that young bulls fed a diet containing wood hydrolysate replacing corn grain at 1.1 to 1.5 kg daily gained 9% more than bulls fed the basal diet. Dagranov (1981) also showed that rearing young cattle for 165 days on a grain diet without roughages negatively affected their physiological condition. Adding 13% wood shavings to the diet improved ration digestibility, increased daily gain and reduced the labor cost per unit of gain. In contrast Muhamedyanov (1983) found that young bulls fed 100% concentrate with or without hydrolyzed wood (3 kg/day) showed no difference in average daily gain, carcass yield or percent of lean carcass. Semenyutin et al. (1983) found that bulls given a mixture of pelleted aspen and pine shavings, grass meal and ground grain did not show significant differences in daily gain, feed efficiency or amount of lean carcass compared to the control group receiving a pelleted diet of barley and silage.

Block et al. (1980) studying the effects of wood pulp fines as roughages in a ration for young dairy replacement cows found that with 11% wood pulp supplement, calves gained more weight than those given
silage and were of equal weight to calves fed a commercial diet from birth until 8 weeks. Calves fed silage had higher plasma urea-N concentrations than calves fed wood-pulp. Rumen epithelial tissue obtained from males 18 weeks of age fed wood pulp had normal papillae color, density and length. Muhamedyanov (1982) fed heifers a diet of hay, silage and milled grains with or without 3 to 5 kg of hydrolyzed sugar and observed that there was no effect on average daily gain. Incorporation of hydrolyzed sugar in the diet increased percentage fertility at first heat (P < .05) and percentage returning to heat during the first four months of lactation (P < .05).

Trufanov et al. (1981) found that wood hydrolysate added to a low carbohydrate basal diet given to lactating cows caused some increase in milk production, milk protein and fat content. Hydrolyzed wood was recommended for correcting the sugar: protein ratio of diets for lactating cows (Duckin, 1981; Muhamedyanov, 1983). A corn silage diet plus 50% pulp fines yielded similar performance to a silage diet plus concentrates fed to young dairy replacement heifers (Block et al., 1980). In their study, they found no significant difference in average daily gain or feed intake of heifers at 23 weeks of age.

Starodubstev et al. (1982) observed that milk fat production by dairy cows receiving a 2 kg wood sugar supplement did not differ from a control group fed corn silage. Milk quantity required per kg butter was 26.0 vs 24.9 kg for the wood sugar supplemented and control groups, respectively. Butter quality was not affected by the diet.
Duckin et al. (1981) found that replacing fodder beet with an equivalent amount of wood hydrolysate to produce a diet with a sugar: protein ratio of 1:1 had no adverse effect on nutrition of cows, their milk yield or milk quality. However increasing the level of hydrolyzed sugar in the diet depressed voluntary intake and digestibility and utilization of nutrients.

The different sources cited in this review showed that wood residues such as wood pulp and sawdust, treated by alkali or acid hydrolysis can effectively be used as ruminant feed supplement. Chemical treatment enhances the digestibility of cell wall content and decreases lignin content of these products. The substitution of these roughages for a given quantity of concentrates in ruminant diet did not induce toxicity effect and did not affect animal performance.
PART I
INTAKE BY BEEF HEIFERS OF DIETS
CONTAINING ACID HYDROLYZED WOOD PULP

BY
ABOUBACAR S. N'DIAYE

SOUTH DAKOTA STATE UNIVERSITY
Summary

This preliminary experiment was conducted to determine the effect of acid hydrolyzed wood pulp (AHWP) concentration in the diet on dry matter intake by beef heifers. Diets containing 0, 30 and 60% AHWP were fed to 6 yearling heifers. Daily dry matter intake was measured during a 28 day period. Total dry matter consumption for the 0, 30 and 60% diets was 220, 270 and 176 kg, respectively. Mean values of dry matter intake for each pair of heifers during the last 7 days of the trial were 9.73, 9.90 and 6.10 kg·hd⁻¹·d⁻¹, respectively. Feed efficiencies for the 28 day period were 4.26, 4.88 and 8.2, respectively. An attempt to include higher dietary levels of AHWP resulted in feed refusals.

Introduction

Wood pulps have been used as energy sources for ruminants during periods of critical feed shortage but have never been recognized as alternatives for conventional feedstuffs under normal economic conditions. Recently re-evaluation of these roughage substitutes has become important for a number of reasons including: a source of tactile stimulation necessary for rumen function, normally provided by the fibrous nature of the product; the great increase in cost of conventional feedstuffs, particularly for animals kept at maintenance; and the potential of treated wood pulps and pulp fines as energy sources for ruminants.

Besides any positive aspects of utilizing wood residues in ruminant diets, limiting factors such as low palatability associated...
with the physical texture of ration containing high percentage of wood residues and chemicals added during treatment procedures could induce a sharp decrease in feed consumption and affect animal performance.

This preliminary study was conducted to determine whether an aspen wood byproduct that had undergone novel chemical and physical conditioning was acceptable and safe for beef cattle.

Materials and Methods

The test material used was provided by researchers in the Applied Sciences Department at New York University. Ammonium hydroxide had been added to the AHWP to buffer the acid present. This product was 33% dry matter and contained 16% crude protein, 46% acid detergent fiber, 12.8% lignin, .2% Ca, .05% P on a dry matter basis.

Test diets formulated to contain 0, 30 or 60% AHWP (Table 1) were fed to yearling beef heifers. Two individually fed heifers were assigned to each treatment.

Substitution of experimental diet for basal diet was done over a 4 day period. During this time intake was maintained at 5 kg DM·hd⁻¹·d⁻¹. On day 5, dry matter intake was increased 15% daily until feed refusals appeared. Feed refusals were removed daily to assure that feed consumed was fresh. This feeding regime was followed for 28 days.

Results and Discussion
Initially higher levels of AHWP (0, 40 and 80%) in the diet were fed. No apparent toxicity problems were observed, but heifers refused to eat the 80% AHWP diet. The levels of test material were then reduced to 30 and 60% of the diet.

Mean values (Table 2) for dry matter intake for the 0, 30 and 60% AHWP were 220, 270 and 176 kg, respectively. One of the animals receiving the control diet developed pneumonia during the 5th day of the trial causing a sharp decrease in feed intake for 6 days. Observation of the feeding behavior during the final 7 days of the study (Table 2) indicated that heifers consumed the 30% and 60% AHWP diets readily after a suitable adaptation period.

The AHWP used had a high moisture content and poor blending characteristics. Butterbaugh and Johnson (1974) found that the physical texture is a factor limiting AHWP at more than 35% of the ration and it would appear that a similar response would be expected with this product. No gross toxicity problems were observed even with the high NPN content of the diets. It appears that diets that contain at least 30% AHWP can be fed to ruminants.
<table>
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<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Cracked Corn</td>
<td>80</td>
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<tr>
<td>AHWP</td>
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<tr>
<td>Corn Cobs</td>
<td>14.17</td>
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<tr>
<td>Soybean meal, 44%</td>
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<tr>
<td>Dicalcium phosphate</td>
<td>--</td>
</tr>
<tr>
<td>Limestone</td>
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<tr>
<td>Trace Mineral Salt</td>
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<tr>
<td>Potassium Chloride</td>
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<tr>
<td>Crude Protein</td>
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<td>Calcium</td>
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<tr>
<td>Potassium</td>
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<sup>a</sup> All values expressed as a percent of diet dry matter

<sup>b</sup> Treatment refers to percent acid hydrolyzed wood pulp in the diet
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<td>Initial weight, kg</td>
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<tr>
<td>Final weight, kg</td>
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<td>Average daily gain, kg</td>
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<td>Daily dry matter intake, kg·hd&lt;sup&gt;-1&lt;/sup&gt;·d&lt;sup&gt;-1&lt;/sup&gt;</td>
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<td>Feed/Gain</td>
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<td>Dry matter intake for last 74 days, kg·hd&lt;sup&gt;-1&lt;/sup&gt;·d&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>9.73</td>
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<sup>a</sup>Treatment refers to percent acid hydrolyzed wood pulp in the diet
PART II

REPLACEMENT VALUE OF ACID HYDROLYZED WOOD PULP FOR CORN IN DIETS FED TO LAMBS

BY

ABOUBACAR S. N'DIAYE

SOUTH DAKOTA STATE UNIVERSITY
Summary

The effect of percentage dietary acid hydrolyzed wood pulp (AHWP) on dry matter, crude protein and acid detergent fiber digestibility, and nitrogen retention by feeder lambs was examined. Sixteen wether lambs were fed a diet based on corn grain, corn cobs and soybean meal. Treatments included the replacement of corn with AHWP as 0, 15, 30 or 45% of the dry matter intake. Dry matter digestibility (DMD) was 76.5, 69.3, 65.6, and 78.5% for treatment 0, 15, 30, and 45% respectively. Dry matter digestibility decreased (P < .05) when the 15 and 30% levels of AHWP were fed. Crude protein digestibility (DP) was 81.7, 78.2, 75.2 and 85.2% respectively. As the percent AHWP increased from 30 to 45% DP increased (P < .05). Mean values for nitrogen retention were 85.4, 81.9, 75.6 and 83.7% of N digested and was lower on diet 30% than diet 15% or 45% (P < .05). Acid detergent fiber (ADF) content of the diets was 19.1, 25.8, 34.8 and 48.3%, respectively. Mean values for ADF digestibility were 49.51, 35.19, 32.9 and 73.36%, respectively and was higher for the 45% diet (P < .05). In vitro dry matter digestibility (IVDMD) was determined for 6 ratios of wood pulp:corn grain substrate. Percentages of AHWP used as substrates were 0, 20, 40, 60, 80 and 100%, respectively. Mean values for IVDMD were 79.5, 82.8, 61.9, 48.2, 41.0 and 40.3%, respectively. The regression equation predicting the effect of AHWP concentration on in vitro (IVDMD) was defined as: IVDMD = 83.09 - .48X (r² = .87; P < .05). The control
substrate was more digestible than substrates containing more than 20% AHWP.

Introduction

Butterbaugh and Johnson (1974) indicated that wood and wood residues have evoked little interest as dietary ingredients for ruminants although they contain 70 to 80% total carbohydrates. Inclusion of more than 15% raw sawdust into ruminant diets usually depresses intake and weight gains (Anthony et al. 1969). Other workers have studied the use of chemical treatment of wood and poor quality forage by adding alkaline or acid ingredients (Pidgen and Heaney, 1969; Feist and Tarkow, 1969) to break down the ligno-cellulose complex and enhance the utilization of these products. Millet et al. (1970) observed an increased digestibility of aspen wood from 32 to 50% when the material was treated with ammonia. Treatment of wheat straw with 6% alkali increased digestible energy content from 35 to 65% (Baumgardt, 1969). Improvement in digestibility was due to increased amount of free carboxyl groups.

The study reported here was to determine the feeding value of novel acid hydrolyzed wood product relative to corn grain for ruminants.
Materials and Methods

Sixteen crossbred wether lambs ($\bar{x} = 31.8$ kg) were used in an experiment to determine the feeding value of AHWP. Lambs had previously been treated for internal and external parasites and received injectable vitamins A, D and E.

Treatments included a control diet and 3 diets in which acid hydrolyzed wood pulp replaced corn as 15, 30 or 45% of the control diet dry matter, each fed to 4 lambs.

All lambs were readily consuming 800 g DM·hd$^{-1}$·d$^{-1}$ after 7 days. They were transferred to metabolism cages and allowed 4 day adaptation to the new environment. Feces and urine were collected for the next 4 days. Intake was raised to 1000 g DM·hd$^{-1}$·d$^{-1}$, maintained for 3 days and was followed by a second 4 day period of urine and feces collection.

Fecal samples were pooled within each 4 day collection period for each lamb and stored at 2°C. At the end of the collection period feces were mixed well and subsampled for DM, N and ADF determination. Feed and feces were dried in a force draft oven at 100°C for 36 hours to determine dry matter content.

Urine was collected in a vessel containing 100 ml of 30% HCl solution. Urine output of < 1000 ml was adjusted to volume (1 l) with deionized water to avoid precipitation. Subsamples (10%) of urinary output were stored at 2°C. Nitrogen content of urine, wet feed and wet feces were determined by the Kjeldahl method. Acid detergent
fiber content of dry feed and dry feces was determined as described by Goering and Van Soest (1970).

Nitrogen retention values reported reflect the percentage of digestible N retained by the lambs.

Single stage in vitro dry matter digestibility (Tilley and Terry, 1963) was determined for substrates containing 0, 20, 40, 60, 80, and 100% AHWP. The balance of substrate was ground corn. Incubation was stopped after 48 hours and dry matter disappearance was determined.

In the in vivo study no differences due to period and no period x diet interactions existed. Therefore, period values were pooled and data analyzed as a completely random design experiment with subsamples. The in vitro data was analyzed as a randomized complete block with the replication of all treatments considered as the block (Steele and Torrie, 1980). In all cases mean separation tests were made using linear contrasts.

Results

Lambs adapted to the diets rather quickly although 45% AHWP was less readily consumed apparently due to ration texture. Higher levels of DMI were not attempted because of the limited supply of test material on hand. All lambs exhibited positive weight gains (\(\bar{x} = 242\ \text{g} \cdot \text{hd}^{-1} \cdot \text{d}^{-1}\)) while in the metabolism crates. Diet did not affect weight change.
Dry matter intake, crude protein and acid detergent fiber digestibilities and N retention are shown in Table 2. There were no differences related to period and no period x diet interactions. Therefore, combined mean values will be discussed. Dry matter digestibility was affected by the percentage of AHWP in the diet (P < .05). Digestibility was depressed when the diet contained 15 or 30% AHWP but increased to a level similar to the control diet when the 45% AHWP diet was fed.

Digestibility of crude protein was increased when AHWP content increased from 30 to 45% (P < .05). A similar response was noted for N retention.

Acid detergent fiber content increased as percentage AHWP increased in the diet. No difference in ADF digestibility was observed between diet 0, 15, and 30. ADF digestibility was higher (P < .05) when 45% AHWP was fed.

In vitro dry matter digestibility with wood pulp replacing corn grain at 6 different levels decreased linearly (P < .05) with increasing level of test material. Under these conditions AHWP contains only 35.1% fermentable dry matter.

Discussion

Lowered digestion coefficients for dry matter, crude protein and acid detergent fiber and decreased N retention were observed as dietary AHWP increased from 0 to 30%. These results are consistent
with those found by Butterbaugh and Johnson (1984) who found that incorporation of high acid hydrolyzed wood pulp (HA-HWP-2.3% $H_2SO_4$) at 20 and 35% of the diet depressed nutrient digestibility compared to the basal ration. Negative associative effects may have been involved in this response. With certain feedstuffs there seems to be some antagonism in ruminal fermentation. Changing the ratio of these ingredients in the diet may eliminate the problem as was indicated when 45% AHWP was fed. The 15 and 30% AHWP had a concentrate:roughage ratio of 55:45 and 40:60, respectively, which fell into the range where such negative interactions have been noted previously (Church, 1975). The concentration and amount of acid used to delignify the product could also cause lowered nutrient digestibilities. Butterbaugh and Johnson (1974) found that diets containing up to 75% of low acid hydrolyzed wood pulp (LA-HWP-8% $H_2SO_4$) were consumed well by growing lambs. There were no effects on weight gains and feed efficiency compared to lambs fed the basal diet.

Although DMD is improved by chemical treatment in some instances, the response may be limited unless supplemental N is included in the diet. Sorokin (1982) reported that substitution of hydrolyzed pine residue for 15% alfalfa meal diet fed to feeder lambs decreased crude protein digestibility by 5.8%. Supplementation with protein as soybean meal and chemical treatment tended to alleviate this depression in digestibility. In this study soybean meal was included at a constant level that would meet the animal protein
requirement making it impossible to evaluate the affect of supplemental protein on digestibility.

AHWP contributed 0, 18, 36.7 and 52.9% of dietary crude protein for treatment 0, 15, 30 and 45% respectively. CP digestibility appeared related to DMD indicating that the NPN in the AHWP was probably bound. Nitrogen retention also appeared related to DMD. This suggested that digestible energy was also limiting in the diets tested.

Lignin content present in the AHWP used in this study was 12% and may have affected nutrient and DM digestibility. Baker, et al. (1973) found that digestibility of a wood residue depends upon the quantity of lignin removed, but not upon the method of removal. In general, they observed that wood pulp had a higher digestibility when the lignin content was < 5%. Digestibility and feed consumption are generally inversely related to lignin content of wood pulp and as lignin content increases, digestibility of dry matter decreases in the same order as rate of passage and feed intake decrease.

Regression analysis of in vitro dry matter digestibility (IVDMD) data showed that corn and AHWP digestibilities were 83.1 and 35.1%, respectively, and a linear decrease (P < .05) was noticed with increasing level of AHWP in the media (Table 3). No quadratic effects were observed using this procedure. In vitro DMD of sawdust was estimated to be 31% (Mellenberg, 1971) and that of AHWP to be 32% (Butterbaugh and Johnson, 1974), indicating that acid hydrolysis did not result in a significant increase in feed value of sawdust.
The bottom line of this study showed that the lignin content (12%) of AHWP was not changed from values expected for aspen sawdust. The high acid and NPN content of the product tested was apparently safe for ruminants. Texture and moisture content of AHWP incorporated at high levels may limit acceptability and manageability of the product. The in vivo and in vitro DMD values appear low. Quadratic response of DMD observed in vivo and unanswered questions about N retention merit further studies.
**TABLE 1. FEEDER LAMB BASAL AND EXPERIMENTAL DIETS**

<table>
<thead>
<tr>
<th>IFN</th>
<th>Diet&lt;sup&gt;a&lt;/sup&gt;</th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>15</td>
<td>30</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Soybean meal, 44%</td>
<td>5-04-604</td>
<td>11.26</td>
<td>11.26</td>
<td>11.26</td>
<td>11.26</td>
</tr>
<tr>
<td>Corn cobs</td>
<td>1-02-782</td>
<td>30.00</td>
<td>30.00</td>
<td>30.00</td>
<td>30.00</td>
</tr>
<tr>
<td>Cracked Corn</td>
<td>5-02-842</td>
<td>57.56</td>
<td>42.56</td>
<td>27.56</td>
<td>12.56</td>
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<td>AHWP&lt;sup&gt;b&lt;/sup&gt;</td>
<td>---</td>
<td>---</td>
<td>15.00</td>
<td>30.00</td>
<td>45.00</td>
</tr>
<tr>
<td>Limestone</td>
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<td>0.78</td>
<td>0.78</td>
<td>0.78</td>
<td>0.78</td>
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<tr>
<td>Trace Mineral/Salt</td>
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<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
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<tr>
<td>Dry Matter</td>
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<td>93.30</td>
<td>76.0</td>
<td>62.5</td>
<td>54.4</td>
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<td>Crude Protein</td>
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<td>12.84</td>
<td>13.25</td>
<td>13.44</td>
<td>13.60</td>
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<tr>
<td>Acid Detergent Fiber</td>
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<td>19.1</td>
<td>25.8</td>
<td>34.80</td>
<td>48.40</td>
</tr>
</tbody>
</table>

<sup>a</sup>Percent of diet dry matter  
<sup>b</sup>Acid hydrolyzed wood pulp
<table>
<thead>
<tr>
<th>Diet</th>
<th>DRY MATTER</th>
<th>CRUDE PROTEIN</th>
<th>ACID DETERGENT FIBER</th>
<th>NITROGEN RETENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>76.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>81.7</td>
<td>49.5</td>
<td>85.4</td>
</tr>
<tr>
<td>15</td>
<td>69.3</td>
<td>78.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>35.2</td>
<td>81.9&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>30</td>
<td>65.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>75.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>33.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>75.6&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>45</td>
<td>78.5</td>
<td>85.3</td>
<td>73.4</td>
<td>83.7</td>
</tr>
<tr>
<td>SEM</td>
<td>3.5</td>
<td>7.1</td>
<td>5.6</td>
<td>3.5</td>
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</tbody>
</table>

<sup>a</sup> Diet refers to percent acid hydrolyzed wood pulp  
<sup>b</sup> Nitrogen retention, % of N digested  
<sup>c,d</sup> Adjacent means in the same column differ (<sup>c</sup>P < .05; <sup>d</sup>P < .10)
TABLE 3. IN VITRO DRY MATTER DIGESTIBILITY OF ACID HYDROLYZED WOOD PULP AND CORN MIXTURES

<table>
<thead>
<tr>
<th>Treatment a</th>
<th>Mean Values of IVDMD, %</th>
<th>Regression Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>79.85</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>82.85&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$Y = 83.09 - .48X$</td>
</tr>
<tr>
<td>40</td>
<td>61.96&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$r^2 = .87$</td>
</tr>
<tr>
<td>60</td>
<td>48.26&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$Y = IVDMD$</td>
</tr>
<tr>
<td>80</td>
<td>41.00</td>
<td>$X = %$ AHWP</td>
</tr>
<tr>
<td>100</td>
<td>40.32</td>
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</tr>
<tr>
<td>SEM</td>
<td>2.70</td>
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</tbody>
</table>

<sup>a</sup>Treatment refers to percent acid hydrolyzed wood pulp

<sup>b</sup>Adjacent means in the same column differ (<sup>b</sup>P < .05)
LITERATURE CITED


Block, E. and P. R. Shellenberg. 1980. Wood pulp fines or corn silage as roughages in complete rations or a pelleted complete ration for young dairy replacement from birth through 18 weeks of age. J. Dairy Sci. 51 (Suppl):74.


Harold, T. and C. F. Williams. 1969. Results of the chemical changes that occur when hardwoods are treated with dilute NaOH or with liquid ammonia. J. Amer. Chem. Soc. 95:205.


## TABLE 1. HEIFER MAINTENANCE DIET

<table>
<thead>
<tr>
<th>Item</th>
<th>IFN</th>
<th>%</th>
<th>NE&lt;sub&gt;m&lt;/sub&gt;</th>
<th>Crude Protein</th>
<th>Calcium</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Cobs</td>
<td>1-02-782</td>
<td>50</td>
<td>0.485</td>
<td>1.60</td>
<td>0.060</td>
<td>0.020</td>
</tr>
<tr>
<td>Cracked Corn</td>
<td>5-02-842</td>
<td>30</td>
<td>0.672</td>
<td>3.03</td>
<td>0.006</td>
<td>0.105</td>
</tr>
<tr>
<td>Dehydrated Alfalfa</td>
<td>1-00-022</td>
<td>14</td>
<td>0.135</td>
<td>1.80</td>
<td>0.212</td>
<td>0.035</td>
</tr>
<tr>
<td>Soybean meal, 44%</td>
<td>5-04-004</td>
<td>3</td>
<td>0.062</td>
<td>1.49</td>
<td>0.009</td>
<td>0.002</td>
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<tr>
<td>Molasses</td>
<td>4-00-671</td>
<td>1.5</td>
<td>0.026</td>
<td>0.12</td>
<td>0.003</td>
<td>0.240</td>
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<tr>
<td>Dicalcium phosphate</td>
<td>6-01-080</td>
<td>1.0</td>
<td>---</td>
<td>---</td>
<td>0.380</td>
<td>---</td>
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<tr>
<td>Trace mineral/salt</td>
<td>6-04-151</td>
<td>0.5</td>
<td>---</td>
<td>---</td>
<td>---</td>
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<tr>
<td>Vitamin A&lt;sup&gt;b&lt;/sup&gt;</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
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</table>

100.0 1.38 8.04 0.67 0.40

<sup>a</sup>Percent dry matter basis

<sup>b</sup>Vitamin A included at 2200 I.U./kg diet
TABLE 2. FEEDER LAMB RECEIVING DIET a

<table>
<thead>
<tr>
<th>Item</th>
<th>IFN</th>
<th>%</th>
<th>Crude Protein</th>
<th>Calcium</th>
<th>Phosphorus</th>
<th>DE b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Cobs</td>
<td>1-02-782</td>
<td>39.0</td>
<td>1.170</td>
<td>0.046</td>
<td>0.015</td>
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<td>Cracked Corn</td>
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<td>42.5</td>
<td>3.825</td>
<td>0.008</td>
<td>0.123</td>
<td>1.683</td>
</tr>
<tr>
<td>Dehydrated Alfalfa</td>
<td>1-00-002</td>
<td>10.0</td>
<td>1.700</td>
<td>0.140</td>
<td>0.019</td>
<td>0.220</td>
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<tr>
<td>Soybean Meal, 44%</td>
<td>5-04-804</td>
<td>6.0</td>
<td>3.000</td>
<td>0.018</td>
<td>0.042</td>
<td>0.220</td>
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<tr>
<td>Dried Molasses</td>
<td>4-00-668</td>
<td>1.0</td>
<td>0.100</td>
<td>0.011</td>
<td>0.001</td>
<td>0.022</td>
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<tr>
<td>Trace Mineral/Salt</td>
<td>6-04-151</td>
<td>0.5</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Dicalcium Phosphate</td>
<td>6-01-080</td>
<td>1.0</td>
<td>--</td>
<td>0.220</td>
<td>0.180</td>
<td>--</td>
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</tbody>
</table>

Total Diet                | 100.0     | 9.750 | 0.443         | 0.380   | 2.967      |

a Percent dry matter basis
b Mcal/Kg