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The effect of sodium hydroxide on the composition, digestibility and feeding value of grain hulls and other fibrous material

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THE DIGESTIBILITY OF TREATED GRAIN HULLS

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THE EFFECT OF SODIUM HYDROXIDE ON THE COMPOSITION, DIGESTIBILITY AND FEEDING VALUE OF GRAIN HULLS AND OTHER FIBROUS MATERIAL.

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The Effect of Sodium Hydroxide on the Composition, Digestibility and Feeding Value of Grain Hulls and other Fibrous Material.

Introduction.

The basic problem of an adequate food supply for our own nation and also for the whole world becomes with the passing of the years increasingly harder to grapple with. Day by day our civilization increases in complexity; year by year the classes of society that do not produce food are augmented at the expense of the food-producing class. These facts coupled with the natural increase in population tend to bring about a situation, the remedy for which lies principally in two directions, (1) greater per capita production by the food-producing class, and (2) more economical utilization of what is now produced.

For realization of the latter aim it has become necessary to divert for human consumption more and more of our primary agricultural products, which formerly served principally as food for live stock. The logical sequences of such a development have been: more careful husbanding of those agricultural products which because of their nature are unsuitable for human consumption; more rational and economical methods of feeding; the feeding to animals of substances formerly wasted both in agriculture and industry; and, lastly, attempts to improve by various processes the food value of substances which in their natural state have either a low

food value or none at all.

To this last category belongs the investigation which forms the subject of this paper. The aim of the investigation has been to improve the digestibility and feeding value of grain hulls and similar fibrous material. The agency used for this purpose has been sodium hydroxide, and its effect in varying concentrations on five different substances has been studied. The substances have been: oat hulls, barley hulls, rice hulls, cottonseed hulls and flax shives.

The possible practical value of such experiments is apparent from what has already been said. It is of interest to note in this connection that the annual output of oat hulls by three of the leading oat-milling concerns in the United States totals over 100,000 tons.[1] Although at the present time this by-product is mixed with the oat middlings and dust, which are also by-products of the mills, and is marketed as "oat feed," the product is admittedly of inferior feeding value, due to its high content of indigestible fiber. Any method, the employment of which will bring about a considerable increase in digestibility of this and similar by-products is worthy of investigation.

Aside altogether from their possible significance in a practical way, the facts brought out by the investigation are of considerable scientific interest.

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[1]From approximate estimates furnished by the manufacturers.

Originality is not claimed for the method employed in the work. It was devised by Dr. Ernst Beckmann of Berlin, Germany, for the purpose of hydrolyzing straw and has been patented by him both in Germany and the United States (3)[1]. A careful search of the literature reveals however that although considerable investigation has been carried on with straw, work with hulls has never before been attempted. We have studied the action of dilute sodium hydroxide as it affects the proximate and, to a certain extent, the ultimate composition of hulls; and have fed the untreated and treated hulls to sheep, ascertaining by the usual procedure of digestion experiments the effect of the alkali on the digestibility of the hulls.

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[1]Reference is made by number to literature cited.

Review of the Literature.

The review has been arranged under three headings:

A. The chemistry of fibrous material.

B. The action of sodium hydrate and other alkalies on fiber.

C. Development of the process of hydrolyzing fibrous material for feeding purposes, together with the results of feeding experiments with the various products.

These different phases of the problem overlap more or less and some investigators have dealt with all three of them, but each forms a sufficiently clear-cut division to warrant dealing with them individually.

A. The chemistry of fibrous material.

The amount of work which has been done on the chemistry of plant fibers is nothing short of monumental, and yet, despite the vast accumulation of information now available, the chemistry of cellulose and of its combinations with pentosans, lignin and allied substances in woody fiber is but imperfectly understood. Investigators are still at variance over the structure of the cellulose and the lignin molecule.

We have made no attempt to review all or even any considerable portion of the literature on the subject. A great deal of it is of a highly technical nature and of importance

to the paper industry rather than to agriculture. It will be sufficient for our purpose to outline the general concept of the chemistry of fiber as it exists at the present time, with such references as may be necessary.

Plant fibers are simply an aggregation of the cell walls of certain specialized cells occurring in the plant. These cell walls become elaborated, enlarged, and strengthened with age until maturity is reached, at which time, in high-fiber plants at least, they constitute the major portion of the individual cells and of the vegetative portion of the plant, the protoplasm having been almost, if not altogether, absorbed, or transported to the seed.

In the early stages of growth the cell wall is known to consist of practically pure cellulose. But with advancing age it becomes changed to a compound cellulose known as ligno-cellulose which is characteristic of all fibrous or woody material and which imparts to such substances their property of rigidity. The process by which the cellulose is converted into ligno-cellulose is known as lignification. Just what this process involves in the way of chemical change and how it proceeds are still matters of dispute. Some investigators are of the opinion that it is purely a physical phenomenon, that the cellulose is simply embedded in, or incrusted by, the lignin, while others hold that the two are chemically combined, and that the ligno-cellulose is formed at the expense of the cellulose.

Magnus (35) considers that a definite linkage exists between the cellulose and the lignin.

Casparis (7) in a paper published in 1920 concludes that "lignified cell walls do not consist of chemically homogeneous material" and that "it appears likely that intra-molecular formation of lignin takes place from the carbohydrates originally present in the cell wall."

Rassow and Zschenderlein (42) have evidence which points toward the pentosans as intermediate products in the formation of lignin.

Perhaps the most recent view of the process of lignification is that set forth by Esselen (12). He says in part: "It has been demonstrated that lignin is made up of hydrosols of high molecular weight which are adsorbed from the sap by the cellulose fibers .... The maximum lignification coincides with the maximum percentage of adsorbable colloidal substances in the sap. While the lignification depends mainly on the adsorption referred to, it may be followed by certain chemical reactions, particularly dehydration, which manifest themselves in toughening and ageing."

In whatever way the transformation is brought about, the final product is the highly complex ligno-cellulose, the ultimate structure of which still baffles the chemist. It is however generally agreed that the complex consists of cellulose linked in some way with two non-cellulose substances, one of which contains

an aromatic nucleus, while the other, because it yields furfural on distillation with HCl, is presumed to be pentosan in nature. The latter two substances are so closely associated that they are grouped together under the term lignin, a complex containing a considerably higher percentage of carbon than does cellulose (about 60 per cent), and less resistant to the action of alkali. For this substance many formulae have been proposed. For a fairly complete list of these the reader is referred to a recent article by Beckmann, Liesche, and Lehmann (4). The most recent empirical formula possessed of any degree of definiteness is that of F. Lehmann (4), who suggests $C_{40}H_{44}O_{15}$. The work of Melander (40) is more recent but his results are not conclusive, several formulae being suggested.

Klason's conception that lignin is allied to coniferyl alcohol and derived from it by condensation and oxidation is worthy of consideration.

The outstanding characteristic of lignin and one on which almost all authorities agree is the presence in the molecule of methoxy ($CH_3.O$) and acetyl ($CH_3.CO$) groups. These are readily split off by the action of heat and dilute alkali with the formation of acetic acid, the residue left behind being much more stable and insoluble than the original lignin.

There are some data to show that some of the methoxy groups are contained in the cellulose but this is not definitely

established, and the generally accepted idea is that the methoxy is characteristic of lignin. The subject is well summed up by Schorger (43) in a treatise on the chemistry of wood.

B. The action of sodium hydroxide and other alkalies on fiber.

When such material as straw or wood is macerated with a solution of an alkali the solution becomes colored dark brown and if the process be continued sufficiently long the material becomes more or less completely disintegrated into a pulpy mass, which can be bleached by chlorine or any other suitable bleaching agent to a white or nearly white substance. This residue is a crude form of cellulose, which, depending upon its subsequent use, may or may not be further purified.

What are the changes involved in the destruction of the complex lignified tissue? What is it that the alkali removes? From this point on we shall consider only the action of dilute alkali on straw as our problem is not the production of cellulose but simply the utilization of the principle in sufficient degree to render the fiber more digestible, at the same time holding at a minimum, losses of valuable food substances.

The most clear and concise explanation is that given by Magnus in his "Theorie und Praxis der Strohaufschliessung" (36). He considers that the reaction proceeds in a threefold manner:

1. Separation and solution of the silicic acid which constitutes a portion of the incrusting substance of the straw and is present in most straws to the extent of one to two per cent, while some straws contain as much as five per cent.

2. Splitting off of the methoxy and acetyl groups (already referred to in the previous section) from the lignin, of which they form a characteristic part. This results in the production of acetic acid with consequent neutralization of more or less of the alkali employed in the process. The lignin itself is also profoundly changed and is rendered more insoluble and inactive. It should be borne in mind however that complete, or nearly complete, solution and removal of the lignin can be brought about when desired by repeated treatment with alkali at higher temperatures than those successfully employed for straw hydrolysis. In paper manufacture this is what actually takes place.

3. Forcing or springing of the bonds which link the lignin and cellulose together. The theory of a linkage between these two substances in the fiber is advanced by Magnus, and he considers that the springing apart of these bonds is the most important and essential feature in the action of the alkali. As a result the intestinal bacteria of animals are enabled to attack the cellulose and split it up into simpler substances, such as sugars and organic acids which can then be utilized by the animal organism.

These changes take place at ordinary temperatures and the maximum action of the alkali is reached in a comparatively short time. It should be said in addition that coincident with these favorable changes there is more or less destruction of pentosans and cellulose by the alkali, but in the improved process patented by Beckmann (3) this unfavorable action is held at a minimum.

Neger (41) has advanced the idea that the mechanical effect of the alkali on the straw is also important, the middle lamella of the cell wall being dissolved and the thick walled cells separated from one another.

The action of calcium hydroxide is similar to that of sodium hydroxide, but is less marked, the lignin and silicic acid being less attacked.

C. Development of the process of hydrolysis of fiber.

An endeavor has been made to cover the subject matter on this particular phase of the problem as completely as possible.

Practically all the work of developing a suitable process of fiber hydrolysis has been carried on in Germany, straw being the material generally used. Although many of the investigations were a result of the acute food shortage in that country during the war, the idea of utilizing processed fiber as an animal or even a human food is by no means a new one.

As early as 1865 Hellriegel and Lucanus (22) investigated the feeding value of straw which had been chopped up, moistened, and allowed to heat spontaneously. They concluded that such treatment diminished somewhat the food value of the straw.

In 1890 Henneberg and Lehmann (23) carried on feeding experiments with crude fiber prepared from rye straw by the action of sodium hydroxide. They concluded that cellulose prepared in this way was nearly equal in value as an albuminoid conserver to the easily soluble carbohydrates, and also that cellulose aided in fat production.

In 1894 Lehmann (32) showed that the food value of straw could be increased by cooking it with caustic soda in ordinary open kettles. In 1902 (32) he modified his process and made use of the pressure cookers of the paper industry, heating the straw and soda lye under pressure for several hours. The digestibility of straw thus treated was raised from 42 per cent to 56-60 per cent. The process has not however come into general use.

In 1899 Kellner (31) observed that rye straw hydrolyzed by the process used in paper manufacture had a digestibility of 88 per cent, and was capable of producing more fat in ruminants than pure potato starch.

in 1906 Ustyantzev (52) found that cellulose from straw freed from incrusting substances had a decided food value and was equal to isodynamic quantities of starch and sugar as a protector

of protein and fat. When fed to both rabbits and sheep it was almost completely digested.

Altmannsberger (1) in 1907 fed sheep with straw that had been treated with sodium hydroxide under pressure and found that the straw was readily eaten and that the digestibility of the crude fiber and ash had been materially increased.

About the same time, Diffloth (10) published data showing the increased value as a feeding stuff of straw from which the incrusting substance had been removed.

Gregoire (20) reported in 1907 on the method of Seidl and Bauriedl in which straw was treated under pressure with three per cent NaOH. The material was fed while still wet and was claimed to be fully as digestible as starch.

After the outbreak of the world war investigations of this nature became quite numerous. One of the first processes proposed was that of Oexmann, who utilized the straw pulp of the paper industry, mixing it with thirty-five per cent of molasses. The mixture was dried, ground and placed on the market as "Strohkraftfutter II." With protein added to it, it was known as "Strohkraftfutter I."

Lehmann's process of cooking the straw under pressure with varying concentrations of NaOH was also further experimented with at this time but was found to be uneconomical, due to costly equipment and handling of large amounts of water.

Colsmann's process was devised to overcome these defects and consisted of cooking the straw without pressure for twelve hours, using simple equipment. The element of time was the main consideration here and in that respect the Muller process which shortened the time somewhat by stirring was an improvement over Colsmann's method.

The Dahlemer process is similar in principle to Colsmann's and to Lehmann's original method, cast iron vessels being employed for the hydrolysis of the straw.

Fingerling reports that Colsmann's product had a digestibility of 60-65 per cent (13) while that of the Dahlemer process was 75 per cent digestible (16).

Unfortunately we have not been able to find in the literature any original accounts of the Oexmann, Colsmann, Muller and Dahlemer processes, but they are reported in some detail by Fingerling (14) and by Magnus (37). Because of the lack of references we are unable to assign definite dates as to the chronological sequence of their publication or introduction into practice. It ie inferred however from a careful study of the literature that they were all developed during the early part of the war. Other investigators about the same time were Stutzer (50), Dannfelt (9), Tollens (51) and Hansen (21).

All the processes devised for straw hydrolysis up to as late as 1917 required as an essential feature of their operation

the application of heat. In 1918 Beckmann put forward his process of hydrolysis in the cold, which was so much more simple and economical that it rapidly superseded those already in use and became the subject of careful investigation by the German experiment stations and others. Since that time practically all the literature on the subject (in Germany at least) deals with this process or modifications of it. The process has been patented, in Germany about 1919, and in the United States more recently (3).

The essential features of the method are hydrolysis of the material with eight times its weight of 1.5 per cent NaOH in open vats for a comparatively short time--three hours is usually sufficient--draining off the liquor and washing with water until the product no longer turns red litmus paper blue. The process is carried on at ordinary temperature and those who have investigated the method thoroughly claim that the hydrolysis is as complete at this temperature and in the relatively short time recommended as it is when the material is subjected to cooking either with or without pressure for longer periods of time. Also the loss of valuable nutritive substance is very much reduced.

The method is discussed in considerable detail by Magnus (34) and also by Fingerling (15).

Magnus has reviewed and discussed in his text on the subject (34) all of the more important processes of straw hydrolysis which had been devised up to the date of its publication in 1919.

In addition he has given a detailed account of the theory of straw hydrolysis, and of many of his own investigations. Though rather out of date now it is the only text on the subject that we are aware of.

In 1919 Jonscher (30) reported on his investigations in treating straw meal and wood meal with HCl and (or) NaOH, recommending some of the products as suitable for animal and human food.

Within the past four years Honcamp and his co-workers have carried on quite extensive investigations into the relative merits of various methods of straw hydrolysis. In his first paper (25) published in 1919 he reports unfavorably on the methods proposed by Minck and Schwalbe for hydrolysis with hydrochloric acid. Such treatment makes the straw no more digestible.

His second paper (26) published in 1921 deals with hydrolysis of straw by calcium hydroxide without pressure. Such treatment increases the starch value above that of the original straw or to about the same extent as does sodium hydroxide. Loss of organic substance is greater when the hydrolysis takes place under pressure than by simply boiling.

In his third contribution (27) published coincident with the second he discusses the effect of hydrolyzing with sodium carbonate, which is similar to that of NaOH and $Ca(OH)_2$. Using concentrations of Na_2CO_3 similar to those of NaOH and $Ca(OH)_2$ employed, the fodder value of the straw was considerably improved.

His fourth paper (28) published about the same time as II and III deals with hydrolysis by sodium hydroxide under pressure. Only cereal straw is suitable for such treatment. Results obtained with a definite amount of NaOH (3.5 kg. per 100 kg. of straw) were about the same as where twice that amount was used.

In his most recent work (29) Honcamp investigated the Beckmann methods using both sodium hydroxide and calcium hydroxide. His conclusion was that the loss in crude and digestible nutrients was greater with NaOH than with $Ca(OH)_2$.

In addition to this series of five papers he published a general paper (24) in 1919 with some rather important conclusions. He states that pressure cooking results in greater destruction of organic matter than when the cooking is done in open vessels, and that hydrolysis with NaOH results in a substantial increase in digestibility in rye, barley, and oat straw, but only slight increases in pea, seed beet, and rape straw.

Semmler and Pringsheim (48) found that usually less than fifty per cent of the crude fiber of natural products is digested when the lignin content is in excess of twenty per cent, but up to seventy-five per cent may be digested in the case of straw hydrolyzed by sodium hydroxide, despite a much higher lignin content.

Fingerling has made some important contributions to the subject. In addition to his numerous experiments already referred

to (13, 14, 15 and 16)[1], he has investigated Beckmann's process quite thoroughly. In 1919 he published a paper (17) dealing with the influence of time of hydrolysis upon the amount of nutritive material liberated. The results showed that the greatest amount of hydrolysis took place in the first three hours, and that action of the NaOH was practically completed in four hours. In a second paper (18) published in 1922 he shows quite conclusively that within reasonable limits the stronger the NaOH solution used the higher is the digestibility of the hydrolyzed straw.

Wagner and Scholer (54) treated straw with two per cent lye by the Beckmann process and found that the product when fed to sheep was very serviceable fodder fed either wet or dry.

The work of Scurti, et al., reported in 1919 and later, is worthy of mention. They have investigated the influence of hydrolysis on the composition and nutritive value of corn cobs (44), wheat straw (45), and grapevine shotts and hemp (46). Sulphuric acid was the principal hydrolyzing agent used, but nitric and hydrochloric acids and sodium hydroxide were also employed. The products from wheat straw and corn cobs were compressed into cakes and fed to farm animals with fair success (47).

In 1919 Ellenberger (11) reported some experiments with hydrolyzed wood meal as a feed for working horses. He concludes

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[1]See also Kellner's "Ernahrung der landwirtschaftlichen Nutztiere." Achte Auflage.

that this material may not only be substituted for the hay of the ration but may also replace the oats if some supplemental protein is furnished.

Voltz (53) in 1920 treated straw and chaff by Beckmann's process and reports considerably more digestible nutrients in chaff treated for eighteen hours than in chaff treated for three hours. Straw treated for twenty-four hours contained slightly more digestible nutrients than straw treated for twelve or seventy-two hours.

In 1920 Godden (19) published an account of his method of straw hydrolysis, which he devised for small-scale operations and which differs somewhat from any of the German processes. The chopped straw is soaked overnight in 1.5 per cent of NaOH and then steamed for an hour in a specially constructed boiler. After draining and cooling it is fed immediately. The dry matter of the treated straw has approximately one and one-half times the value of the original dry matter, and for production purposes its value is nearly doubled. He concludes that the gain in nutritive efficiency compensates for the loss in dry matter but emphasizes the need of further investigation of the possibilities of such treatment.

Weiser and Zaitschek (55) carried on an investigation similar to one by Fingerling (18) in which they studied the effect of the amount of soda used on the digestibility of straw. The

Lehmann apparatus was used and contrary to the findings of Fingerling they found that the highest starch values were obtained when the NaOH solution used was weakest. From the large number of variables in their experiments we are inclined to view their results with some misgivings.

Sherrard and Blanco (49) have described a method for preparation of a cattle food from hydrolyzed sawdust. The product was fed to three cows at the Wisconsin College of Agriculture "with highly gratifying results." The essential feature of the method consisted in the digestion of the sawdust with 1.8 per cent sulphuric acid under pressure. About twenty-one per cent of the original wood meal was converted into sugar.

Braunschild (6) patented in 1921 a process for treatment of substances rich in cellulose with a strong solution of calcium chloride.

Blasweiler (5) has recently described Steffen's method of straw digestion. Straw is cooked under pressure for one and one-half hours with ten per cent sodium hydroxide. The product has a composition similar to that obtained by Oexmann's process.

From the many investigations cited it is clear that the action of various hydrolyzing agents upon straw, while attended with some loss, noticeably improves its digestibility. Sodium hydrate proved to be the most effective agent, followed closely by calcium hydrate, the latter naturally proving the more economical.

Experimental.

As already stated, the method of hydrolysis employed for the treatment of grain hulls in this investigation was that of Beckmann. The apparatus consisted of a tank constructed of two-inch spruce planking, coated on the inside with asphalt, and provided with a strainer and outlet tap at the bottom to drain off the lye and wash water. The inside dimensions of this tank are: length, six feet; breadth, three feet; depth, one and one-half feet. Fifteen kilos of grain hulls can be readily handled in it at one time. In addition to the tank a homemade filter press for removal of the excess water after hydrolysis, and an eight-compartment special drying oven, constituted the major portion of the equipment.

The procedure in treatment of the hulls was as follows. An amount of sodium hydroxide equivalent in weight to eight times the amount of hulls used was made ready in the tank, the exact strength being adjusted by titration and addition of more NaOH or water as required. The desired amount of hulls was weighed out and transferred at once to the tank where it was thoroughly mixed with the alkali by means of a wooden hoe. The strengths of sodium hydroxide used were one per cent, one and one-half per cent, and three per cent. The one and one-half per cent strength is that employed by Beckmann. The three per cent strength, used with rice hulls only, was employed in order to ascertain whether it would have any more marked action on the very woody, gritty rice hulls

than the one and one-half per cent strength did. The one per cent strength was used with the idea of economy in mind. The mixture was allowed to stand for three hours, with frequent stirring; the soda liquor was then drained off as completely as possible and the hulls thoroughly washed with cold water until the wash-water no longer showed a pink tinge with phenolphthalein, about six changes of water being usually sufficient. The hulls were then transferred to the filter press where the excess water was removed, and they were finally spread out in as thin layers as possible in shallow galvanized pans and dried in the special steam oven. When dry they were bagged and stored until such time as the digestion experiments could be carried on, which, as a matter of fact, was almost immediately.

As in all the digestion work done at this station, sheep were used for the digestion experiments, all the individuals employed being aged wethers well trained in the routine of the work, a detail of no small significance, as anyone can attest who has attempted work of this kind. The feeding trials were carried on in the usual manner, ample details of which are given in an earlier publication of this station (33). Two sheep were used for each trial throughout. The hulls, both treated and untreated, were fed at the rate of one hundred grams[1] daily along with a basal ration[2]

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[1]In the case of the untreated oat hulls and rice hulls and the oat hulls and rice hulls treated with 1.5 per cent sodium hydroxide the amount of hulls fed was 150 grams.

[2]The basal ration for the trials in which untreated oat hulls and oat hulls treated with 1.5 per cent sodium hydroxide were fed contained no gluten feed, otherwise it was identical with that given above.

of five hundred grams English hay, one hundred and fifty grams gluten feed, ten grams salt, and water ad libitum.

The hulls were mixed with the gluten feed and no trouble was experienced in getting the sheep to eat them. No further preparation of the hulls was necessary except in the case of the rice hulls which had to be ground before the sheep would eat them.

Each digestion period lasted sixteen days, the first nine of which were preliminary, collection of the feces being made during the last seven days. No trouble or serious digestive disturbance of any kind was experienced and in only one instance[1] in the twenty-six single trials was any of the feed refused.

The entire ration for any one trial was weighed out at the beginning of the period and careful samples of all the feeds taken. These were transferred to air-tight containers, and taken to the laboratory where dry matter determinations were made immediately and the feeds were prepared for analysis. The feces were collected daily, and one-tenth of the daily output from each sheep was carefully dried. The seven daily portions from each sheep were composited at the end of each period and prepared for analysis, dry matter determinations being made after the composite samples had been coarsely ground.

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[1]Sheep 11 when fed on 500 grams of hay, 150 grams of gluten feed and 150 grams of rice hulls (treated 1.5 per cent NaOH), wasted for the entire period an average of 32.14 grams, or about 4 per cent of his daily ration.

All feeds and feces were subjected to the usual fodder analyses according to the methods of the Association of Official Agricultural Chemists (56), the following determinations being made: moisture, total ash, protein, crude fiber, ether extract, and nitrogen-free extract by difference. In addition, the water-soluble acidity of the samples of treated and untreated oat hulls was determined.

As a special feature of the investigation some of the ultimate constituents of the treated and untreated hulls were determined in order to throw some light on the effect of the sodium hydroxide on the ultimate composition of the hulls. Also because the digestibility of some of these ultimate constituents as affected by the action of the soda was a point to be considered, certain of the special determinations were made in the feces, and in the other feeds which composed the ration.

These determinations were as follows:

<u>Starch</u> in all of the samples of hulls.

<u>Pentosans</u> in all samples of feeds and feces.

<u>Lignin</u> in all samples of feeds and feces.

Pentosans were determined according to the official method as described in the manual of the Association of Official Agricultural Chemists (57).

Starch was determined by pancreatin in the following manner:

> Two grams of finely ground (100 mesh) material were transferred to a hardened filter paper and washed with several portions of hot 10 per cent ethyl alcohol to remove the sugars. The residue was immediately transferred by means of a stemless funnel and a minimum of water from a wash bottle, to a 250 cc volumetric flask. The suspension if not already diluted sufficiently by the water used for transferring, was further diluted to about 100 cc and boiled for half an hour to rupture the cell walls and the starch granules and liberate the starch. The flask was then filled almost to the mark with distilled water and allowed to cool to below 37° C. A pinch of sodium bicarbonate was then added to insure slight alkalinity for optimum action of the pancreatin, followed by one-tenth of a gram of full-strength pancreatin.[1] The solution was at once made up to the mark, shaken well, and placed in a water bath at 37-40° C for half an hour, at the end of which time the contents of the flask were emptied into a 500 cc beaker to facilitate subsequent pipetting; 200 cc of the liquid were immediately pipetted off into another 500 cc beaker as rapidly as possible, and 20 cc of HCl (sp. gr. 1.125) were added at once, thus inactivating the pancreatin. The 220 cc of liquid were then filtered by suction into another 250 cc flask, using a platinum cone to support the filter paper, and a bell jar of suitable size on a ground glass plate to hold the flask into which the filtrate passed. As soon as possible after filtration was complete the flask was placed under a reflux condenser and heated gently for two hours, the solution was then cooled, nearly neutralized with NaOH and made up to 250 cc. With some materials another filtration was necessary at this point, but suction was not required. Reducing sugar was then determined in aliquots of the solution by Allihn's modification of Fehling's method (58).

Lignin was determined by a modification of the method of Ost and Wilkening (8) proposed by Mahood and Cable (39). The

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[1]This material was furnished to us through the courtesy of Parke, Davis & Co., of Detroit, Mich., and, unlike the ordinary reagent, contained no diluent.

principle of the method consists in the hydrolysis of all the constituents of the material except the lignin, by means of concentrated sulphuric acid. The dissolved substances are removed by filtration and washing and the residue is dried and weighed as lignin. The details are as follows:

> Two[1] grams of the material was extracted with ether in an ordinary fat extraction apparatus, transferred to a 1000 cc Erlenmeyer flask and covered with ten times its weight (13 cc) of 72 per cent sulphuric acid. Considerable care and some practice were necessary at this point in order to get all particles of the dry material in contact with the relatively small amount of acid. The hydrolysis was allowed to proceed for sixteen hours at room temperature, at the end of which time the solution was diluted with ordinary tap water to a strength of 3 per cent (480 cc of water was the amount necessary for that degree of dilution). The solution was then boiled under a reflux condenser for two hours, filtered through linen, washed with hot water, transferred to a tared Gooch crucible, dried at 100° C, weighed, ignited, and weighed again. The loss in weight was considered as Lignin.

Some preliminary work was done in determination of lignin by the method of Willstatter (38) in which forty-two per cent hydrochloric acid is used as the hydrolyzing agent instead of sulphuric acid. This method proved less satisfactory because of the high cost of HCl so highly concentrated, the difficulty of keeping it at that strength, and the extreme unpleasantness of the dense fumes given off by it.

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[1]Mahood and Cable use four grams, but half that amount was better adapted to our purposes.

Presentation and Discussion of Experimental Data.

The results secured in the investigation group themselves under two headings.

1. Effect of the sodium hydroxide on the composition of the hulls.

2. Effect on the digestibility and feeding value of the hulls.

The first of the above groupings can be further subdivided into four distinct topics:

(a) Losses in weight in the treated materials due to the action of the sodium hydroxide, and reduction in the strength of the sodium hydroxide.

The loss in weight was ascertained on a dry matter basis by weighing the material and making dry matter determinations, both before and after treatment. The reduction in strength of the soda was determined by titration with N/2 sulphuric acid. The following table (Table I) sets forth the figures:-

Table I.

Material.	Loss in weight on treatment. Dry matter basis. Per cent.	Strength of NaOH employed. Per cent.	Strength of NaOH after use. Per cent.	NaOH consumed. Per cent.
Oat hulls	16.54	1.5	0.70	53.33
Oat hulls	10.74	1.0	0.46	54.00
Barley hulls	20.29	1.5	1.04	30.66
Barley hulls	19.31	1.0	0.64	36.00
Rice hulls	15.60	1.5	0.75	50.00
Rice hulls	19.51	3.0	2.28	24.00
Cottonseed hulls	9.69	1.5	0.75	50.00
Flax shives	25.03	1.5	0.80	46.66

These losses are chiefly due as already explained (see p. 9) to solution and separation of the silicic acid, a portion of the lignin, and more or less of the cellulose and pentosans. It should be noted however that a small part of the reduction in weight was due to unavoidable mechanical loss. In draining off the soda liquor and subsequent wash-water, more or less of the fine particles of the treated hulls passed through the finest sieve that it was practicable to use. This was especially true for the flax shives as they were ground quite fine when received.

The average loss in weight for the several substances when one and one-half per cent NaOH was used was equivalent to 17.43 per cent of the original material; when one per cent NaOH was used the average loss was slightly less, 15.03 per cent; and in the single instance where three per cent NaOH was employed the loss was slightly higher, 19.5 per cent, indicating that the stronger the soda solution, the greater the loss, and that for a given strength of soda the loss depended upon the character of the material treated.

The reduction in strength of the sodium hydroxide is due to neutralization by the acetic acid formed (see p. 9). In this connection it may be worth while to record our observation of what took place when the hulls were added to the NaOH solution in the tank. During the first few minutes of the treatment there was always a noticeable formation of small bubbles, accompanied by a

quite audible crackling sound, suggestive of a mild effervescence. This phenomenon ceased to be perceptible after the first fifteen to twenty minutes which would seem to indicate a slowing up of the reaction and that the action of the alkali takes place largely in the first few minutes. These assumptions are borne out by the work of Magnus (35) and of Beckmann (3).

The average amount of alkali consumed or neutralized in the process was 45 per cent of the total amount when the strength employed was one per cent; 46.66 per cent when the strength employed was one and one-half per cent; 24 per cent when the strength employed was three per cent. Or in other words the percentage strength of the exhausted solutions averaged 0.45 per cent, 0.70 per cent, and 2.28 per cent respectively for the one per cent, one and one-half per cent and three per cent NaOH solutions.[1]

It will be noted that the percentage amount of NaOH consumed is about the same for the one per cent and one and one-half per cent--around 45 per cent, or slightly less than half of the total amount employed--while the actual amount consumed is about the same for the one and one-half per cent and three per cent solutions, viz., about 0.7 per cent.

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[1]The 3 per cent NaOH solution was used only in one instance, hence does not represent an average.

Beckmann recommends the use of the exhausted alkali a second and even a third time, bringing it back to the desired strength by adding the required amount of fresh sodium hydrate. In the practical operation of the process this procedure is in the interests of economy, but for our experimental work we considered it inadvisable and accordingly a fresh solution was prepared for each lot of hulls.

(b) Reaction of the materials before and after treatment.

In order to ascertain if there was any residual uncombined alkali in the treated materials the water-soluble acidity or alkalinity of all the treated and untreated samples was determined according to the method given in the manual of the Association of Official Agricultural Chemists (59). Table II sets forth the results.

Table II.

Laboratory number.	Material.	N/10 NaOH required per gram of substance. cc.	N/10 H_2SO_4 required per gram of substance. cc.
248	Oat hulls, untreated	0.23	
503	Oat hulls, treated 1% NaOH	0.10	
293	Oat hulls, treated 1.5% NaOH		0.16
453	Barley hulls, untreated	1.14	
491	Barley hulls, treated 1% NaOH	0.23	
482	Barley hulls, treated 1.5% NaOH	0.42	
337	Rice hulls, untreated	0.22	
321	Rice hulls, treated 1.5% NaOH		0.07
512	Rice hulls, treated 3% NaOH		0.08
449	Cottonseed hulls, untreated	0.23	
460	Cottonseed hulls, treated 1.5% NaOH	0.08	
485	Flax shives, untreated	0.47	
494	Flax shives, treated 1.5% NaOH	0.08	

It is seen that all untreated materials showed a slight water-soluble acidity measured in terms of N/10 NaOH--varying from 0.22 cc N/10 NaOH in the case of rice hulls to 1.14 cc in the case of barley hulls. A slight acidity is normal to most feeding stuffs. The relatively high acidity of the barley hulls may be attributed to a slight fermentation of the considerable amount of carbohydrate present which had not been separated from the hulls. In the case of the treated materials five lots showed a slight acidity varying from .08 cc to .42 cc N/10 NaOH, and three lots showed a slight alkalinity (from .07 cc to .16 cc N/10 H_2SO_4 per gram of substance). From these results it is evident that in the majority of cases there was no residual uncombined soda from the treatment left in the materials after thorough washing, and in those cases where there was any alkalinity it was so slight that it would be readily taken care of by the hydrochloric acid in the animal's stomach. Taking the case of the one and one-half per cent oat hulls which showed the highest alkalinity (.16 cc N/10 HCl required for one gram of material), this is equivalent to 96 mgm of NaOH per day on the basis of 150 grams of the hulls which was the amount actually fed. This would require for its neutralization 87 mgm of HCl (or roughly the amount in 45-50 cc of average gastric juice). The animal's stomach could easily take care of such an amount. Care should however be used to wash out the soda after treatment as thoroughly as possible compatible with good practice.

(c) Effect of the treatment on the proximate constituents of the hulls.

The detailed results of all the proximate analyses together with percentage increases or decreases of the various constituents due to the action of the alkali are given in the accompanying table (Table III).

Table III.

Laboratory number.	Material.	Moisture as fed.	Dry matter basis. Total ash.	Crude protein.	Crude fiber.	N-free extract.	Crude fat.
248	Oat hulls, untreated	7.70	6.33	2.26	33.24	57.24	0.93
503	Oat hulls, treated 1% NaOH	5.77	5.69	2.05	34.80	56.99	0.47
	Percentage increase or decrease due to treatment		10.12-	9.30-	4.69+	0.44-	49.47-
293	Oat hulls, treated 1.5% NaOH	4.05	5.23	1.37	40.20	52.65	0.55
	Percentage increase or decrease due to treatment		17.38-	39.39-	20.93+	8.02-	40.86-
337	Rice hulls, untreated	6.25	19.06	3.02	41.80	35.38	0.75
321	Rice hulls, treated 1.5% NaOH	3.61	17.46	2.51	46.08	33.41	0.58
	Percentage increase or decrease due to treatment		8.40-	16.89-	10.23+	5.57-	22.67-
512	Rice hulls, treated 3% NaOH	5.92	13.13	1.83	50.26	34.23	0.55
	Percentage increase or decrease due to treatment		31.12-	39.40-	20.23+	3.25-	26.67-
453	Barley hulls, untreated	6.76	4.50	10.81	15.56	66.86	2.27
491	Barley hulls, treated 1% NaOH	6.24	4.74	10.41	18.97	63.89	1.99
	Percentage increase or decrease due to treatment		5.33+	3.63-	21.91+	4.45-	12.34-
482	Barley hulls, treated 1.5% NaOH	5.09	4.33	9.25	19.03	65.40	1.99
	Percentage increase or decrease due to treatment		3.78-	14.44-	22.30+	2.18-	12.34-
449	Cottonseed hulls, untreated	6.93	2.13	4.08	43.99	48.60	1.19
460	Cottonseed hulls, treated 1.5% NaOH	5.15	2.75	3.03	49.83	43.55	0.84
	Percentage increase or decrease due to treatment		29.10+	25.74-	13.27+	10.40-	29.42-
485	Flax shives, untreated	6.78	4.09	5.24	53.81	35.05	1.81
494	Flax shives, treated 1.5% NaOH	5.54	5.35	4.41	62.84	26.07	1.33
	Percentage increase or decrease due to treatment		30.81+	15.84-	16.77+	25.63-	26.52-

+ Increase.

- Decrease.

The treatment relatively increased the fiber and decreased all other constituents except ash which was increased in three instances. In one of these instances (barley hulls) the increase was so slight as to be of no significance. The considerable increase in ash in cottonseed hulls and flax shives can probably only be explained by considering it as a relative increase, the ash of these materials being so insoluble that it was unattacked by the alkali while a portion of the more soluble organic constituents was removed. It is possible also that sufficient residual soda remained combined in these materials to account for the ash increase.

The striking feature of the results is the appreciable percentage increase of fiber in all cases, but it must be borne in mind that this is only relative, due to the removal of the more soluble portions of the hulls, while the fiber was attacked to a much smaller extent. For the same reason the increase in fiber was consistently greater, the higher the concentration of sodium hydroxide. Although the protein and fat suffered considerable loss they are present in relatively small amounts and hence are of minor importance.

In Table IV is set forth the net loss in pounds on a dry matter basis of each proximate constituent.

Table IV.

Loss in pounds for each 100 pounds of dry matter treated.

Material.	Total ash.	Crude protein.	Crude fiber.	N-free extract.	Crude fat.	Total.
Oat hulls, treated 1% NaOH	1.26	0.43	2.18	6.37	0.51	10.75
Oat hulls, treated 1.5% NaOH	1.97	1.12	0.31*	13.30	0.47	16.55
Barley hulls, treated 1% NaOH	0.68	2.41	0.25	15.31	0.66	19.31
Barley hulls, treated 1.5% NaOH	1.05	3.44	0.39	14.73	0.68	20.29
Rice hulls, treated 1.5% NaOH	4.32	0.90	2.91	7.18	0.26	15.57
Rice hulls, treated 3% NaOH	8.49	1.55	1.35	7.83	0.31	19.53
Cottonseed hulls, treated 1.5% NaOH	0.35*	1.34	1.01*	9.27	0.43	9.68
Flax shives, treated 1.5% NaOH	0.08	1.93	6.70	15.51	0.81	25.03

*Those figures marked with an asterisk represent gains instead of losses. In the case of the crude fiber an absolute gain is impossible, so these small increases are explainable only on the basis of analytical or experimental error. In the case of the ash which showed an absolute increase it is possible that residual NaOH might account for it.

Considering the results from this angle we see that the fiber was practically unattacked in so far as its removal by solution was concerned, while greater or lesser amounts of all the other constituents were removed. The greatest actual losses were in the case of the nitrogen-free extract, which includes the starch, a portion of the pentosans and lignin, and allied substances.

(d) Effect of the treatment on some of the ultimate constituents of the hulls.

It was thought that a more detailed analytical examination of the hulls than that involved in the conventional fodder analyses would furnish still more accurate information as to the chemistry involved in the process. Table V gives the results of starch, pentosan, and lignin determinations made as described in a previous section of this paper.

Table V.

Material (dry matter basis).	Starch per cent.	Pentosans per cent.	Lignin per cent.
Oat hulls, untreated	4.73	40.02	20.20
Oat hulls, treated 1% NaOH	5.59	43.80	23.54
Percentage increase or decrease due to treatment	18.18+	9.45+	16.53+
Oat hulls, treated 1.5% NaOH	7.67	44.16	18.61
Percentage increase or decrease due to treatment	62.16+	10.34+	7.87-
Rice hulls, untreated	5.65	21.98	22.72
Rice hulls, treated 1.5% NaOH	5.67	24.10	23.09
Percentage increase or decrease due to treatment	0.35+	9.65+	1.63+
Rice hulls, treated 3% NaOH	5.67	25.28	25.10
Percentage increase or decrease due to treatment	0.35+	15.01+	10.48+
Barley hulls, untreated	13.41	23.50	14.87
Barley hulls, treated 1% NaOH	15.78	26.61	15.83
Percentage increase or decrease due to treatment	17.67+	13.23+	6.46+
Barley hulls, treated 1.5% NaOH	22.55	26.21	15.01
Percentage increase or decrease due to treatment	68.16+	11.53+	0.94+
Cottonseed hulls, untreated	5.87	32.52	25.29
Cottonseed hulls, treated 1.5% NaOH	6.08	34.10	21.97
Percentage increase or decrease due to treatment	3.58+	4.86+	13.13-
Flax shives, untreated	6.26	27.16	33.28
Flax shives, treated 1.5% NaOH	6.89	25.92	32.40
Percentage increase or decrease due to treatment	10.06+	4.57-	2.64-

\+ Increase.

\- Decrease.

An examination of the figures in Table V shows that relatively the starch was increased by treatment in all instances, the pentosans in all but one instance, and the lignin in five out of eight. In a general way, the increases in pentosans and lignin parallel those for fiber, which is what would be expected.

One is impressed with the high percentage of pentosans in the untreated oat hulls; in fact, pentosans together with the lignin make up the major portion of the hulls. The rice hulls are composed largely of ash, fiber, including pentosans, and lignin. They are somewhat more lignified than the oat hulls, and the presence of the lignin together with the high ash percentage accounts for their inferior nutritive value. Cottonseed hulls with their very high crude fiber percentage, together with the large amount of pentosans and lignin, are in the same class with the rice hulls. Flax shives, containing approximately fifty-four per cent of fiber, twenty-seven per cent of pentosans and thirty-three per cent of lignin, the most lignified of the several substances examined, should prove to be the least digestible.

Table VI shows the actual net losses of these constituents resulting from treatment.

Table VI.

Loss in pounds for each 100 pounds of dry matter treated.			
Material.	Starch.	Pentosans.	Lignin.
Oat hulls, treated 1% NaOH	0.26*	0.98	0.81*
Oat hulls, treated 1.5% NaOH	1.67*	3.16	4.67
Barley hulls, treated 1% NaOH	0.68	2.03	2.10
Barley hulls, treated 1.5% NaOH	4.56*	2.61	2.91
Rice hulls, treated 1.5% NaOH	0.86	1.64	3.23
Rice hulls, treated 3% NaOH	0.91	1.63	2.52
Cottonseed hulls, treated 1.5% NaOH	0.38	1.72	5.45
Flax shives, treated 1.5% NaOH	1.09	7.73	8.99

* Represents a gain, which of course is impossible and is explainable only on the basis of analytical or experiment error.

The losses due to treatment seem to be distributed between the ash, protein, fat, pentosans and lignin. The most pronounced losses occur in the pentosans and lignin. Even after all of these are accounted for there is more or less loss of alkali soluble constituents not identified, which because of a lack of complete identification are still grouped under the term nitrogen-free extract. In fact in substances of this nature the non-nitrogenous materials are of such a complex nature and are so interwoven with each other that it does not appear possible to determine the different constituents with quantitative exactness. This difficulty in case of starch has led Armsby (2) to remark that "unfortunately, starch can be determined only more or less approximately."

2. Effect of sodium hydroxide on the digestibility and feeding value of the hulls.

This is revealed by a study of the digestion coefficients of the various constituents of the hulls which were determined as already described (see p. 21). In addition to the usual constituents as determined in fodder analyses, the digestibility of the pentosans and lignin, and the effect of the alkali on it, were also ascertained. For the purposes of this investigation we need consider only the digestion coefficients of the total dry matter, crude fiber, nitrogen-free extract, pentosans, and lignin. These are the important constituents, the protein, fat and ash being present for the most part in unimportant amounts. Table VII presents the results in condensed form.[1] For the benefit of the critical student of these detailed results it is appropriate to remark here that the digestion trials were conducted with the greatest care. Where the coefficients from two individuals differ materially it should be borne in mind that work of this nature cannot be controlled in the same way that laboratory determinations can be. Biological processes are too complex to permit it and it frequently happens also that the individuality of the animal exerts an influence on the final result. Accordingly the coefficients must be viewed as giving general rather than absolutely definite information.

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[1]For detailed data of the digestion experiments see the appendix.

Oat hulls, treated 1% NaOH	16	26.50	57.88	26.65	51.18	negative
Oat hulls, treated 1% NaOH	17	70.37	82.77	64.67	71.07	39.63
Oat hulls, treated 1.5% NaOH	12	73.31	84.91	71.55	84.56	28.15
Oat hulls, treated 1.5% NaOH	13	87.90	97.22	86.53	62.99	46.56
Average		80.61	91.07	79.04	73.78	37.36
Increase due to treatment (1% NaOH)		34.13[a]	30.20[a]	30.59[a]	35.16[a]	28.40[a]
Percentage increase		94.17[a]	57.43[a]	89.76[a]	97.91[a]	252.89[a]
Increase due to treatment (1.5% NaOH)		44.37	38.50	44.96	37.87	26.13
Percentage increase		122.43	73.24	131.92	105.46	232.68
Barley hulls, untreated	16	65.77	42.73	64.24	50.02	18.76
Barley hulls, untreated	17	53.17	46.86	55.47	44.77	negative
Average		59.97	44.79	59.85	47.40	-
Barley hulls, treated 1% NaOH	16	64.56	37.99	70.04	52.87	23.85
Barley hulls, treated 1% NaOH	17	72.83	66.55	79.57	76.91	45.55
Average		68.69	52.28	74.81	64.89	34.70
Barley hulls, treated 1.5% NaOH	16	79.49	70.76	81.98	73.91	negative
Barley hulls, treated 1.5% NaOH	17	85.52	91.80	87.22	92.16	negative
Average		82.50	81.28	84.60	83.04	-
Increase due to treatment (1% NaOH)		8.72	7.49	14.96	17.49	15.96
Percentage increase		14.54	16.72	25.00	36.90	84.97
Increase due to treatment (1.5% NaOH)		22.53	36.49	24.75	25.64	negative
Percentage increase		37.57	81.47	41.35	75.19	negative
Rice hulls, untreated	9	negative	negative	14.57	3.34	negative
Rice hulls, untreated	12	4.97	12.08	5.21	negative	negative
Average		-	-	9.89	-	-
Rice hulls, treated 1.5% NaOH	9	23.72	20.28	35.04	51.36	13.87
Rice hulls, treated 1.5% NaOH	11	34.60	36.67	41.04	60.43	18.06
Average		29.16	28.48	38.04	55.92	15.97
Rice hulls, treated 3% NaOH	18	34.02	28.42	50.53	48.91	10.97
Rice hulls, treated 3% NaOH	19	33.96	22.71	39.57	29.27	21.73
Average		33.99	25.57	45.05	39.09	16.35
Increase due to treatment (1.5% NaOH)		24.19	16.40	28.15	52.58	15.97
Percentage increase		486.72	135.76	284.63	1674.25	-[b]
Increase due to treatment (3% NaOH)		29.02	13.49	35.16	35.75	16.35
Percentage increase		583.90	111.67	355.51	1170.36	-[b]
Cottonseed hulls, untreated	18	46.06	54.00	54.74	92.26	negative
Cottonseed hulls, untreated	19	59.98	62.41	62.66	88.10	31.26
Average		53.02	58.21	58.70	90.18	-
Cottonseed hulls, treated 1.5% NaOH	18	51.84	51.29	66.84	108.87	negative
Cottonseed hulls, treated 1.5% NaOH	19	57.21	53.83	68.53	92.70	9.45
Average		54.52	52.56	67.69	100.78	-
Increase due to treatment		1.50	5.65[c]	8.99	10.60	21.81[c]
Percentage increase		2.83	9.71[c]	15.32	11.75	69.77[c]
Flax shives, untreated	18	negative	negative	3.92[d]	6.91[d]	negative
Flax shives, untreated	19	30.15	18.67	33.18	25.36	27.79
Flax shives, treated 1.5% NaOH	18	18.31	20.15	31.34	39.09	negative
Flax shives, treated 1.5% NaOH	19	39.21	25.37	45.43	46.32	20.32

Careful scrutiny of the individual and average digestion coefficients reveals the following facts:

1. The digestibility of the total dry matter was substantially increased by treatment in case of the oat, barley, and rice hulls.

2. The digestibility of the crude fiber, nitrogen-free extract and pentosans in oat, barley, and rice hulls was markedly increased by treatment.

3. The results in case of lignin are not so consistent, but it must be remembered that treatment has changed its molecular structure, hence the data cannot be considered of any particular value. It seems evident that in the untreated material, in several instances some little use was made of the lignin complex, the results varying with the different materials. After treatment, in case of the oat, rice and barley hulls the digestibility of the lignin residue seems to have been somewhat improved. In view, however, of our incomplete knowledge of the structure of the lignin molecule and of the varying results secured with two sheep on the same material, it may be concluded that lignin is of quite doubtful value as a source of nutrition. Some investigators consider it to be entirely indigestible.

Table VIII gives a general resume of the effect of the alkali upon the digestibility of the hulls.

Table VIII.

Effect of varying strengths of sodium hydrate in increasing digestibility of fibrous material.

Solution used.	Percentage increase over untreated hulls.				
	Total dry matter.	Crude fiber.	N-free extract.	Pentosans.	Lignin.
1% NaOH (oats)	94.17	57.45	89.76	97.91	252.89
1% NaOH (barley)	14.54	16.72	25.00	36.90	84.97
1.5% NaOH (oats)	122.43	73.24	131.92	105.46	232.68
1.5% NaOH (barley)	37.57	81.47	41.35	75.19	negative
1.5% NaOH (rice)	486.72	135.76	284.63	1674.25	a
3% NaOH (rice)	583.90	111.67	355.51	1170.36	a

The cottonseed hulls and flax shives are not included in this summary because of the negligible effect the soda solution had on their digestibility.

[a]Averages not available for lignin because of varying results in its digestibility.

In addition to the facts mentioned under Table VII, the following general statements seem to be warranted:

1. Expressed on a percentage basis, treatment with varying strengths of dilute NaOH invariably increased the total digestible dry matter of oat hulls, barley hulls and rice hulls. In the majority of cases it also increased markedly the digestibility of the important constituents of these materials.

2. Cottonseed hulls and flax shives appear to have been unaffected by the treatment. It is probable that the lignin-cellulose linkage was broken only to a slight extent, due no doubt to the higher degree of lignification in these materials, as compared with the hulls of the cereal grains.

3. Although the rice hulls showed by far the greatest response to the action of the soda, the original material was so much inferior in digestibility to the untreated oat and barley hulls that the net result of treatment was a product considerably inferior in total digestible nutrients to even the untreated oat hulls, hence the action of soda on this material is not likely to be of economic value.

4. Where varying strengths of NaOH were used on the same material, an increase in strength of solution was almost invariably accompanied by a considerable increase in digestibility of the hulls, most marked when the comparison was between one per cent NaOH and one and one-half per cent NaOH, not so marked where three

per cent NaOH was used. In this connection it should be noted that losses in weight due to treatment were slightly increased by an increase in strength of the soda.

5. As a rule, increases in the relative amount of a component due to treatment were accompanied by an increase in its percentage digestibility.

6. Taking into consideration both the loss in weight and the increased digestibility due to the action of the soda (see Tables IV and VI) we obtain net gains as shown in Table IX.

Table IX.

Average net gain in total digestible dry matter and in the important digestible nutrients of oat hulls and barley hulls on the basis of 100 pounds of dry matter treated.

Material.	Total digestible dry matter.	Digestible crude fiber.	Digestible N-free extract.	Digestible pentosans.	Digestible lignin.
Oat hulls, treated 1% NaOH	7.72	5.47	3.60	11.81	7.06[a]
Oat hulls, treated 1.5% NaOH	31.04	19.14[a]	11.59	15.88	2.94
Barley hulls, treated 1% NaOH	4.55[b]	2.81	3.68[b]	4.81	1.97
Barley hulls, treated 1.5% NaOH	5.79	8.18	11.31	8.46	c

[a]Referring to Tables IV and VI it will be seen that the total crude fiber and total lignin of oat hulls each showed a net gain instead of a net loss after treatment. As already noted, this is impossible, so the results in question are obtained by assuming that no loss of these constituents was involved.

[b]This result represents a net loss.

[c]Digestibility of lignin in this instance was a minus quantity.

Because of the considerable amount of calculation involved in obtaining the figures in Table IX a sample page of the computations is given in the Appendix.

Considering the net gains as shown in the table it can be said that with one exception (barley hulls, one per cent NaOH) the increase in digestibility outweighed the loss by solution in the soda. It is questionable however whether in those materials showing the smaller gains the increase would offset the cost of treatment. The extra half per cent of soda apparently makes a great difference in the final result.

The barley hulls would probably have made a more favorable comparison with the oat hulls had they not contained so much starchy material. Unfortunately, the separation of the endosperm from the hull had not been nearly so complete as in the case of the oat hulls (due in part probably to the greater tenacity with which the barley hulls cling to the endosperm or possibly to a less perfect mechanical method of separation) and as a result there was quite a large amount of the floury portion of the grain adherent to tho hulls.

Considering in detail only that lot of treated hulls which showed a rather high net gain in total digestible nutrients, viz., the oat hulls treated with one and one-half per cent NaOH, we find by a simple calculation that on a dry matter basis the treatment has increased the total digestible dry matter per ton of hulls from 725 pounds to 1345 pounds, the digestible crude fiber from 349

pounds to 732 pounds, and the digestible nitrogen-free extract from 390 pounds to 622 pounds. The digestibility of the pentosans which are distributed between the fiber and nitrogen-free extract was increased from 287 pounds per ton to 605 pounds. In short, the feeding value of the oat hulls was about doubled. It seems that such a result should warrant further investigation of the problem, with the idea of making the process of economic importance.

Summary and Conclusions.

This paper reports the results of an investigation on the problem of increasing the digestibility and feeding value of grain hulls.

A review of the literature shows:

1. That the important constituent of the cereal and other straws is ligno-cellulose, a compound the chemistry of which is not clearly understood. It is known however that it consists of cellulose linked in some manner with lignin and that the presence of the latter compound is characterized by the splitting off of methoxy ($CH_3.O$) groups upon hydrolysis.

2. That the action of dilute alkali on fiber is three-fold, consisting of separation of the silicic acid which forms a part of the incrusting material; splitting off of the methoxy groups of the lignin with formation of acetic acid; and springing of the bonds which exist between the lignin and cellulose.

3. That practically all of the work on this problem has been carried on in Germany, most of it since the commencement of the world war, and the material most generally investigated has been straw, the digestibility of which has been decidedly improved. Grain hulls do not appear to have been worked with heretofore.

In this investigation the method used for treatment of the hulls was that of Beckmann. The materials treated were oathulls, barley hulls, rice hulls, cottonseed hulls and flax shives. The hydrolyzing agent was cold dilute sodium hydroxide, the strengths employed being one per cent, one and one-half per cent and three per cent.

Best results were obtained with NaOH of one and one-half per cent strength, one per cent was apparently too dilute, and three per cent in the one instance used did not have sufficient increased action over the one and one-half per cent to warrant its use.

The effect of the alkali on the composition of the hulls was ascertained by the usual methods of fodder analyses supplemented by determination of some of the ultimate constituents of the hulls both before and after treatment. The result of treatment was a decrease in all proximate constituents except the crude fiber which from an absolute standpoint remained practically the same, but relatively was considerably increased.

Losses in weight due to the treatment were noticed in all materials; they were greatest in the case of the flax shives (25 per cent), least in the case of the cottonseed hulls (9.7 per cent).

The effect of the alkali on the digestibility of the hulls was ascertained by the usual methods employed in digestion experiments, sheep being the animals used. As a result of the treatment

with one and one-half per cent NaOH the digestibility of the important constituents of oat hulls and barley hulls was markedly increased, the feeding value of the oat hulls being doubled. The digestibility of rice hulls was also improved greatly but not sufficiently to be of economic significance. The results with cottonseed hulls and flax shives were in the main negative.

Since the digestibility of oat and barley hulls is greatly improved by the action of dilute alkali, some method should be devised that could be applied on an economic scale. Also, a method for the improvement of the digestibility of cottonseed hulls is worthy of further attention.

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APPENDIX.

Sample Page of Calculations involved in finding Net Gain of Digestible Nutrients due to Treatment.

Material: Oat Hulls treated with 1 1/2 per cent NaOH. Dry Matter Basis.

Item.	Total dry matter.	Crude fiber.	N-free extract.	Pentosans.	Lignin.
(1) Composition of original material (from Tables III and V)	100.00	33.24	57.24	40.02	20.20
(2) Digestibility of original material (from Table VII)	36.24	52.57	34.08	35.91	11.23
(3) Digestible nutrients before treatment: (1) multiplied by (2) divided by 100	36.24	17.47	19.51	14.37	2.27
(4) Composition of treated material (from Tables III and V)	100.00	40.20	52.65	44.16	18.61
(5) Net loss of each component due to treatment (from Tables I, IV and VI)	16.54	0.31[a]	13.30	3.16	4.67
(6) Net total nutrients after treatment: (4) minus (5)	83.46	40.20	39.35	41.00	13.94
(7) Digestibility of treated material (from Table VII)	80.61	91.07	79.04	73.78	37.36
(8) Digestible nutrients after treatment: (6) multiplied by (7) divided by 100	67.28	36.61	31.10	30.25	5.21
(9) Net gain in digestible nutrients due to treatment: (8) minus (3)	31.04	19.14	11.59	15.88	2.94

[a]See note "a" under Table IX.

Detailed Data of Digestion Experiments.

Series XXVI[b], Digestion Experiment II. English Hay and Oat Hulls. Sheep 11 and 15. Fall 1920.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams English hay, 150 grams untreated oat hulls, 10 grams salt, and water ad libitum.

Date.	Sheep 11.					Sheep 15.				
				Body weight, pounds.					Body weight, pounds.	
1920	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Dec. 4				119.50					118.50	
5	605	32.80	365	118.00		417	23.55	15	115.50	
6	425	22.87	1375			424	24.35	1665		
7	550	30.72	1100			546	29.74	1460		
8	426	22.42	785			455	26.04	325		
9	482	27.78	1240		117.50	567	31.75	1035		115.00
10	509	28.21	285		115.50	562	30.75	2180		116.00
11	532	28.92	1420			588	32.85	535		
Average	504	27.674	939	118.75	116.50	508	28.433	1031	117.00	115.50

Table II. Data of Digestion Coefficients.

Sheep 11.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams English hay	445.00	22.96	36.80	153.35	217.96	13.93	110.67	83.48
150 grams oat hulls	138.45	8.76	3.13	46.02	79.25	1.29	55.41	27.97
Total, grams	583.45	31.72	39.93	199.37	297.21	15.22	166.08	111.45
Feces excreted, 276.74 grams	262.90	24.95	21.74	74.16	134.21	7.83	72.88	82.16
Ration digested (by difference) grams	320.55	6.77	18.19	125.21	163.00	7.39	93.20	29.29
Ration digested (by difference) per cent	54.94	21.34	45.55	62.80	54.84	48.55	56.12	26.28
Hay digested[a], grams	271.45	7.81	20.97	102.74	135.14	5.43	71.93	31.72
Oat hulls digested (by difference) grams	50.00	-	-	22.47	28.86	1.96	21.27	-
Oat hulls digested (by difference) per cent	36.11	-	-	48.82	36.42	151.94	38.38	-

Sheep 15.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Total ration as above	583.45	31.72	39.93	199.37	297.21	15.22	166.08	111.45
Feces excreted, 284.33 grams	271.54	25.58	20.12	76.84	141.28	7.71	80.05	81.60
Ration digested (by difference) grams	311.91	6.14	19.81	122.53	155.93	7.51	86.03	29.85
Ration digested (by difference) per cent	53.46	19.36	49.61	61.46	52.46	49.34	51.80	26.78
Hay digested[a], grams	261.55	8.95	21.71	96.61	130.78	7.10	67.51	26.71
Oat hulls digested (by difference) grams	50.36	-	-	25.92	25.15	0.41	18.52	3.14
Oat hulls digested (by difference) per cent	36.37	-	-	56.32	31.73	31.78	33.43	11.23

Average for the Two Sheep.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration digested, per cent	54.20	20.35	47.58	62.13	53.65	48.95	53.96	26.53
Oat hulls digested, per cent	36.24	-	-	52.57	34.08	-[c]	35.91	-

Nutritive Ratio of this Ration, 1 : 15.79.

[a]Coefficients for Hay from Experiments III and IX, Series XXV.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Experiment III, Sheep 11	61	34	57	67	62	39	65	38
Experiment IX, Sheep 15	59	39	59	63	60	51	61	32

[b]A series represents one season's work, commencing about November 1 and continuing to about April 15.

[c]Not feasible to average these two coefficients.

Series XXVI, Digestion Experiment VII. English Hay and Treated Oat Hulls. Sheep 12 and 13. Winter 1921.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams English hay, 150 grams oat hulls (treated 3 hrs. with 1.5% NaOH), 10 grams salt, and water ad libitum.

Date.	Sheep 12.					Sheep 13.				
				Body weight, pounds.					Body weight, pounds.	
1921	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Feb. 5				126.50					101.50	
6	590	21.5	720	125.50		459	22.8	2165	103.00	
7	616	22.6	1320			496	24.0	935		
8	690	26.1	1280			424	20.6	1430		
9	700	25.8	1390			530	26.3	1430		
10	556	22.1	805		120.50	413	20.5	1920		105.50
11	644	23.1	1650		120.50	434	22.5	1145		105.00
12	784	26.6	915			467	16.3	1675		
Average	654	23.971	1154	126.00	120.50	460	21.857	1529	102.25	105.25

Table II. Data of Digestion Coefficients.

Sheep 12.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams English hay	455.00	24.98	37.86	153.29	227.14	11.74	113.16	85.36
150 grams treated oat hulls	143.93	7.53	1.97	57.86	75.78	0.79	63.56	26.79
Total, grams	598.93	32.51	39.83	211.15	302.92	12.53	176.72	112.15
Feces excreted, 239.71 grams	229.52	22.01	22.88	62.38	114.69	7.55	52.81	79.00
Ration digested (by difference) grams	369.41	10.50	16.95	148.77	188.23	4.98	123.91	33.15
per cent	61.68	32.30	42.56	70.46	62.14	39.74	70.12	29.56
Hay digested[a], grams	263.90	5.50	20.07	99.64	134.01	5.28	70.16	25.61
Treated oat hulls digested (by difference) grams	105.51	5.00	-	49.13	54.22	-	53.75	7.54
per cent	73.31	66.40	-	84.91	71.55	-	84.56	28.15
Sheep 13.								
Total ration as above	598.93	32.51	39.83	211.15	302.92	12.53	176.72	112.15
Feces excreted, 218.57 grams	208.52	22.17	20.71	55.26	103.34	7.05	46.52	74.07
Ration digested (by difference) grams	390.41	10.34	19.12	155.89	199.58	5.48	110.20	38.08
per cent	65.18	31.81	48.00	73.83	65.89	43.73	62.36	33.95
Hay digested[a], grams	263.90	5.50	20.07	99.64	134.01	5.28	70.16	25.61
Treated oat hulls digested (by difference) grams	126.51	4.84	-	56.25	65.57	0.20	40.04	12.47
per cent	87.90	64.28	-	97.22	86.53	25.32	62.99	46.56
Average for the Two Sheep.								
Ration digested, per cent	63.43	32.06	45.28	72.65	64.02	41.74	66.24	31.76
Treated oat hulls digested, per cent	80.61	65.34	-	91.07	79.04	-	73.78	37.36

Nutritive Ratio of this Ration, 1 : 19.90.

[a]Coefficients for Hay from Experiment II, Series XXV.								
Average for two sheep	58	22	53	65	59	45	62	30

Series XXVII, Digestion Experiment XV. Hay, Gluten Feed and Treated Oat Hulls. Sheep 16 and 17. Spring 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams oat hulls (treated 1% NaOH), 10 grams salt, and water ad libitum.

Date.	Sheep 16.					Sheep 17.				
				Body weight, pounds.					Body weight, pounds.	
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Apr. 3				130					157	
4	645	24.55	1350	129		507	26.21	1960	156.5	
5	753	29.28	1750			406	20.15	1490		
6	624	22.38	1700			305	14.86	1875		
7	926	31.08	1865			709	32.44	2070		
8	811	27.92	1270		129	284	13.27	1810		155
9	963	32.21	2255			631	28.04	2315		
10	718	24.34	1495			608	26.94	1535		
Average	777	27.394	1669	129.5	129	493	23.130	1865	156.75	155

Table II. Data of Digestion Coefficients.

Sheep 16.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams hay	456.50	30.81	56.51	134.30	222.82	12.05	103.67	84.18
150 grams gluten feed	136.63	4.79	41.81	10.76	75.49	3.74	25.62	4.40
100 grams treated oat hulls	94.23	5.36	1.93	32.79	53.70	0.44	41.27	22.18
Total, grams	687.36	40.96	100.25	177.85	352.01	16.23	170.56	110.76
Feces excreted, 273.94 grams	257.53	29.23	39.71	55.88	122.92	9.79	55.06	82.77
Ration digested (by difference) grams	429.83	11.73	60.54	121.97	229.09	6.44	115.50	27.99
Ration digested (by difference) per cent	62.53	28.63	60.39	68.59	65.08	39.68	67.72	25.27
Hay and gluten feed digested[a], grams	403.33	10.32	70.79	102.99	214.78	7.90	94.38	30.12
Treated oat hulls digested (by difference) grams	26.50	1.41	-	18.98	14.31	-	21.12	-
Treated oat hulls digested (by difference) per cent	28.12	26.31	-	57.88	26.65	-	51.18	-

Sheep 17.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Total ration as above	687.36	40.96	100.25	177.85	352.01	16.23	170.56	110.76
Feces excreted, 231.30 grams	217.72	26.63	32.03	47.72	102.50	8.84	46.85	71.85
Ration digested (by difference) grams	469.64	14.33	68.22	130.13	249.51	7.39	123.71	38.91
Ration digested (by difference) per cent	68.32	34.99	68.04	73.16	70.88	45.53	72.53	35.13
Hay and gluten feed digested[a], grams	403.33	10.32	70.79	102.99	214.78	7.90	94.38	30.12
Treated oat hulls digested (by difference) grams	66.31	4.01	-	27.14	34.73	-	29.33	8.79
Treated oat hulls digested (by difference) per cent	70.37	74.81	-	82.77	64.67	-	71.07	39.63

Average for the Two Sheep.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration digested, per cent	65.44	31.81	64.22	70.88	67.98	42.60	70.13	30.20
Treated oat hulls digested, per cent	49.25	50.56	-	70.33	45.66	-	61.13	39.63[b]

Nutritive Ratio of this Ration, 1 : 5.92.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Average for two sheep	68	29	72	71	72	50	73	34

[b]One sheep only.

Series XXVII, Digestion Experiment VIII. Hay, Gluten Feed and Barley Hulls. Sheep 16 and 17. Winter 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams untreated barley hulls, 10 grams salt, and water ad libitum.

Date.	Sheep 16.					Sheep 17.				
				Body weight, pounds.					Body weight, pounds.	
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Jan. 16				125.0					153.0	
17	600	23.86	1570	125.5		600	24.16	1825	153.5	
18	645	25.88	1430			619	25.47	1195		
19	620	24.33	1425			579	22.23	2300		
20	536	21.47	1725			627	23.10	2240		
21	593	23.76	1780		125.5	752	27.66	1905		152.5
22	592	23.46	1530		125.5	759	25.14	1650		152.0
23	542	22.62	1190			809	25.96	1580		
Average	589	23.626	1521	125.25	125.5	678	24.817	1814	153.25	152.25

Table II. Data of Digestion Coefficients.

Sheep 16.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams hay	464.10	30.58	55.04	136.45	228.85	13.18	105.39	85.58
150 grams gluten feed	137.69	6.28	43.00	10.55	74.60	3.26	25.82	4.43
100 grams barley hulls	93.24	4.20	10.08	14.51	62.34	2.12	21.91	13.86
Total, grams	695.03	41.06	108.12	161.51	365.79	18.56	153.12	103.87
Feces excreted, 236.26 grams	224.49	28.89	30.24	50.94	107.26	7.16	46.38	70.67
Ration digested (by difference) grams	470.54	12.17	77.88	110.57	258.53	11.40	106.74	33.20
Ration digested (by difference) per cent	67.70	29.64	72.03	68.46	70.68	61.42	69.71	31.96
Hay and gluten feed digested[a], grams	409.22	10.69	70.59	104.37	218.48	8.22	95.78	30.60
Barley hulls digested (by difference) grams	61.32	1.48	7.29	6.20	40.05	3.18	10.96	2.60
Barley hulls digested (by difference) per cent	65.77	35.24	72.32	42.73	64.24	150.00	50.02	18.76

Sheep 17.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Total ration as above	695.03	41.06	108.12	161.51	365.79	18.56	153.12	103.87
Feces excreted, 248.17 grams	236.23	33.33	32.08	50.34	112.73	7.72	47.53	75.74
Ration digested (by difference) grams	458.80	7.73	76.04	111.17	253.06	10.84	105.59	28.13
Ration digested (by difference) per cent	66.00	18.83	70.33	68.83	69.18	58.41	68.96	27.08
Hay and gluten feed digested[a], grams	409.22	10.69	70.59	104.37	218.48	8.22	95.78	30.60
Barley hulls digested (by difference) grams	49.58	-	5.45	6.80	34.58	2.62	9.81	-
Barley hulls digested (by difference) per cent	53.17	-	54.07	46.86	55.47	123.58	44.77	-

Average for the Two Sheep.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration digested, per cent	66.85	24.23	71.18	68.64	69.93	59.91	69.34	29.52
Barley hulls digested, per cent	59.97	-	63.19	44.79	59.85	136.79	47.40	18.76[b]

Nutritive Ratio of this Ration, 1 : 5.09.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Average for two sheep	68	29	72	71	72	50	73	34

[b]One sheep only.

Series XXVII, Digestion Experiment XI. Hay, Gluten Feed and Treated Barley Hulls. Sheep 16 and 17. Winter 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams barley hulls (treated 1.5% NaOH), 10 grams salt, and water ad libitum.

Date.	Sheep 16.					Sheep 17.				
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Body weight, pounds. Beginning Experiment.	Body weight, pounds. End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Body weight, pounds. Beginning Experiment.	Body weight, pounds. End of Experiment.
Feb. 27				128.0					153.0	
28	495	22.43	1235	127.0		411	18.15	95	149.5	
Mar. 1	504	22.43	1435			408	19.11	2350		
2	475	21.59	1710			442	20.30	2260		
3	402	18.45	1135			496	22.57	1575		
4	549	25.41	1775		128.0	571	25.77	1550		153.5
5	537	24.63	2100		129.5	500	19.55	2320		152.5
6	448	19.57	840			608	24.48	1410		
Average	487	22.073	1461	127.5	128.75	491	21.419	1651	151.25	153.0

Table II. Data of Digestion Coefficients.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Sheep 16.								
Ration: 500 grams hay	459.75	29.06	54.07	153.10	230.89	12.69	104.41	84.78
150 grams gluten feed	138.00	4.79	41.43	11.16	76.92	3.68	25.88	4.44
100 grams treated barley hulls	94.91	4.11	8.78	18.06	62.07	1.89	24.88	14.25
Total, grams	692.66	37.96	104.28	162.32	369.88	18.26	155.17	103.47
Feces excreted, 220.73 grams	210.75	25.61	32.50	47.12	97.37	8.16	41.67	89.93
Ration digested (by difference) grams	481.91	12.35	71.78	115.20	272.51	10.10	113.50	13.54
Ration digested (by difference) per cent	68.13	32.53	68.83	70.97	73.68	55.31	73.15	13.09
Hay and gluten feed digested[a], grams	406.47	9.81	68.76	102.42	221.62	8.19	95.11	30.33
Treated barley hulls digested (by difference) grams	75.44	2.54	3.02	12.78	50.89	1.91	18.39	-
Treated barley hulls digested (by difference) per cent	79.49	61.80	34.40	70.76	81.98	101.05	73.91	-
Sheep 17.								
Total ration as above	692.66	37.96	104.28	162.32	369.88	18.26	155.17	103.47
Feces excreted, 214.19 grams	205.02	27.49	31.55	43.32	94.12	8.55	37.13	87.30
Ration digested (by difference) grams	487.64	10.47	72.73	119.00	275.76	9.71	118.04	16.17
Ration digested (by difference) per cent	70.40	27.58	69.74	73.31	74.55	53.18	76.07	15.63
Hay and gluten feed digested[a], grams	406.47	9.81	68.76	102.42	221.62	8.19	95.11	30.33
Treated barley hulls digested (by difference) grams	81.17	0.66	3.97	16.58	54.14	1.52	22.93	-
Treated barley hulls digested (by difference) per cent	85.52	16.06	45.22	91.80	87.22	80.42	92.16	-
Average for the Two Sheep.								
Ration digested, per cent	69.26	30.06	69.78	72.14	75.11	54.24	74.61	14.36
Treated barley hulls digested, per cent	82.50	38.93	39.81	81.28	84.60	90.74	83.04	-

Nutritive Ratio of this Ration, 1 : 5.68.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.

Average for two sheep	68	29	72	71	72	50	73	34

Series XXVII, Digestion Experiment XIII. Hay, Gluten Feed and Treated Barley Hulls. Sheep 16 and 17. Winter 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams barley hulls (treated 1% NaOH), 10 grams salt, and water ad libitum.

Date.	Sheep 16.					Sheep 17.				
				Body weight, pounds.					Body weight, pounds.	
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Mar. 15				127.5					154.0	
16	488	22.33	1565	127.5		494	20.95	1415	154.0	
17	628	27.60	1415			558	22.66	1270		
18	488	21.55	1345			553	22.23	1760		
19	455	20.75	1940			762	29.24	2270		
20	610	27.91	765		127.5	372	13.99	1795		154.0
21	427	19.20	1565		127.5	770	28.58	2040		154.0
22	525	24.78	1835			548	20.48	1545		
Average	517	23.446	1490	127.5	127.5	579.	22.590	1728	154.0	154.0

Table II. Data of Digestion Coefficients.

Sheep 16.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams hay	451.25	31.36	57.26	127.07	224.68	10.83	102.48	83.21
150 grams gluten feed	136.29	4.55	42.36	10.89	74.99	3.52	25.55	4.39
100 grams barley hulls	93.76	4.44	9.76	17.79	59.90	1.87	24.95	14.84
Total, grams	681.30	40.35	109.38	155.75	359.57	16.22	152.98	102.44
Feces excreted, 234.46 grams	221.24	25.73	34.96	51.04	101.86	7.68	46.33	69.12
Ration digested (by difference) grams	460.06	14.62	74.42	104.71	257.71	8.54	106.65	33.32
Ration digested (by difference) per cent	67.52	36.23	68.04	67.22	71.67	52.65	69.71	32.53
Hay and gluten feed digested[a], grams	399.53	10.41	71.72	97.95	215.76	7.18	93.46	29.78
Treated barley hulls digested (by difference) grams	60.53	4.21	2.70	6.76	41.95	1.36	13.19	3.54
Treated barley hulls digested (by difference) per cent	64.56	94.82	27.66	37.99	70.04	72.73	52.87	23.85

Sheep 17.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Total ration as above	681.30	40.35	109.38	155.75	359.57	16.22	152.98	102.44
Feces excreted, 225.90 grams	213.48	28.91	34.03	45.96	96.15	8.41	40.33	65.90
Ration digested (by difference) grams	467.82	11.44	75.35	109.79	263.42	7.81	112.65	36.54
Ration digested (by difference) per cent	68.67	28.35	68.89	70.49	73.26	48.15	73.64	35.67
Hay and gluten feed digested[a], grams	399.53	10.41	71.72	97.95	215.76	7.18	93.46	29.78
Treated barley hulls digested (by difference) grams	68.29	1.03	3.63	11.84	47.66	.63	19.19	6.76
Treated barley hulls digested (by difference) per cent	72.83	23.20	37.19	66.55	79.57	33.69	76.91	45.55

Average for the Two Sheep.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration digested, per cent	68.10	32.29	68.47	68.86	72.47	50.40	71.67	34.10
Treated barley hulls digested, per cent	68.69	59.01	32.43	52.28	74.81	53.21	64.89	34.70

Nutritive Ratio of this Ration, 1 : 5.16.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Average for two sheep	68	29	72	71	72	50	73	34

Series XXVI, Digestion Experiment XI. English Hay, Gluten Feed and Rice Hulls. Sheep 9 and 12. Winter 1921.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams English hay, 150 grams gluten feed, 150 grams ground untreated rice hulls, 10 grams salt, and water ad libitum.

Date.	Sheep 9.					Sheep 12.				
				Body weight, pounds.					Body weight, pounds.	
1921	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Mar. 25				110.00					122.00	
26	728	35.90	2040	111.00		962	38.25	2220	122.00	
27	779	38.65	560			857	33.46	2135		
28	714	35.02	1485			895	35.59	1660		
29	1089	48.60	1675			892	34.78	1935		
30	608	27.42	1210		108.00	711	28.70	1990		124.00
31	662	27.67	1760		108.50	888	37.92	1450		119.00
Apr. 1	1075	44.78	2060			861	33.50	2315		
Average	808	36.863	1540	110.50	108.25	867	34.600	1958	122.00	121.50

Table II. Data of Digestion Coefficients.

Sheep 9.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams English hay	450.85	24.66	38.50	147.61	227.41	12.58	112.13	84.58
150 grams gluten feed	137.07	6.10	39.48	8.16	80.31	3.03	20.57	2.10
150 grams rice hulls	141.63	26.99	4.28	59.20	50.11	1.06	31.13	32.18
Total, grams	729.55	57.75	82.26	214.97	357.83	16.67	163.83	118.86
Feces excreted, 368.63 grams	352.19	54.17	30.46	112.59	144.36	10.57	76.53	98.47
Ration digested (by difference) grams	377.36	3.58	51.80	102.38	213.47	6.10	87.30	20.39
Ration digested (by difference) per cent	51.72	6.20	62.97	47.63	59.66	36.59	53.29	17.15
Hay and gluten feed digested[a], grams	382.15	9.23	53.81	102.81	206.17	8.59	86.26	24.27
Rice hulls digested (by difference) grams	-	-	-	-	7.30	-	1.04	-
Rice hulls digested (by difference) per cent	-	-	-	-	14.57	-	3.34	-

Sheep 12.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Total ration as above	729.55	57.75	82.26	214.97	357.83	16.67	163.83	118.86
Feces excreted, 346.00 grams	328.60	46.63	28.78	104.46	139.82	8.97	74.99	94.93
Ration digested (by difference) grams	400.95	11.12	53.48	110.51	218.01	7.70	88.84	23.93
Ration digested (by difference) per cent	54.96	19.26	65.01	51.41	60.93	46.19	54.23	20.13
Hay and gluten feed digested[a], grams	393.91	8.31	56.15	103.36	215.40	8.59	90.24	24.27
Rice hulls digested (by difference) grams	7.04	2.81	-	7.15	2.61	-	-	-
Rice hulls digested (by difference) per cent	4.97	10.41	-	12.08	5.21	-	-	-

Average for the Two Sheep.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration digested, per cent	52.80	12.73	63.99	49.52	60.30	41.39	53.77	18.64
Rice hulls digested, per cent	2.48	5.21	-	6.04	9.89	-	-	-

Nutritive Ratio of this Ration, 1 : 6.41.

[a]Coefficients for Hay and Gluten Feed from Experiments I and IV, Series XXV.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Experiment I, Sheep 9	65	30	69	66	67	55	65	28
Experiment IV, Sheep 12	67	27	72	67	70	55	68	28

Series XXVI, Digestion Experiment IX. English Hay, Gluten Feed, and Treated Rice Hulls. Sheep 9 and 11. Winter 1921.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams English hay, 150 grams gluten feed, 150 grams ground rice hulls (treated 3 hrs. with 1.5% NaOH), 10 grams salt, and water ad libitum.

Date.	Sheep 9.					Sheep 11.				
				Body weight, pounds.					Body weight, pounds.	
1921	Daily fecee grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Mar. 8				109.00					119.00	
9	686	32.88	1340	109.50		467	27.20	1375	118.50	
10	692	34.62	1475			421	23.87	1230		
11	677	34.18	1385			516	28.41	1000		
12	474	24.98	1600			363	19.52	250		
13	676	33.40	1800		111.00	605	31.40	2350		116.00
14	642	32.65	790		110.00	768	38.15	995		117.50
15	681	34.92	1325			742	39.17	2150		
Average	647	32.519	1388	109.25	110.50	555	29.674	1336	118.75	116.75

Table II. Data of Digestion Coefficients.

Sheep 9.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams English hay	452.25	24.56	38.98	150.96	224.09	13.75	112.47	84.84
150 grams gluten feed	136.49	5.98	39.65	8.38	79.26	3.18	20.49	2.09
150 grams treated rice hulle	144.59	25.24	3.63	66.62	48.31	0.84	34.85	33.39
Total, grams	733.33	55.78	82.26	225.96	351.66	17.77	167.81	120.32
Feces excreted, 325.19 grams	310.46	44.89	28.22	102.51	125.42	9.38	63.49	91.34
Ration digested (by difference) grams	422.87	10.89	54.04	123.45	226.24	8.39	104.32	28.98
Ration digested (by difference) per cent	57.66	19.52	65.69	54.63	64.33	47.20	62.17	24.09
Hay and gluten feed digested[a], grams	388.57	9.16	55.04	109.94	209.31	9.48	86.42	24.35
Treated rice hulls digested (by difference) grams	34.30	1.73	-	13.51	14.93	-	17.90	4.63
Treated rice hulls digested (by difference) per cent	23.72	6.85	-	20.28	35.04	-	51.36	13.87

Sheep 11.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Total ration as above	733.33	55.78	82.26	225.96	351.66	17.77	167.81	120.32
Waste, 32.14 grams	26.10	3.71	3.79	6.58	11.65	0.37	4.71	4.47
Ration consumed	707.23	52.07	78.47	219.38	340.01	17.40	163.10	115.85
Feces excreted, 296.74 grams	284.33	42.68	25.70	89.14	118.31	8.50	58.63	86.64
Ration digested (by difference) grams	422.90	9.39	52.77	130.24	221.70	8.90	104.47	29.21
Ration digested (by difference) per cent	59.80	18.03	67.25	69.37	65.20	51.15	64.05	25.21
Hay and gluten feed digested[a], grams	374.57	8.26	52.88	106.26	202.77	9.31	83.96	23.34
Treated rice hulls digested (by difference) grame	48.33	1.13	-	23.98	18.93	-	20.51	5.87
Treated rice hulls digested (by difference) per cent	34.60	46.05	-	36.67	41.04	-	60.43	18.06

Average for the Two Sheep.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration digested, per cent	58.73	18.78	66.47	62.00	64.77	49.18	63.11	24.65
Treated rice hulls digested, per cent	29.16	-[b]	-	28.48	38.04	-	55.92	15.97

Nutritive Ratio of this Ration, 1 : 7.14.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXV.								
Average for two sheep	66	30	70	69	69	56	65[c]	28[c]

[b]Not feasible to average these two coefficients.

[c]Through an error determinations of pentosans and lignin were not made on the feces of Sheep 11 in the basal experiment (Series XXV, Experiment I) from which the coefficients for hay and gluten feed were obtained for use in this experiment. Rather than prepare fresh reagents and set up laboratory apparatus for only one sample we applied the pentosan and lignin coefficients obtained for Sheep 9 in the basal trial to both sheep in this trial. The coefficients of the two agree quite closely with respect to digestibility of dry matter, protein, fiber, etc., so we consider that the error of applying to both sheep the values obtained for pentosans and lignin with one sheep (Sheep 9) are not great.

Series XXVII, Digestion Experiment XVI. Hay, Gluten Feed and Treated Rice Hulls. Sheep 18 and 19. Spring 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams finely ground rice hulls (treated with 3% NaOH), 10 grams salt, and water ad libitum.

Date.	Sheep 18.					Sheep 19.				
				Body weight, pounds.					Body weight, pounds.	
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Apr. 7				123.5					132.0	
8	550	25.51	2275	124.0		579	29.07	2080	131.0	
9	619	29.19	2330			782	37.67	2330		
10	528	24.58	1685			329	16.12	1940		
11	466	23.38	3185			477	24.63	2600		
12	636	29.51	1395		123.0	587	29.40	2080		129.0
13	544	25.49	2065		123.5	424	22.09	1780		129.0
14	593	26.71	2150			483	25.04	2350		
Average	562	26.339	2155	123.75	123.25	523	26.289	2166	131.5	129.0

Table II. Data of Digestion Coefficients.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Sheep 18.								
Ration: 500 grams hay	451.50	30.57	57.84	131.52	219.52	12.01	102.54	83.26
150 grams gluten feed	136.44	4.72	42.28	10.82	74.81	3.79	25.58	4.39
100 grams treated rice hulls	94.08	12.35	3.00	47.28	30.93	0.52	23.78	23.61
Total, grams	682.02	47.64	103.12	189.62	325.26	16.32	151.90	111.26
Feces excreted, 263.39 grams	250.22	35.93	32.63	75.12	97.71	8.83	46.74	78.87
Ration digested (by difference), grams	431.80	11.71	70.49	114.50	227.55	7.49	105.16	32.39
Ration digested (by difference), per cent	63.31	24.58	68.35	60.38	69.95	45.89	69.23	29.11
Hay and gluten feed digested[a], grams	399.80	10.23	72.09	101.06	211.92	7.90	93.53	29.80
Treated rice hulls digested (by difference), grams	32.00	1.48	-	13.44	15.63	-	11.63	2.59
Treated rice hulls digested (by difference), per cent	34.02	11.98	-	28.42	50.53	-	48.91	10.97
Sheep 19.								
Total ration as above	682.02	47.64	103.12	189.62	325.26	16.32	151.90	111.26
Feces excreted, 262.89 grams	250.27	34.44	28.61	77.82	101.10	8.31	51.41	76.33
Ration digested (by difference), grams	431.75	13.20	74.51	111.80	224.16	8.01	100.49	34.93
Ration digested (by difference), per cent	63.30	27.70	72.25	58.95	68.91	49.08	66.16	31.39
Hay and gluten feed digested[a], grams	399.80	10.23	72.09	101.06	211.92	7.90	93.53	29.80
Treated rice hulls digested (by difference), grams	31.95	2.97	2.42	10.74	12.24	0.11	6.96	5.13
Treated rice hulls digested (by difference), per cent	33.96	24.05	80.67	22.71	39.57	21.15	29.27	21.73
Average for the Two Sheep.								
Ration digested, per cent	63.31	26.14	70.30	59.67	69.43	47.49	67.70	30.25
Treated rice hulls digested, per cent	33.99	18.02	-	25.57	45.05	-	39.09	16.35

Nutritive Ratio of this Ration, 1 : 4.92.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.

Average for two sheep	68	29	72	71	72	50	73	34

Series XXVII, Digestion Experiment VII. Hay, Gluten Feed and Cottonseed Hulls. Sheep 18 and 19. Winter 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams untreated cottonseed hulls, 10 grams salt, and water ad libitum.

Date.	Sheep 18.					Sheep 19.				
				Body weight, pounds.					Body weight, pounds.	
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Jan. 9				123.0					132.0	
10	743	26.23	1825	123.5		487	21.85	1705	132.5	
11	635	21.71	2295			507	23.39	1585		
12	582	20.53	2150			562	26.67	1235		
13	811	26.97	2295			558	24.48	1950		
14	747	26.11	2300		121.5	526	23.30	1710		130.0
15	824	25.25	2850		122.0	530	22.82	1745		129.5
16	1008	32.55	2555			627	26.69	1455		
Average	764	25.621	2324	123.25	121.75	543	24.171	1626	132.25	129.75

Table II. Data of Digestion Coefficient.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Sheep 18.								
Ration: 500 grams hay	466.25	28.91	56.32	133.35	234.76	12.87	105.89	85.98
150 grams gluten feed	137.25	5.79	43.04	10.83	74.58	2.99	25.73	4.42
100 grams cottonseed hulls	93.07	1.98	3.80	40.94	45.23	1.11	30.27	23.54
Total, grams	696.57	36.68	103.16	185.12	354.57	16.97	161.89	113.94
Feces excreted, 256.21 grams	243.32	30.49	36.81	60.64	107.09	8.30	37.88	83.87
Ration digested (by difference) grams	453.25	6.19	66.35	124.48	247.48	8.67	124.01	30.07
Ration digested (by difference) per cent	65.07	16.88	64.32	67.24	69.79	51.09	76.60	26.39
Hay and gluten feed digested[a], grams	410.38	10.06	71.54	102.37	222.72	7.93	96.08	30.74
Cottonseed hulls digested (by difference) grams	42.87	-	-	22.11	24.76	0.74	27.93	-
Cottonseed hulls digested (by difference) per cent	46.06	-	-	54.00	54.74	66.67	92.26	-
Sheep 19.								
Total ration as above	696.57	36.68	103.16	185.12	354.57	16.97	161.89	113.94
Feces excreted, 241.71 grams	230.37	27.07	34.33	57.20	103.51	8.27	39.14	75.84
Ration digested (by difference) grams	466.20	9.61	68.83	127.92	251.06	8.70	122.75	38.10
Ration digested (by difference) per cent	66.93	26.20	66.72	69.10	70.81	51.27	75.81	33.44
Hay and gluten feed digested[a], grams	410.38	10.06	71.54	102.37	222.72	7.93	96.08	30.74
Cottonseed hulls digested (by difference) grams	55.82	-	-	25.55	28.34	0.77	26.67	7.36
Cottonseed hulls digested (by difference) per cent	59.98	-	-	62.41	62.66	69.37	88.10	31.26
Average for the Two Sheep.								
Ration digested, per cent	66.00	21.54	65.52	68.17	70.30	51.18	76.21	29.92
Cottonseed hulls digested, per cent	53.02	-	-	58.21	58.70	68.02	90.18	31.26[b]

Nutritive Ratio of this Ration, 1 : 5.73.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.								
Average for two sheep	68	29	72	71	72	50	73	34

[b]One sheep only.

Series XXVII, Digestion Experiment IX. Hay, Gluten Feed and Treated Cottonseed Hulls. Sheep 18 and 19. Winter 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams cottonseed hulls (treated with 1.5% NaOH), 10 grams salt, and water ad libitum.

Date.	Sheep 18.					Sheep 19.				
				Body weight, pounds					Body weight, pounds.	
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Jan. 25				123.5					132.0	
26	702	22.06	2040	125.0		766	27.02	1470	131.5	
27	796	25.85	1985			654	24.26	1955		
28	1075	31.91	2270			755	28.01	1895		
29	993	31.75	2300			811	30.13	2060		
30	449	13.40	1850		121.5	394	13.92	1875		128.5
31	712	23.78	2525		123.0	640	23.72	2220		130.0
Feb. 1	663	25.09	2235			610	22.70	2070		
Average	770	24.834	2172	124.25	122.50	661	24.250	1935	131.75	129.75

Table II. Data of Digestion Coefficients.

Sheep 18.

		Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams hay		452.50	26.65	54.89	125.80	231.00	14.12	102.76	83.44
150 grams gluten feed		135.03	4.51	40.97	11.13	74.55	3.88	25.32	4.35
100 grams treated cottonseed hulls		94.85	2.61	2.87	47.24	41.31	.80	32.34	20.84
Total, grams		682.38	33.77	98.73	184.17	346.86	18.80	160.42	108.63
Feces excreted, 248.34 grams		233.69	28.95	35.10	62.72	99.25	7.67	31.71	85.65
Ration digested (by difference)	grams	448.69	4.82	63.63	121.45	247.61	11.13	128.71	22.98
	per cent	65.75	14.27	64.45	65.94	71.39	59.20	80.23	21.15
Hay and gluten feed digested[a], grams		399.52	9.04	69.02	97.22	220.00	9.00	93.50	29.85
Treated cottonseed hulls digested (by difference)	grams	49.17	-	-	24.23	27.61	2.13	35.21	-
	per cent	51.84	-		51.29	66.84	266.25	108.87	-

Sheep 19.

		Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Total ration as above		682.38	33.77	98.73	184.17	346.86	18.80	160.42	108.63
Feces excreted, 242.50		228.60	26.81	34.20	61.52	98.55	7.52	36.94	76.81
Ration digested (by difference)	grams	453.78	6.96	64.53	122.65	248.31	11.28	123.48	31.82
	per cent	66.49	20.61	65.36	66.59	71.59	60.00	76.97	29.29
Hay and gluten feed digested[a], grams		399.52	9.04	69.02	97.22	220.00	9.00	93.50	29.85
Treated cottonseed hulls digested (by difference)	grams	54.26	-	-	25.43	28.31	2.28	29.98	1.97
	per cent	57.21	-	-	53.83	68.53	285.00	92.70	9.45

Average for the Two Sheep.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration digested, per cent	66.12	17.44	64.91	66.27	71.49	59.60	78.60	25.22
Treated cottonseed hulls digested, per cent	54.52	-	-	52.56	67.69	275.63	100.78	9.45[b]

Nutritive Ratio of this Ration, 1 : 6.17.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Average for two sheep	68	29	72	71	72	50	73	34

[b]One sheep only.

Series XXVII, Digestion Experiment XII. Hay, Gluten Feed and Flax Shives. Sheep 18 and 19. Winter 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams untreated flax shives, 10 grams salt, and water ad libitum.

Date.	Sheep 18.					Sheep 19.				
				Body weight, pounds.					Body weight, pounds.	
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Mar. 6				123.0					127.5	
7	762	27.62	1910	122.0		553	25.26	1545	128.5	
8	878	29.62	2310			583	26.19	2350		
9	845	25.83	2280			587	27.50	1675		
10	970	31.35	1750			520	25.77	1580		
11	841	24.95	2280		122.0	610	29.53	1430		129.5
12	1198	36.60	2345		121.0	550	26.36	2105		129.0
13	1233	36.04	2170			588	26.07	1135		
Average	961	30.287	2149	122.5	121.5	570	26.669	1689	128.0	129.25

Table II. Data of Digestion Coefficients.

	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Sheep 18.								
Ration: 500 grams hay	454.50	30.81	56.36	133.17	222.34	12.99	103.22	83.81
150 grams gluten feed	137.09	4.74	42.68	10.72	75.02	3.93	25.70	4.41
100 grams flax shives	93.22	3.81	4.88	50.16	32.67	1.69	25.32	31.02
Total, grams	684.81	39.36	103.92	194.05	330.03	18.61	154.24	119.24
Feces excreted, 302.87 grams	288.60	33.30	37.81	94.03	114.66	8.80	58.38	93.16
Ration digested (by difference) grams	396.21	6.06	66.11	100.02	215.37	9.81	95.86	26.08
Ration digested (by difference) per cent	57.86	15.40	63.62	51.54	65.25	52.71	62.15	21.87
Hay and gluten feed digested[a], grams	402.28	10.30	71.31	102.16	214.09	8.46	94.11	29.99
Flax shives digested (by difference) grams	-	-	-	-	1.28	1.35	1.75	-
Flax shives digested (by difference) per cent	-	-	-	-	3.92	79.88	6.91	-
Sheep 19.								
Total ration as above	684.81	39.36	103.92	194.05	330.03	18.61	154.24	119.24
Feces excreted, 266.69 grams	254.42	28.27	31.14	82.53	105.10	7.38	53.71	80.63
Ration digested (by difference) grams	430.39	11.09	72.78	111.52	224.93	11.23	100.53	38.61
Ration digested (by difference) per cent	62.85	28.18	70.03	57.46	68.15	60.34	65.18	32.38
Hay and gluten feed digested[a], grams	402.28	10.30	71.31	102.16	214.09	8.46	94.11	29.99
Flax shives digested (by difference) grams	28.11	0.79	1.47	9.36	10.84	2.77	6.42	8.62
Flax shives digested (by difference) per cent	30.15	78.64	-	18.67	33.18	163.96	25.36	27.79
Average for the Two Sheep.								
Ration digested, per cent	60.36	21.79	66.83	54.50	66.70	56.52	63.67	27.13
Flax shives digested, per cent	-	-	-	-	18.55	121.92	-	27.79[b]

Nutritive Ratio of this Ration, 1 : 5.03.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.								
Average for two sheep	68	29	72	71	72	50	73	34

[b]One sheep only.

Series XXVII, Digestion Experiment XIV. Hay, Gluten Feed and Treated Flax Shives. Sheep 18 and 19. Winter 1922.

Table I. Food and Water Consumed, Feces Excreted, and Body Weight.

Ration: 500 grams hay, 150 grams gluten feed, 100 grams flax shives (treated with 1.5% NaOH), 10 grams salt, and water ad libitum.

Date.	Sheep 18.					Sheep 19.				
				Body weight, pounds.					Body weight, pounds.	
1922	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.	Daily feces grams.	1/10 air dry sample grams.	Water cc.	Beginning Experiment.	End of Experiment.
Mar. 22				121.0					130.0	
23	1166	34.36	2325	120.5		619	26.39	2140	130.0	
24	1004	30.23	3285			618	28.17	2105		
25	1117	34.22	2210			647	30.05	2300		
26	875	27.43	3520			567	25.55	2110		
27	790	25.90	3140		124.0	612	27.75	1665		127.5
28	857	28.04	1715		122.5	497	22.75	2145		128.5
29	644	19.53	2350			510	23.73	2285		
Average	922	28.530	2649	120.75	123.75	581	26.341	2107	130.0	128.0

Table II. Data of Digestion Coefficients.

Sheep 18.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration: 500 grams hay	457.00	31.40	57.63	135.41	220.18	12.34	103.78	84.27
150 grams gluten feed	137.09	4.88	42.61	10.91	75.28	3.41	25.70	4.41
100 grams treated flax shives	94.46	5.05	4.17	59.36	24.63	1.26	24.48	30.61
Total, grams	688.55	41.33	104.41	205.68	320.09	17.01	153.96	119.29
Feces excreted, 285.30 grams	267.27	30.42	38.46	89.83	99.64	8.95	49.87	91.59
Ration digested (by difference) grams	421.28	10.91	65.95	115.85	220.45	8.06	104.09	27.70
Ration digested (by difference) per cent	61.18	26.40	63.16	56.33	68.87	47.38	67.61	23.22
Hay and gluten feed digested[a], grams	403.98	10.52	72.17	103.89	212.73	7.88	94.52	30.15
Treated flax shives digested (by difference) grams	17.30	.39	-	11.96	7.72	.18	9.57	-
Treated flax shives digested (by difference) per cent	18.31	7.72	-	20.15	31.34	14.21	39.09	-

Sheep 19.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Total ration as above	688.55	41.33	104.41	205.68	320.09	17.01	153.96	119.29
Feces excreted, 263.41 grams	247.53	26.56	30.20	86.73	96.17	7.87	48.10	82.92
Ration digested (by difference) grams	441.02	14.77	74.21	118.95	223.92	9.14	105.86	36.37
Ration digested (by difference) per cent	64.05	35.74	71.08	57.83	69.95	53.73	68.76	30.49
Hay and gluten feed digested[a], grams	403.98	10.52	72.17	103.89	212.73	7.88	94.52	30.15
Treated flax shives digested (by difference) grams	37.04	4.25	-	15.06	11.19	1.26	11.34	6.22
Treated flax shives digested (by difference) per cent	39.21	84.16	-	25.37	45.43	100.00	46.32	20.32

Average for the Two Sheep.	Dry matter.	Ash.	Protein.	Fiber.	N-free extract.	Fat.	Pentosans.	Lignin.
Ration digested, per cent	62.62	31.07	67.12	57.07	69.41	50.56	68.18	26.86
Treated flax shives digested, per cent	28.76	45.94	-	22.76	38.38	57.11	42.71	20.32[b]

Nutritive Ratio of this Ration, 1 : 5.12.

[a]Coefficients for Hay and Gluten Feed from Experiment I, Series XXVII.								
Average for two sheep	68	29	72	71	72	50	73	34

[b]One sheep only.

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