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Digestibility of Sunflower Hulls Treated with Sodium, Ammonium, and Potassium Hydroxides

Bal Krishna Sharma

DIGESTIBILITY OF SUNFLOWER HULLS TREATED WITH SODIUM AMMONIUM, AND POTASSIUM HYDROXIDES

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BAL KRISHNA SHARMA

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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.

Dr. David J. Schingoethe — Date
Thesis Adviser

Dr. John G. Parsons — Date
Head, Dairy Science Dept.

This manuscript is dedicated to my parents and all those who, in spite of being uneducated, insisted their children get an education.

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TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

In vitro dry matter digestibility (IVDMD) of sunflower hulls (SFH) treated with sodium hydroxide (NaOH), ammonium hydroxide (NH_4OH), and potassium hydroxide (KOH) at increasing levels were studied. Tested concentrations of each alkali as percent dry matter (DM) on SFH were 1.63, 2.45, 3.26, and 4.08. In vitro dry matter digestibility of sunflower hulls increased with higher concentrations of NaOH and KOH. Percent IVDMD for control (untreated SFH) was 18.0. Percent IVDMD for SFH treated at 1.63, 2.45, 3.26, and 4.08% of DM were: 18.9, 21.4, 22.2, and 22.9 for NaOH; 18.3, 18.0, 18.3, and 18.5 for NH_4OH; and 18.9, 20.2, 21.0, and 22.5 for KOH. Twenty wethers averaging 41 kg were utilized in a switch-back design experiment to evaluate the in vivo digestibility of alkali treated SFH. Diets contained 0% SFH (positive control), 25% of DM as untreated SFH (negative control), or 25% of DM as SFH treated with 2.45% NaOH, 2.45% KOH, or 3.42% NH_4OH. Other ration components were alfalfa meal, corn, soybean meal, dicalcium phosphate, trace mineralized salt, and vitamins. All rations were made isonitrogenous at 14.6% crude protein and pelleted. Feed and water consumptions were highest with diets containing alkali treated SFH, especially NaOH and KOH treated SFH. Digestibilities of acid detergent fiber and neutral detergent fiber (%) for the respective diets were: positive control, 42.6 and 58.2; untreated SFH, 30.2 and 42.9; NaOH treated SFH, 34.3 and 44.0; NH_4OH treated SFH, 26.2 and 35.3; and KOH treated SFH, 37.4 and 42.0.

INTRODUCTION

Whole oil sunflower seeds contain 40 to 45% of oil (68) which is of very good quality with high levels of polyunsaturated fatty acids (41, 81). Because the sunflower protein is also highly digestible and is of high biological value (71, 81), harvested acreage of high oil variety of sunflowers is increasing, especially in the Midwest. In the year 1982, over 258,000 metric tons of sunflower seeds were produced in the United States (95). The hull content of oil type sunflower seeds is about 20 to 25% (29). To obtain maximum yield and high quality sunflower meal, the hulls must be removed. This constitutes a huge amount of byproduct to be handled by the related industries. To date, little, if any, market except for bedding (75) or burning for steam boilers has been found for this material.

Sunflower hulls could possibly be an important roughage source for ruminants if its nutritive value could be improved by chemical treatment. Such treatment has been successfully performed with similar kinds of other fibrous residues (4, 47, 69). Improving the feeding value of sunflower hulls would not only help in disposing of this byproduct, but would also provide an economical fiber component for ruminant rations. With this in mind, the objectives of this experiment were to assess the digestibility, in vitro, of alkali treated sunflower hulls and to study the digestibility by animals when alkali treated sunflower hulls were incorporated into their rations.

LITERATURE REVIEW

Availability and Nature of Crop Residues

Increasing amounts of grains are produced every year to meet the demand for food for an expanding world population. The world production of wheat, rice, and coarse grains in the year 1982-83 was 447.8, 277.6, and 464.9 million metric tons, respectively, and the United States alone produced 76.2, 6.0, and 249.0 million metric tons of these grains, respectively (102). Grain plants produce at least the same amounts of vegetative material as the grain (70), and harvesting of the same amounts of these crop residues is possible (57). These residues constitute a tremendous amount of organic matter available each year for various uses. If these crop residues could be used efficiently as feedstuffs for animals, a greater proportion of grains, currently used for livestock, could be released for human consumption.

By nature, the framework of plants and the protective coating of their seeds are made up of cellulose. Cellulose is a complex carbohydrate consisting of linear chains of glucose units linked together by β 1-4 glycosidic bonds. Hemicellulose is a polymer of D-xylose in β 1-4 linkage, with side chains containing other sugars. With the advancing age of the plants, pure cellulose becomes transformed to lignocellulose, a lignin encrusted structure (3). Percent composition and the ratio between the amount of lignin, hemicellulose, and cellulose of crop residues vary with the type of material (43).

The complex biochemical nature of cellulose and the lack of cellulase enzyme in vertebrate animals contribute to the poor nutritive value of this carbohydrate source. Cellulose can therefore be available to higher animals as a nutrient source only through microbial fermentation. Ruminant animals are equipped with a suitable anatomy and physiology for the growth of anaerobic microorganisms (84). Although a part of fiber digestion can take place in post-ruminal areas (36, 78), cellulose degradation takes place primarily in the rumino-reticulum by the action of rumen microflora.

A number of physical and chemical factors inherent to the plants are responsible for controlling the nutritive value of forages (23). Rumen fermentation of cellulose is a complex biological phenomenon (61). It involves a complex of interacting microbial species and depends on factors such as crystallinity of cellulose and its association with lignin, cutin, and silica (96). Lignin acts as a physical barrier between cellulose and cellulolytic bacteria (6, 27), and separating cellulose from lignin has been reported to increase the cellulose digestibility (24, 25, 54). Letchenberg et al. (62) have reported that lignin prevented digestion of a portion of the cell wall constituents and cellulose in vivo, while not interfering with the rate of digestion of lignin-free cell wall constituents.

The amount of total digestible nutrients of fibrous crop residues is generally low (70), even though there is much more potentially available energy in the form of cellulose. Treatment of

cellulosic materials to improve digestibility has been a subject of interest for some time. Present day interest on improving the use of low quality roughages began when grain and high quality roughage prices increased substantially. Consequently, numerous research articles (2, 7, 11, 19, 21, 22, 31, 33, 45, 47, 60, 72, 79, 91) have been published in this area, especially in the last decade. Tested methods of treatment include physical processes such as pressure treatment, grinding, and irradiation and chemical processes like hydrolysis, steaming, and alkali treatment. The combination of both physical and chemical methods have also been tested.

One widely researched technique has been the treatment of crop residues with alkali solutions. Many chemicals have been used in laboratory experiments to enhance the fiber digestibility of low quality residues. The most widely used techniques for increasing the digestibility of crop residues in animal rations have been via treatment with sodium hydroxide (NaOH), ammonium hydroxide (NH_4OH), potassium hydroxide (KOH), and calcium hydroxide ($Ca(OH)_2$).

Methods of Alkali Treatment of Roughages

In 1922, Beckmann (10) developed a technique utilizing sodium hydroxide to delignify roughages, thereby increasing their nutritive value. The process involved soaking roughages in a dilute solution of NaOH (1.5%) for at least 4 h, followed by a washing step to remove residual alkali. Treatment by the Beckmann method (10) was found to be expensive mainly because of heavy losses

of roughage nutrients. Oat straw soaked in a 1.5% (w/v) solution of NaOH at room temperature for 22 h and then washed, resulted in a loss of about 25% of straw dry matter (85). Similar losses were reported for NaOH treated and washed rice hulls (47) and barley straw (19). In addition, the residual alkali, if not removed, may result in a sodium load that could cause a mineral imbalance in animals (57).

Wilson and Pigden (101) developed a treatment procedure to avoid nutrient losses and one that required less labor, water, and capital investment. Their procedure involved spraying dry roughages with a small amount of alkali and then feeding the treated roughage directly to animals without washing. Chandra and Jackson (21) compared several chemical agents for their ability to remove lignin and to increase digestibility of roughages in laboratory experiments. They reported that NaOH was the most effective chemical when roughages were treated with alkali at 10% of the roughage dry matter. Singh and Jackson (87) evaluated a sodium hydroxide spray treatment of ground and chaffed wheat straw (at 3.3, 6.7, and 10% concentrations). In a calf feeding experiment, they observed a higher organic matter digestibility with treated wheat straw when compared to untreated straw. Anderson et al. (2), however, reported that spraying ryegrass straw with a 2% NaOH solution did not significantly improve digestible dry matter, while soaking at the same level increased dry matter (DM) digestibility significantly. This suggests that soaking the roughage in alkali solution is superior to

spray treatment at the same level of alkali.

Excess alkali present in treated material can be neutralized to minimize its possible adverse effects when feeding. Neutralization can be achieved by adding various acids to the treated material or to the total rations containing treated roughage (45, 49).

An alternative method used to treat roughages is through the addition of dry alkali to roughage and then subjecting the roughage to high temperature and pressure (80). This treatment omits the need for washing since adequate results may be obtained using alkali levels of less than 4 to 5% of the roughage dry matter (79). The type of alkali treatment used depends upon available facilities and the characteristics of the crop residue.

Mechanism of Action of Alkali Treatment

The mode of action of alkali treatment on crop residues has not been completely elucidated. A study utilizing microscopic techniques determined that wheat straw was effected differently when treated with NH_4OH than with NaOH (40). Treatment with ammonium hydroxide resulted in separation of the ground parenchymal cells but had no effect on vascular tissue, thick walled sclerenchyma and epidermal silica. Hydrolysis of cellular material began with the inner cuticle and continued to the large vascular bundles. Only a 10% NaOH solution was able to separate the highly lignified dense sclerenchymal cells, near the outer cuticular surface. It was

postulated that NH_4OH (4% solution) treatment removed pectin or altered its structure. In another study using electron microscopic techniques, NaOH was used to treat rice hulls and the treated hulls were subjected to digestion in vivo using sheep. The examination of the hulls removed from the digestive tract revealed confirmatory visual evidence of enhanced degradation due to sodium hydroxide treatment. Sodium hydroxide treatment caused sheets of silicified cuticle to dissolve and lift away from the underlying lignocellulose matrix (69).

Spencer and Akin (90) conducted a similar study with 10% KOH treated coastal bermudagrass leaves. It was observed that the KOH treatment disrupted the tissue separating parenchymal bundle sheaths and schlerenchyma tissues into individual cells. In addition, they also postulated that KOH treatment removed pectin or altered its structure, similar to that reported by Harber et al. (40).

The effect of alkali treatment on improving the digestibility of crop residues depends on several factors, such as type of crop residue (89), their chemical characteristics (17), the type and level of alkali used (87), and the method of treatment and treatment conditions. In in vitro rumen fermentation experiments, the amount of cellulose digested by the microflora in the fermentation flask is dependent upon the amount of available carbohydrate in the flask (54). In addition, the digestion of native cellulose of forages is generally initiated at a much earlier time than that

of purified cellulose, which is not digested until 12 or more hours after initiating the fermentation process (51). The reason for these differences is probably due to the degree of crystallinity of cellulose or its association with lignin, cutin, or silica.

Chemical treatment, especially with sodium hydroxide, solubilizes some of the hemicellulose while not changing the cellulose content, and the extent of bacterial digestion in vitro is increased for both cellulose and hemicellulose (57). Sodium hydroxide causes cellulose to swell by reducing the strength of intermolecular hydrogen bonds which bind cellulose molecules together (92). Simpson et al. (86) observed a weight increase of cotton fiber due to swelling when immersed in an 18% solution of sodium hydroxide. Leatherwood (61) indicated that variation in hydrolytic activity of different celluloses does exist because of their chemical and physical characteristics. Alkali treatment may cause changes in the fiber structure with saponification of ester linkages, thereby permitting additional swelling in water. It is speculated that the hydrolyzed ester linkages are those between uronic acid groups of hemicellulose and cellulose (32). Swollen cellulose should be more easily penetrated by rumen fluid, thus rumen microorganisms, accounting for a greater digestibility.

Increases in in vitro digestibilities of alkali treated residues may be brought about in part by increased water solubility and destruction and partial solubalization of cell wall constituents (74). Experiments using straw (85) and rice hulls (47) show that

alkali treatment removes silica from the crop residues. Along with silica, hemicellulose and lignin are also dissolved by alkali treatment (48). In addition to the solubilization of a portion of hemicellulose and lignin, removal of silica might be another possible factor in increasing the digestibility of treated material.

As previously mentioned, delignification has been reported to increase the relative amount of potentially digestible cellulose available and the rate of cellulose digestion (24, 25). Various research articles have indicated that the lignin content of cellulosic materials is not generally reduced by chemical treatments (47, 58, 74, 79). Klopfenstein (56) reported that an increase in digestibility of crop residues may be due to an altered bonding between lignin and hemicellulose, without the actual removal of lignin.

Available literature on the mode of action of alkali on crop residues support that alkali treatment: a) dissolves lignin, silica, and hemicellulose depending on the strength of the alkali and nature of residue; b) increases the rate of cellulose and hemicellulose digestion by changing the fiber structure and possibly by swelling of the fibers; and c) increases the extent of hemicellulose and cellulose digestion.

Effect of Alkali Treatment on In Vitro and In Vivo Digestibility of Crop Residues

Sodium hydroxide treatment has frequently been used to

increase the digestibility and nutritive value of various kinds of crop residues. Sodium hydroxide is less expensive and safer than most other alkalis (21). Potassium hydroxide produces similar effects to that of sodium hydroxide (2) while ammonium hydroxide has a variable (2), positive (26, 88, 92, 97) or no effect (11, 40) on the digestibility of crop residues. Studies comparing sodium, ammonium, and potassium hydroxides show that sodium and potassium hydroxides are superior to ammonium hydroxide in improving the in vitro digestibility of crop residue (7). Jackson (48), in his review article, made similar conclusions. The additional advantage of ammonium hydroxide or of ammoniation over other hydroxides is that there is no potential mineral imbalance to contend with. Also, the crude protein content of treated material can be increased (2, 26, 33, 42, 44, 46, 60, 83, 88, 97).

Sodium hydroxide treatment has been shown to improve the level of digestible nutrients of corn stalks, corn cobs, corn stover, and soybean stover. In vitro dry matter digestibility of corn stover was reported to increase with increasing levels of NaOH (74). Summers and Sherrod (91) also found a significant increase in in vitro dry matter digestibility of corn cobs and corn stover treated with NaOH (5% of the DM). However, in vivo dry matter digestibility coefficients did not show similar increases in digestibility. Paterson et al. (76) observed greater dry matter digestibility in vitro for NaOH treated corn cobs or corn stalks than in vivo. Berger et al. (13) treated corn cobs with various

concentrations of NaOH and fed them to lambs in complete mixed diets. Diets contained NaOH treated corn cobs and resulted in levels of 0, 2, 4, 6, and 8% NaOH (% ration dry matter). Incorporation of NaOH treated corn cobs (8% NaOH ration dry matter) increased in vitro dry matter digestibility of the diet from 45.1% to 83.1%. In contrast, in vivo dry matter digestibilities were 5, 12, and 5 percentage units less than corresponding in vitro digestibilities at 4, 6, and 8% levels of treatments, respectively. In an in vivo experiment (13), NaOH concentrations greater than 2% of the ration dry matter decreased the percentage of potentially digestible corn cob fiber in the rumen.

Klopfenstein et al. (58) treated whole corn plants, corn cobs, and corn stalks with NaOH. At 5% NaOH (DM basis) the digestibilities of those residues were increased over untreated controls. When treated stalks were fed to lambs in combination with ground alfalfa stems, organic matter digestibility was increased by 20.5 percentage units over untreated controls. Oji et al. (72) also observed increased organic matter and gross energy digestibilities for alkali treated corn stovers.

Daily gains and ration digestibilities of steers fed NaOH (4% DM basis) treated and ensiled corn cobs and corn stovers were reported by Koer et al. (59). Treated silage was supplemented with alfalfa and soybean meal. Steers fed the treated ration had increased weight gains and required less feed per unit of gain than control fed animals. However, dry matter, organic matter, and true

dry matter digestibilities were not significantly affected by the treatment.

Rounds and Klopfenstein (83) treated corn cobs either with NaOH, NH_4OH, KOH, and $Ca(OH)_2$ alone or in combinations with other alkalies at various proportions. In vitro dry matter digestibilities of corn cobs were improved due to NaOH or KOH (4 to 5% DM basis) treatment. Increased digestibility in vitro was also observed for NH_4OH treated cobs, but $Ca(OH)_2$ treatment alone failed to improve digestibility of corn cobs. When a portion of the $Ca(OH)_2$ was replaced by NaOH or KOH, the in vitro digestibility of corn cobs was increased. Waller and Klopfenstein (98) observed the highest daily weight gains of lambs and steers fed rations containing corn cobs treated with 3% NaOH + 1% $Ca(OH)_2$ (DM basis). In both of these experiments, $Ca(OH)_2$ probably served as the calcium source.

Alkali treatment, especially with sodium hydroxide, improves the nutritive value of various types of straws. Animals fed diets incorporating treated straw show growth patterns similar to those fed alfalfa based rations (34, 49). The effect of sodium hydroxide treatment on affecting the digestibility of barley straw has been reported by various investigators (22, 37, 50, 64, 76, 79). Coombe et al. (22) treated barley straw with a NaOH solution at 4% of the straw dry matter by ensiling chaffed straw or pelleting ground straw mixed with alkali solutions. In either of these cases, alkali treatment increased the digestibility of dry matter, organic matter, and neutral detergent fiber. Grinding and pelleting of straw

reduced the digestibility of these components when measured in vivo using a dacron bag technique with steers. In this experiment (22), alkali treatment increased the amount of potentially digestible straw dry matter and results of in vitro experiment and in vivo dacron bag procedures were similar.

Greenhalgh et al. (37) fed lambs milled barley straw treated with 16% NaOH (DM basis). When compared with control fed lambs, alkali treatment resulted in higher straw consumption. Jayasuriya and Owen (50) treated barley straw with NaOH at 4.5 and 9.0% (DM basis). Excess alkali was neutralized with dilute HCl. When sheep were fed untreated and treated straws, organic matter digestibility increased significantly by 8 and 11% units with increasing treatment levels, respectively. Intake of treated straw was higher, but animals fed straw treated at the 4.5% level had the highest intakes. At the same level of alkali addition, increasing the volume of water (more dilute alkali solution) increased the digestibility of straw. This increase in digestibility may be due to an increased volume of water available for soaking the straw fibers.

Application of sodium hydroxide using a spray technique was equally effective in increasing the digestibility of ground or chaffed wheat straw (87). Increases in digestibility were reported to be greater in vitro than in vivo (1). Although the digestibility of straws increases with higher concentrations of alkali dry matter, no improvement in digestibility of wheat straw in vitro was obtained beyond a 9% level of NaOH (DM basis) treatment (101). In a digestion

trial (1) using lambs, the apparent digestibility of straw was increased by using a 4% NaOH treatment. When sodium intake was balanced by the use of other cations, the results of digestibility were not changed, indicating a positive role of NaOH beyond a cation source.

The nutritive value of wheat straw can also be improved by ammoniation or by NH_4OH treatment. Herrara-Saldana et al. (44) treated wheat straw at a rate of 50 g NH_3/kg DM of straw and conducted a steer feeding trial using the resultant product. Voluntary intake of dry matter, organic matter, crude protein, and gross energy were improved by ammoniation. Ammoniation also improved apparent crude protein, acid detergent fiber, and gross energy digestibilities of the straw. Effect of ammoniation of straw, with the reaction time of 30 or 56 days, was examined by Lawlor and O'Shea (60). Irrespective of the reaction time, they observed a mean increase of 15% units for dry matter digestibility in vitro with treated straw, while the corresponding increase in dry matter digestibility in vivo was 14.2%. Wethers consumed higher amounts of ammoniated straw when compared to untreated straw fed wethers (60). A similar type of study was conducted by Horton (46) involving feeding of 3.5% anhydrous ammonia treated wheat, barley, and oat straws. Consumption of all straws by steers increased after the straws were subjected to ammoniation. Rations containing ammoniated wheat and oat straws showed increased crude fiber digestibilities. In this experiment (46) and in that of Summers and Sherrod (91), different

species of crop residues responded differently to ammonium and sodium hydroxide treatments. Improvement in in vivo digestible dry matter of oat straw soaked in 1.5% (w/v) solution of NaOH was observed by Saxena et al. (85). Rexen and Thomsen (79), however, treated oat straw with NaOH at varied concentrations using a dry alkali and pressure treatment. They observed an increase in the rate of digestion and in vitro digestibility when straw was treated at levels below 7% NaOH (% of ration DM). However, an increase in in vivo digestibilities of sheep fed treated oat straw was observed only up to a 4 to 5% level of alkali addition.

Digestibility of rice straw can also be improved by alkali treatment (33, 97). Waiss et al. (97) observed increased in vivo digestibility of rice straw with additions of ammonia (5% by wt) and water (30% by wt), and stored for 30 days at ambient temperature. Garret et al. (33) conducted comparative feeding trials with sheep and steers to determine the value of 4% NaOH (DM basis) treated rice straw. The diets formulated contained 36 or 72% rice straw on an as fed basis. The general pattern of response was the same for both lambs and steers. Sodium hydroxide treated straw had a higher net energy value. In this experiment (33), the diet containing 72% treated rice straw was consumed in greater quantities. Lambs fed 4% NaOH treated rice straw approached weight gains similar to those fed a positive control diet containing alfalfa hay.

Alkali treatment, especially with sodium hydroxide, has been reported to increase the digestibility of other crop residues

such as rice and cotton seed hulls. An evaluation of methods for improving the in vitro digestibility of rice hulls was conducted by Hutanuwatr et al. (47). When ground rice hulls were treated with 12% NaOH (DM basis) then washed and dried, the treatment increased the in vitro dry matter disappearance of rice hulls from 21 to 30 percentage units over the control. McManus et al. (69) fed sheep ad libitum, three pelleted diets containing alkali treated ground rice hulls (0, 5, and 10% NaOH on DM basis) in a 1:1 ratio with ground lucern. In their experiment (69), alkali treatment of rice hulls increased the percent of total digestion of organic matter in the foregut and the percent digestibility of cell wall constituents in the whole digestive tract by approximately 1.6 times that of the control diet. Determination of the effect of feeding 4% NaOH (DM basis) treated cotton byproducts on the growth of growing steers and lambs was done by Arndt and Richardson (4). Sodium hydroxide treatment improved average daily gains of lambs by 18 and 33% and feed to gain ratio by 17 and 27% over average daily gains when compared to those observed with untreated cotton byproduct and cotton seed hulls.

The incorporation of alkali treated corn cobs (76) and barley straw (64) in rations containing alfalfa hay or silage, respectively, resulted in a positive associative effect for both dry matter digestibility and intake. Soofi et al. (89) reported a significant positive associative effect on digestibility and intake when alkali treated soybean stover was blended with alfalfa and fed

to sheep. In this experiment (89), associative effects were more dramatic when a mixture of two parts of soybean stover to one part of alfalfa was fed. However, an improvement in intake and digestibility was not observed when treated soybean stover was fed as the only source of nutrients.

In addition to a direct effect of alkali on fibrous crop residues, alkali treatment can be beneficial through its effect on rate of passage. A relationship exists between the digestibility of ration ingredients and the rate of passage through the digestive system (15). Adjustment of the rate of passage and fermentation efficiency can be achieved by controlling the rate of water removal from the rumen and regulating rumen pH (20). The literature indicates that consumption of water by animals increases when fed alkali treated roughages especially with NaOH treatment (31, 48, 64, 69, 80). McManus et al. (69) observed an increased rate of passage of sheep ingesta when fed diets containing rice hulls treated with NaOH. Berger et al. (14) studied the effect of sodium hydroxide treatment on the rate of passage. In their study utilizing sheep, they observed a linear increase in the rate of passage with increases in the level of NaOH treatment of corn cobs. Mean ruminal retention time decreased from 32.4 h for control to 20.7 h for NaOH treated diets (8% ration dry matter).

Use of Sunflower Hulls in Ruminant Rations

Sunflower hulls (SFH) are highly fibrous (18, 30, 94).

Because of the high cellulose and lignin content this byproduct is not recommended as the feed for nonruminant animals (16, 71). Available literature indicates variable responses when sunflower hulls are fed to different classes of ruminant animals.

A feeding trial (39) with finishing lambs showed that animals fed rations containing sunflower hulls gained less than when sunflower hulls were replaced with dehydrated alfalfa pellets. Results indicated that 10% sunflower hulls (as fed basis) provided adequate fiber in lamb rations. Jordon and Hanke (53) determined the relative value of pelleted sunflower hulls as a roughage source for finishing lambs. In their feeding trial, lambs fed sunflower hulls gained 94.1% as much as lambs fed alfalfa hay. From their study (53), it was concluded that pelleted sunflower hulls can be substituted in rations to increase their bulkiness. Trotter et al. (94) reported sunflower hulls as an acceptable and useful roughage source for livestock feeds. A similar report was made by Kinard (55) on the use of finely ground sunflower hulls. Dinnusson et al. (28) conducted an experiment on the feeding of sunflower hulls with alfalfa hay to finishing steers. Inclusion of alfalfa pellets with sunflower hull pellets made sunflower hulls more acceptable and improved the overall quality of the roughage for steers. In their experiment, steers receiving sunflower hull pellets with alfalfa pellets (50:50) gained 6% faster than those receiving corn roughage pellets (made from the forage remaining after the corn syrup was extracted from high sugar corn plants).

Marx (66) reported that dairy heifers receiving 57.1% of the ration dry matter as sunflower hulls developed impacted abomasums and suggested that SFH should be limited in rations to ensure adequate growth. Dinusson et al. (29) suggested that sunflower hulls should be limited to 25% of the total ration for cattle.

Park et al. (75) conducted a digestion trial involving Holstein heifers to evaluate isonitrogenous rations containing varying amounts of sunflower hulls. Increasing the quantity of sunflower hulls in the rations decreased nutrient digestibility for dry matter, acid detergent fiber, and protein. Park and coworkers (75) also conducted a heifer feeding trial to determine the nutritive value of sunflower hulls as a roughage source in growing ruminant rations. Animals fed a lower level of sunflower hulls (27% of ration DM) consumed less feed and gained more than those consuming diets containing 50% sunflower hulls. However, on the basis of overall growth, it was concluded that the use of sunflower hulls as a sole source of roughage for growing heifers could not be recommended.

Methods to improve the digestibility of sunflower hulls, such as alkali treatment, have not been studied as extensively as other crop residues. Fibrous residues containing low levels of digestible energy such as rice hulls, cotton seed hulls, corn stover, soybean stover, and various kinds of straws, for the most part are similar to sunflower hulls in their nutritive value and chemical composition and have been reported to give positive

responses to alkali treatment. Gross (38) treated sunflower hulls with sodium hydroxide at 4 and 8% (DM basis) levels. Sodium hydroxide treatment increased digestible energy, dry matter, protein, and cellulose digestibilities in vivo when fed to lambs. It was observed that in vivo and in vitro digestibilities were highly correlated, although for the in vivo study, increases in apparent cellulose or protein digestibility of treated hulls were not significantly different from controls.

MATERIALS AND METHODS

Preparation of Samples for in vitro Digestion Studies

Ground oil seed sunflower hulls[1] (SFH) were treated with dilute solutions of sodium hydroxide (NaOH), ammonium hydroxide (NH_4OH) and potassium hydroxide (KOH) at increasing concentrations. Twenty grams of sunflower hulls were immersed in 150 ml of .2, .3, .4, and 5% (w/v) solutions of the respective hydroxides. Final concentrations of each alkali as a percent of SFH dry matter were 1.63, 2.45, 3.26, and 4.08%. Treatment of SFH was accomplished by immersing 20 g of hulls into 150 ml of the respective alkali solution. After 24 h of soaking and reaction time, the SFH were filtered (Whatman #54) and solid residues were placed in a forced air oven and dried to complete dryness (approximately 84 h at 57°C). Sunflower hulls for the control were treated with similar volume of distilled water as used for alkali treatment, filtered, and dried as above.

Chemical Analyses of Sunflower Hull Samples

Treated and control hulls were subjected to laboratory analysis to determine their nutrient composition. Samples were analyzed for nitrogen, ether extract, and ash (5); neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, and cellulose by the procedure described by Goering and Van Soest (35).

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[1]Cargill Incorporated, West Fargo, North Dakota.

In Vitro Digestion Experiment

In vitro dry matter digestibility (IVDMD) of alkali treated and control SFH was conducted by the procedure described by Tilly and Terry (93) using 1 g samples in closed polyethylene tubes (51). Five individual 48 h fermentation trials were run using five replicate tubes of each treatment for each trial. Inoculum was prepared by mixing strained rumen fluid (obtained from fistulated dairy cows receiving 60% forage/40% concentrate) and McDougall's solution (67) at the ratio of 1:1.5. Rumen fluid was strained through eight layers of cheesecloth and tested for pH using a pH meter. Inoculum was added to prewarmed tubes containing SFH (treated and control) with 25 ml of McDougall's solution. In vitro fermentation was conducted by incubating tubes in a water bath at 39°C. Five tubes used for a blank contained McDougall's solution and inoculum mixture but no samples. The weights of the solid residues of these tubes were used to correct for inoculum dry matter.

Thorough mixing of suspended SFH particles on the surface of fermentation tubes was accomplished by shaking the tubes at timed intervals. Shaking of tubes was done 2 h after initiation of incubation, 6 h later, and at 8 h intervals thereafter. After completion of the 48 h fermentation period, tubes were opened and kept at room temperature for 1 h, then centrifuged at 1500 rpm for 10 min. The supernatant was then aspirated off and remaining solid residue was dried to complete dryness in a forced air oven at 57°C. Percent IVDMD of SFH was calculated by difference.

Mean digestibility values were subjected to statistical analysis using General Linear Models procedure (8). Differences among treatment means were evaluated using the Walls-Duncan κ-ratio t test (99).

Digestion Trial

Selected levels of alkali treatment of sunflower hulls (SFH) used for the in vivo digestion trial were 2.45% for NaOH and KOH and 3.42% in case of NH_4OH (DM basis). Sunflower hulls were treated by mixing an alkali solution with ground SFH using a rotary cement mixture. Dry matter content of SFH, treated with different alkali solutions, were similar (61%). Treated hulls were allowed to react for 24 h in 190 liter barrels and then incorporated into complete pelleted rations. Alkali treated rations were dried in an ambient forced air system. Rations were formulated to be isonitrogenous at 14.6% crude protein as shown in Table 1. A positive control ration contained 50% of the DM as alfalfa meal and 48.5% as corn. A negative control diet was formulated by replacing 50% of alfalfa meal DM with untreated SFH and making it isonitrogenous to the positive control with corn and soybean meal. Sodium hydroxide, ammonium hydroxide, and potassium hydroxide diets were formulated using similar amounts of respective alkali treated SFH DM.

Twenty mixed range wethers averaging 41 kg (37.2 to 46.7 kg) were utilized in a complete switch-back design experiment to evaluate the in vivo digestibility of SFH containing rations (Table 1). The

TABLE 1. Treatments and ration formulation for digestion experiment[a].

Ingredients	Ration				
	Positive control	NaOH	NH_4OH	KOH	Negative control
	(% of dry matter)				
Alfalfa meal	50	25	25	25	25
SFH[b] (NaOH 2.45%)	..	25	..	..	..
SFH (NH_4OH 3.42%)	..	..	25	..	..
SFH (KOH 2.45%)	..	..	..	25	..
Untreated SFH	..	..	..	..	25
Corn	48.50	39.43	39.93	39.46	39.87
SBM[c] (44% CP)	..	9.07	8.57	9.04	8.63
Dicalcium phosphate	1.0	1.0	1.0	1.0	1.0
Trace mineral salt	.5	.5	.5	.5	.5

[a]All rations were fomulated to be isonitrogenous at 14.62% CP level.

[b]Sunflower hulls.

[c]Soybean meal.

experiment was conducted for a total of three periods. The switch-back treatment pattern for five treatments with the twenty animals was as described by Lucas (63). Each period consisted of 16 days; 7 days for adaptation to diet, 4 days for adjustment to the metabolism crates, followed by 5 days of total fecal collection. Pelleted rations were fed once daily and water was available at all times. Feed and water intakes and fecal outputs were recorded daily. Sampling of feed was done every other day while fecal samples were taken daily. Samples were frozen for later analyses. Feed samples were composited by period and fecal samples by animal for each period after drying to complete dryness at 57°C. Composite samples were ground and analyzed for nitrogen, ether extract, and ash (5); and ADF and NDF (35). Gross energy content of feed and feces were determined by bomb calorimeter[1]. Total fecal collections and feed intakes were used for calculating digestion coefficients.

Body weight measurements were taken prior to entering and after existing the digestion crates. Blood samples collected from the jugular vein were obtained immediately after weighing. Blood samples were analyzed for packed cell volume[2].

Samples of rumen contents were obtained by esophageal tube and suction strainer into sample bottles containing .5 ml of saturated mercuric chloride solution. Rumen fluid samples for freezing

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[1]Parr Adiabatic bomb calorimeter.

[2]Coulter Electronics, Hialeah, FL.

point determination were collected separately in empty sample bottles. Due to the thick consistency of the rumen fluid, samples were taken one day after the end of the collection period. In order to acquire rumen samples of suitable consistency, animals were denied the pelleted ration and were provided only with drinking water for 12 h before sampling. Rumen fluid pH was analyzed using a pH meter. A 10 ml aliquot of rumen fluid was used for volatile fatty acids (VFA) determination. Rumen volatile fatty acids were determined by the technique of Baumgardt (9). Freezing point of rumen fluid samples was determined using Fiske Milk Cryoscope[1]. These values were utilized to determine potential changes in rumen osmolarity.

Analysis of variance on in vivo data was conducted by procedure reported by Lucas (63). Differences among treatment means were evaluated using the Waller-Duncan κ-ratio t test (99).

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[1]Fiske Associates Inc., Uxbridge, MA.

RESULTS AND DISCUSSION

Alkali Treatment vs Composition of Sunflower Hulls

Sunflower hulls from oil seed variety sunflowers used in this experiment had a chemical composition as presented in Table 2. When compared to previously reported composition of sunflower hulls (28, 39, 55), the hulls used in this experiment contained higher amounts of acid detergent fiber; however, the lignin content was lower than that observed by other workers (28, 38, 82). These differences may have been due to variation in agronomical practices for growing sunflowers, variety of sunflowers, or due to geographical locations.

TABLE 2. Chemical composition of sunflower hulls.

Components	% of dry matter
Crude protein	5.76
Ash	2.34
Ether extract	5.57
Acid detergent fiber	67.85
Neutral detergent fiber	82.70
Permanganate lignin	14.07
Cellulose	53.63

Proximate analyses of sodium, ammonium, and potassium hydroxide treated SFH are shown in Table 3. Increasing the concentration

TABLE 3. Chemical composition of alkali treated sunflower hulls.

Treatment	Alkali % DM[a]	Composition						
		Crude protein	Ash	Ether extract	ADF[b]	NDF[c]	Lignin	Cellulose
		(% of DM)						
Control	0	5.8	2.3	5.6	67.9	82.7	14.1	53.6
NaOH	1.63	5.4	3.9	1.7	69.0	85.9	13.4	54.5
	2.45	5.2	4.8	1.6	66.0	86.5	13.0	53.8
	3.26	5.5	5.3	1.6	65.1	86.4	14.5	51.3
	4.08	4.8	5.7	1.4	64.9	84.4	13.5	53.1
NH_4OH	1.63	6.1	2.5	1.3	69.1	83.7	13.8	54.4
	2.45	6.1	2.4	1.4	69.3	85.0	14.2	55.1
	3.26	6.2	2.6	1.5	68.8	86.1	13.6	54.9
	4.08	6.3	2.6	1.5	69.7	85.5	13.5	54.2
KOH	1.63	5.2	3.9	2.1	67.6	82.0	13.5	54.7
	2.45	5.2	4.5	1.8	67.5	82.5	12.3	54.4
	3.26	5.0	5.4	1.6	67.5	83.0	14.5	53.5
	4.08	5.3	6.3	1.3	67.7	82.3	12.4	54.3

[a]DM = Dry matter.

[b]ADF = Acid detergent fiber.

[c]NDF = Neutral detergent fiber.

of these alkali used to treat sunflower hulls tended to result in lower crude protein in the hulls. This difference may be due to the solubilization of sunflower hulls nutrients with increased levels of alkali. Alkali extracted those components from the hull fibers during cell wall degradation and the extracted materials were removed with liquor effluent during filtration. It indicates that a large proportion of these constituents in sunflower hull fibers exist in an unavailable complex. Consequently, analyzed samples showed a linear decrease in ether extract content with increasing level of NaOH and KOH treatment and increasing levels of alkali tended to decrease crude protein content (Table 3). These results agreed with other reports (2, 73, 85) in that treated crop residues generally have reduced nitrogen content after removal of alkali. Ammonium hydroxide treatment, however, resulted in a progressive increase in crude protein content of SFH with increasing level of NH_4OH (r=.981). An increased crude protein content of crop residues with ammoniation or ammonium hydroxide treatment has been observed by several workers (2, 26, 33, 42, 83, 88, 97). This increase may be due in part to ammonia being bound irreversibly to the treated material (44, 60).

Ash content of sunflower hulls increased when treated with increased concentration of alkali, especially with sodium (r=.99) and potassium (r=.99) hydroxides. This increase was brought about by increased content of sodium (22, 34, 48) and potassium of the hulls through alkali treatment. However, treatment of hulls with

NH_4OH gave no mineral residue (57) and thus, did not increase ash content consistently.

Sodium hydroxide treatment reduced the fibrous components of roughages with the increase in digestible ruminants (64, 91). Sunflower hull ADF was slightly decreased with increasing concentrations of NaOH (Table 3). Ammonium and potassium hydroxides had no noticeable effect on ADF content of sunflower hulls. Although other reports (13, 22) indicated NaOH to reduce NDF content of treated material, reductions in NDF content of SFH due to these treatments were not noticeable. This difference in results may be either due to differences in concentrations of alkali used or due to variation of residues. Alkali treatment in this experiment with any solution had no effect on lignin content of SFH, which agreed with the results of others (58, 74, 79) with various crop residues.

In Vitro Dry Matter Digestibility (IVDMD) of Nontreated and Alkali Treated Sunflower Hulls

Results of the in vitro dry matter digestibility experiments using sunflower hulls (SFH) treated with increasing amounts of NaOH, NH_4OH, and KOH are given in Table 4. As received, sunflower hull samples were poorly digestible with a IVDMD value of only 18.0%. In vitro digestibilities were highly affected by pH of rumen fluid used to prepare inoculum mixture (r^2=.973). So the digestibility in vitro values were covariate adjusted using IVDMD

TABLE 4. In vitro dry matter digestibility (IVDMD) of untreated and alkali treated sunflower hulls (SFH)[1].

Treatment	Alkali	IVDMD[2]
	(% of DM)	(%)
Control	0	18.0 ± 2.48[e]
NaOH	1.63	18.9 ± 2.53[e]
	2.45	21.4 ± 2.79[b,c]
	3.26	22.2 ± 3.50[a,b,c]
	4.08	22.9 ± 3.12[a]
NH_4OH	1.63	18.3 ± 1.65[e]
	2.45	18.0 ± 1.64[e]
	3.26	18.3 ± 2.23[e]
	4.08	18.5 ± 1.69[e]
KOH	1.63	18.9 ± 2.30[e]
	2.45	20.2 ± 2.17[d]
	3.26	21.1 ± 2.53[c,d]
	4.08	22.5 ± 2.33[a,b]

[1]Means of four periods with five replications each.

[2]Mean ± standard deviation.

[a,b,c,d,e]Means with the same superscript are not different ($P<.05$).

of nontreated SFH as the covariate.

In vitro dry matter digestibility of sunflower hulls increased with increasing concentrations of NaOH (r^2=.932) and KOH (r^2=.953), but was not as highly correlated with NH_4OH (r^2=.359). In vitro dry matter digestibility of sunflower hulls at the 1.63% level of both NaOH and KOH were numerically similar. In both cases, the improvements in digestibility were 4.9% over the control, but were not different (P>.05) from control values. This suggested that at the lowest tested level of NaOH and KOH (1.63% of DM), alkali treatment failed to improve digestibility of SFH. Concentrations of 2.45% NaOH and KOH increased IVDMD by 18.5 and 11.9%, respectively, over the control.

In vitro dry matter digestibility of sunflower hulls was improved by 2.45% or more of NaOH or KOH treatment with the greatest improvement with 4.08% of alkali. Sodium hydroxide treatment of sunflower hulls at 4.08% concentration (DM basis) resulted in the highest improvement in digestibility in vitro, but that due to the same level of KOH was also similar (P<.05). In vitro dry matter digestibility of SFH treated with 3.26% NaOH was similar (P>.05) to those treated with 4.08% concentrations of NaOH and KOH. However, numerically the digestibilities due to NaOH were higher than KOH at the same level of treatment. Similar results were obtained by Bales et al. (7) with in vitro digestibility of alkali treated milo stalks.

At all the tested concentrations, NH_4OH treatment failed

to improve in vitro dry matter digestibility of SFH over control values ($P>.05$). When compared to NaOH and KOH, NH_4OH might have caused less extraction of nutrients from the hulls that could be easily digested. This indicated that in addition to the alkali value of NaOH, KOH, and NH_4OH, the cation associated with hydroxides might also have a role in improving digestibility of crop residues. Increases in digestibility of SFH due to NaOH or KOH treatment were not associated with reductions in lignin content of treated hulls indicating that improvement in digestibility arose probably due to solubilization of cell wall constituents without actual removal of lignin.

From the results of the in vitro dry matter digestibility experiments and compositional studies the following conclusions can be made: 1) sunflower hulls are poorly digested; 2) digestibility of SFH in vitro decreases with decrease in pH of rumen fluid; 3) higher concentrations of NaOH and KOH resulted in increased IVDMD of SFH; 4) NH_4OH treatment did not affect IVDMD of SFH; 5) increased concentrations of NaOH and KOH extracted more ether extract and also tend to extract crude protein from SFH fibers; 6) ammonium hydroxide treatment increase CP content of sunflower hulls; and 7) alkali treatment, especially with NaOH and KOH, increase ash content of SFH.

In Vivo Digestion Experiment

Pelleted rations containing both untreated and alkali

treated sunflower hulls were similar in dry matter content (91 to 93%) (Table 5). Although all rations were formulated to be isonitrogenous at 14.6% crude protein, the ration containing NH_4OH treated sunflower hulls was higher in its crude protein content. This may be explained by the amount of ammonium cation retained on the hulls during treatment. Samples treated with NH_4OH for laboratory in vitro digestion may have had the ammonium cation removed partially during the filtration and drying steps, thus, underestimating the actual amount of crude protein for the NH_4OH treated sunflower hulls. The high mineral content of alfalfa meal (70) contributed to higher ash content in the positive control diet. Among the sunflower hull containing diets, ash content of NaOH and KOH diets were higher than that of NH_4OH and negative control diets, due to the increased amount of Na and K cations retained on the treated SFH. Incorporation of SFH into the rations markedly increased the ADF and NDF content similar to that observed by others (75). A rather low digestible energy content of sunflower hulls was suggested, but the gross energy content of different rations were for the most part similar.

Dry matter intakes were highest for the KOH diet followed by the NaOH diet and negative control diet, respectively. Although ammoniation is reported to increase the consumption of treated materials by animals (44, 46, 60), dry matter intakes for the NH_4OH diet were lower than SFH containing diets. Animals fed the positive control diet consumed the least amount of feed dry matter.

TABLE 5. Chemical composition of rations containing sunflower hulls (SFH) fed to growing wethers.

Component	Rations				
	Positive control	$NaOH^a$	NH_4OH^b	KOH^a	Negative control
	(%)				
Dry matter (DM)	91.0	92.9	93.1	92.8	91.3
	(% of dry matter)				
Crude protein	15.0	14.3	15.7	14.3	14.3
Ether extract	2.9	2.8	2.5	2.8	2.8
Ash	7.1	6.5	6.0	6.9	5.7
Acid detergent fiber	18.2	25.0	25.4	26.4	26.3
Neutral detergent fiber	32.6	41.1	41.2	40.7	42.3
Permanganate lignin	4.4	5.2	6.4	6.5	4.6
Cellulose	13.9	19.6	20.4	20.5	20.8
	(KCal/g)				
Gross energy	4.22	4.22	4.33	4.30	4.21

[a]Treated with hydroxide solution at 4.45% of SFH DM.

[b]Treated with ammonium hydroxide solution at 3.42% of SFH DM.

This was probably because the positive control ration was more digestible and so the animals consumed enough energy to meet their needs. The fact that ground sunflower hulls were used in pelleted rations with alfalfa meal could have contributed to higher dry matter intakes observed with sunflower hull diets (28, 52). Intake of nutrients and water by wethers fed different rations are presented in Table 6. Intake of crude protein, ether extract, and ash were numerically highest for the animals fed the KOH treated SFH diet. Ash intake for wethers fed the NaOH and KOH diets were numerically higher than those fed the NH_4OH, positive control, and negative control diets. However, none of the above differences were significant ($P>.05$).

Wethers consuming SFH containing diets consumed more ($P<.05$) acid detergent fiber than those fed the positive control diet. Neutral detergent fiber intake followed similar trends to that of acid detergent fiber intake ($P<.07$). Amounts of acid detergent fiber and neutral detergent fiber consumed by animals fed various SFH-containing diets were similar ($P>.05$), although they were numerically higher for wethers fed the KOH treated diet. The higher acid detergent fiber and neutral detergent fiber intakes observed for animals fed the SFH-containing diets were due to the higher amount of fiber components in SFH. The differences for crude protain, ether extract, and ash along with ADF and NDF intakes can also be explained by the respective dry matter intakes. Gross energy intakes were in a similar pattern to that of dry matter intakes

TABLE 6. Nutrient and water intake of wethers fed rations with or without sunflower hulls.

Nutrient	Treatment					SE[c]
	Positive control	NaOH[a]	NH_4OH[b]	KOH[a]	Negative control	
	(kg/day)					
Dry matter	.69	1.15	1.01	1.45	1.06	.32
Crude protein	.11	.16	.17	.21	.15	.04
Ether extract	.02	.03	.02	.04	.03	.01
Ash	.06	.08	.05	.10	.05	.02
Acid detergent fiber	.05[d]	.30[e]	.27[e]	.39[e]	.30[e]	.10
Neutral detergent fiber	.14	.48	.44	.59	.48	.14
	(liter/day)					
Water	2.02	2.98	2.56	3.51	2.71	.68
	(KCal/day)					
Gross energy	2567.9	4793.7	4384.1	6226.7	4585.1	1461.0

[a]Treated with hydroxide solution at 2.45% of sunflower DM.

[b]Treated with ammonium hydroxide solution at 3.42% of sunflower hull DM.

[c]Standard error of means.

[d,e]Means in the same row with different superscripts are different ($P<.05$).

between different treatment groups. Insignificant differences in results were mainly caused by the individual variation of animals and due to limited number of animals in each treatment group.

Water consumptions with all experimental rations were higher than for the positive control ration. Marked increases in water consumption were observed with KOH and NaOH rations followed by negative control and NH_4OH rations, respectively. Other researchers (31, 48, 64, 69, 77, 80) reported similar increases in water intakes with alkali treated roughage fed animals. Animals fed the positive control ration consumed the lowest volume of water, possibly due to reduced salivation or lower dry matter intakes.

Replacing 50% of alfalfa meal dry matter with SFH depressed dry matter digestibility of rations ($P<.05$) (Table 7) similar to that reported by Park et al. (75). Assuming the digestibility of alfalfa meal to remain constant, higher digestibilities were observed with NaOH and KOH treated SFH when compared to nontreated hulls (negative control ration). Although statistically nonsignificant ($P>.05$), DM digestibility of rations due to incorporation of sunflower hulls treated with NaOH and KOH increased by 2.1 and 1.6% over the digestibility of the negative control ration.

The ration containing NH_4OH treated SFH was higher in percent crude protein and had a numerically higher digestibility coefficient for crude protein than other rations. However, significant increases in crude protein digestibilities were not observed due to alkali treatment, which agreed with observations

TABLE 7. Apparent digestibility by wethers of rations with or without sunflower hulls (SFH).

Parameter	Rations					SE[c]
	Positive control	NaOH[a]	NH_4OH[b]	KOH[a]	Negative control	
	(% digestible)					
Dry matter (DM)	78.1[e]	66.1[d]	63.2[d]	65.6[d]	64.0[d]	4.20
Gross energy	73.0	62.3	60.9	62.2	67.0	5.64
Crude protein	72.0	73.1	74.2	70.6	70.9	3.35
Ether extract	65.1	78.4	65.4	86.9	80.0	8.66
Ash	55.9	57.5	52.0	67.6	54.6	5.81
Acid detergent fiber	42.6	34.3	26.2	37.4	30.2	7.19
Neutral detergent fiber	58.2[e]	44.0[d,e]	35.3[d]	42.0[d]	42.9[d,e]	7.68

[a]Treated with hydroxide solution at 2.45% of SFH DM.

[b]Treated with ammonium hydroxide solution at 3.42% of SFH DM.

[c]Standard error of mean.

[d.e]Means within the same row with the same superscript are similar (P>.05).

by Gross (38) for NaOH treated SFH. Digestibilities of ether extract were numerically higher for SFH-containing rations than for the positive control ration with the highest ether extract digestibility associated with the KOH diet. Digestibility coefficients for ether extract for positive control ration and for NH_4OH ration were similar. Digestibility coefficients for ash for different ration treatments were similar ($P>.05$) although numerically highest for the KOH ration.

Digestibility of acid detergent fiber for the positive control ration was numerically higher than for other experimental rations. Park et al. (75) reported decreased ADF digestibility due to increased amounts of SFH in rations. This indicated that alfalfa fibers are more digestible than SFH fibers when fed to sheep. Among SFH-containing rations, ADF digestibilities were higher for the KOH diet followed by NaOH diet. With a higher crude protein intake and crude protein digestibility, the NH_4OH ration showed depressed fiber digestibility and gave a lower ADF digestibility than the negative control ration. Neutral detergent fiber digestibilities for NH_4OH and KOH diets were lower ($P<.05$) than that of the positive control diet, but were not different ($P>.05$) from NDF digestibilities of the NaOH diet and negative control diet. Gross energy digestibilities of rations containing SFH were depressed due to less digestible energy in hull fibers. In addition, numerically lower gross energy digestibilities were observed for alkali treated hull diets, possibly because of shorter retention time of

those rations in the rumen due to alkali treatment (14, 69).

Table 8 summarizes weight gains, water intake, and dry matter intakes of growing wethers during the digestion trial. All the ration treatments except KOH resulted in weight losses of wethers. Mean daily weight changes for positive control, NaOH, NH_4OH, KOH, and negative control rations were -.31, -.16, -.05, +.30, and -.38 kg/day ± .446, respectively. Because an animal fed the positive control ration went off feed and consumed negligible quantities of dry matter, the values for this animal were discarded and treatment means recalculated for missing values (Table 8). The negative control ration resulted in greater weight losses than other sunflower hull-containing rations though not statistically different ($P>.05$). Smaller losses associated with treated hull diets may be either due to increased digestibility and intake of alkali treated hulls (49) or due to possible "positive associative effect" of alkali treated hulls and alfalfa in the rations (76, 89). Animals fed the ration containing KOH treated hulls consumed more feed and water than animals fed other rations and resulted in positive weight changes. Due to intake of the more digestible positive control ration, animals showed comparatively less weight losses even with lower water and dry matter intakes. Among SFH containing diets, animals consuming the diet containing NH_4OH-treated hulls lost less weight than those fed other rations containing SFH, with the exception of the KOH treated hull-containing ration.

Ingestion of strong bases, especially of sodium and

TABLE 8. Daily dry matter intake, water intake, and body weight changes of wethers fed sunflower hull (SFH) diets.

Parameters	Rations					
	Positive control	NaOH[a]	NH_4OH[b]	KOH[a]	Negative control	SE[c]
Body weight change[d], kg	-.075	-.140	-.031	+.093	-.364	.38
Dry matter intake, kg	.69	1.15	1.01	1.45	1,06	.32
Water intake, liter	2.02	2,98	2.56	3,57	2.71	.68

[a]Treated with hydroxide solution at 2.45% of SFH dry matter.

[b]Treated with ammonium hydroxide solution at 3.42% of SFH dry matter.

[c]Standard error of means.

[d]Means recalculated for one missing value.

potassium have potential to alter the acid base balance of blood. This can be reflected in increased packed cell volume (PCV) values with those alkali fed animals. In this experiment, the PCV of blood from animals fed different rations were not as anticipated, nor were they different ($P>.05$) between treatment groups (Table 9). The nonsignificant difference between PCV content of animals on different rations was possibly due to low levels of alkali used to treat the hulls and also due to wide individual animal variations.

Others (33, 46) reported that consumption of alkali treated roughages did not effect ruminal pH and concentration of volatile fatty acids. Treatment means for rumen VFA, rumen pH, and osmolarity values are presented in Table 10. In this experiment none of the differences in concentration of individual and total volatile fatty acids, and ruminal pH approached significance ($P>.05$). However, numerically higher total VFA concentrations were observed in wethers consuming the ration containing NH_4OH-treated hulls. This difference was caused by higher concentrations of acetate, propionate, and butyrate in wethers fed NH_4OH treated SFH containing rations. Total VFA concentrations were lower for wethers fed control rations, especially with the negative control ration when compared to alkali treated SFH containing rations. Volatile fatty acids concentrations change due to feeding (65) and peak concentrations occur in 2 to 5 h post feeding (12, 100) depending on the type of diet. Rumen fluid pH is also related inversely to VFA concentrations (12). The difference in results of rumen parameters

TABLE 9. Packed cell volume (PCV) of whole blood from wethers fed sunflower hulls (SFH) containing rations.

Treatment	PCV
	(volume %)
Positive control	26.3
NaOH[a]	28.1
NH_4OH[b]	26.4
KOH[a]	26.9
Negative control	30.9
Standard error[c]	±4.06

[a]Rations containing SFH treated with hydroxide solution at 2.45% of SFH DM.

[b]Rations containing SFH treated with ammonium hydroxide solution at 3.42% of SFH DM.

[c]Standard error of mean.

TABLE 10. Rumen volatile fatty acids (VFA), pH, and osmolarity from wethers fed sunflower hull (SFH) containing rations.

Parameter	Rations					
	Positive control	NaOH[a]	NH_4OH[b]	KOH[a]	Negative control	SE[c]
VFA, μm/ml (molar %)						
Acetate	22.4(51.3)	19.2(42.9)	41.2(45.3)	29.0(41.3)	10.9(53.7)	12.07 (7.34)
Propionate	15.9(36.1)	9.0(20.5)	29.4(27.4)	14.7(22.7)	5.8(21.7)	14.31(13.52)
Isobutyrate	.7 (.6)	1.2 (3.0)	1.7 (2.3)	1.7 (2.9)	1.1 (4.2)	1.04 (2.12)
Butyrate	1.0 (1.9)	12.5(21.4)	16.3(14.8)	15.0(20.7)	1.1 (9.7)	7.03 (9.98)
Isovalerate	1.27(3.4)	3.2 (6.5)	4.0 (4.9)	2.6 (4.2)	1.8 (7.0)	1.47 (2.99)
Valerate	1.45(3.6)	1.3 (2.7)	2.2 (2.2)	1.8 (2.7)	.5 (2.8)	.84 (.82)
Total μmole/ml	42.2	46.0	94.7	64.8	21.9	29.13
Acetate/propionate	1.28	2.59	2.05	2.36	2.59	1.20
Rumen pH	7.01	6.49	6.06	6.48	6.90	.451
Rumen osmolarity, mOsm	274.2	278.5	304.8	315.6	260.75	44.192

[a]Treated with hydroxide solution at 2.45% of SFH dry matter.

[b]Treated with ammonium hydroxide solution at 3.42% of SFH dry matter.

[c]Standard error of means.

observed in this experiment with other reports may be primarily due to the long time interval between feeding and rumen sampling rather than due to actual differences in ration treatments.

Rumen osmolarity values for the wethers fed different rations were not different ($P>.05$). However, rumen osmolarity values were higher for alkali-treated hull-containing diets than for the controls. Higher osmolarity values with sodium and potassium hydroxide treated hull diets could have been caused by increased amounts of respective cations due to alkali treatment. Animals fed the ammonium hydroxide diet had lower water intake which probably resulted in a decreased dilution of solutes in the rumen, thereby resulting in higher osmolarity value.

CONCLUSIONS

Conclusions that can be drawn from the results of these investigations are:

1. The incorporation of sunflower hulls in rations increased ADF, NDF, and total dry matter intake.

2. Apparent digestibilities of ADF, NDF, and gross energy for SFH containing rations were lower than control rations.

3. At the tested levels of alkali, KOH treatment of SFH resulted in numerically higher ether extract and ash digestibility.

4. Rations utilizing NH_4OH and KOH treated SFH had NDF digestibilities that were lower ($P<.05$) than the positive control ration.

5. Total dry matter digestibilities of rations were significantly depressed due to incorporation of SFH at 25% ration DM level.

6. Animals fed sodium and potassium hydroxide treated SFH consumed more water than animals fed NH_4OH treated or untreated hulls.

7. Although KOH treated hull fed animals showed positive weight gains, no definite benefit was observed through alkali treatment of SFH in this experiment.

8. Due to the high lignin content and low digestibility, SFH might better be used for other agricultural purposes.

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