89. The Digestibility of Wheat Straw and Wheat-Straw Pulp

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The digestion of straw constituents and cellulose by ruminants was the subject of a recent paper by McAnally [1942]. By means of *in vitro* and also *in vivo* experiments, using a sheep with a rumen fistula, she examined the rate of digestion of straw, straw constituents and cellulose. In the *in vivo* tests small quantities (0.5 g.) of the materials were tied in small silk squares and suspended in the sheep's rumen. McAnally states: 'it is probable that the conditions of digestion in the bag were not as favourable as in the rumen, so that the observed rates of digestion must be regarded as minimal.' The results showed that straw fractions such as cellulose and hemicelluloses were more digestible when separated than when fed in straw form.

A proportion of the straw resists digestion regardless of time, but McAnally thinks that too rapid progress through the rumen can cause considerable wastage and suggests some form of predigestion *in vitro* to eliminate this.

The digestibility of straw soaked for 24 hr. in 1.5% KOH and then thoroughly washed was also investigated, and a marked advantage over untreated straw was obtained. During the first 2 days in the rumen the digestion of the treated straw was no greater than that of untreated straw, and it is concluded that 'wastage through too rapid a passage out of the rumen may not be avoided by the alkali pretreatment'. The digestibility of the lignin in the alkali-treated straw was 71% as compared with 30% in the untreated straw.

Investigations on the alkali treatment of straws to increase their feeding value were commenced at Jealott's Hill in 1938, and in 1940, in view of the inadequacy of the conventional foodstuffs analysis, a trial was made to determine the digestibility of the true straw constituents. The results showed that the digestibility of the cellulose of alkali-treated straw was very high and they suggested that wastage, if any, by too rapid progress through the rumen must be quite small. They also suggest that the technique of McAnally does result in slower rates of digestion than that which occurs normally in the rumen.

The data presented here give only the fate of the various straw fractions during passage through the animal, or the total digestibility as understood in agricultural circles.

EXPERIMENTAL

A uniform sample of good quality wheat straw was used throughout the trials. It was chopped to half-inch lengths and well mixed.

Alkali treatment. The chopped straw was immersed in 1.5% NaOH for 22 hr. at 10–15°, using 10 times the straw weight of solution. At the end of the time, the straw was removed from the liquor and after draining for 30 min. was thoroughly washed with water to remove the excess NaOH. The straw lost 20% of its dry weight in this treatment. For convenience the resulting material was called 'straw pulp'.

Composition. The untreated straw and the straw pulp were dried at 98°, ground and analysed by the standard feedingstuffs methods, and also in greater detail. Cellulose was determined by the method of Norman & Jenkins [1933] and also by that of Kürschner & Hanak [1930] as used by Crampton & Maynard [1938], the cellulosan fraction of the crude cellulose being determined by distillation with 12% HCl. Lignin was determined by the method of Ritter, Seborg & Mitchell [1932] as modified by Norman [1934]. The

total furfuraldehyde yield was obtained by distillation with 12% HCl and subsequent precipitation as the phloroglucide.

Digestibility. Digestibility trials were carried out on sheep. Six sheep were used in each trial, the same sheep being used for both materials. The rations consisted of 600–700 g. of straw dry matter and 100 g. casein to supply protein. Rock salt and steamed bone flour were also provided. The straw pulp was naturally fed in the wet state. After a preliminary period of 4 days the faeces were collected daily for 10 days.

RESULTS

Composition

The standard feedingstuffs analysis is not given here in detail and it need only be stated that the crude fibre fraction which was 42.4% of the dry matter in the untreated straw and 51.5% of the dry matter in the straw pulp consisted of 90–93% crude cellulose and 7–10% lignin. The more detailed composition of the straws is given in Table 1.

Table 1. *Composition of untreated straw and straw pulp (as percentage dry matter)*

	Untreated straw	Straw pulp		Untreated straw	Straw pulp
Ether extract	1.05	1.13	True cellulose*	35.28	43.78
Crude protein	2.78	2.02	Pentosans in cellulose	18.93	20.09
Ash	7.47	6.94	Furfuraldehyde	5.73	6.59
Lignin	15.10	13.64	Other carbohydrates	13.66	5.81
				100.00	100.00

* Norman & Jenkins's true cellulose.

The analysis accounts for most of the dry matter in the straws. In the untreated straw 13.7% was undetermined and has been called 'other carbohydrates'. This fraction presumably consists mainly of carbohydrate material of more simple constitution than cellulose, and was evidently partly soluble in the NaOH. Only traces of reducing sugars were present. The furfuraldehyde fraction represents the hemicelluloses excluding the cellulosan fraction of the cellulose and some doubt exists as to the correct method of expressing the yield. Some workers convert the yield of furfuraldehyde into pentosans which increases the value by about 70%, but Norman [1937] thinks the more accurate way is to leave the fraction expressed as furfuraldehyde.

The most noticeable differences between the straws are the higher cellulose and lower 'other carbohydrate' contents of the straw pulp.

The analytical data clearly showed the mixed nature of the crude fibre and N-free extractives of the standard feedingstuffs analysis. The crude fibre consists mainly of cellulose from which a considerable part of the cellulosan has been removed, and some lignin. The N-free extractives are made up of part of the lignin, part of the cellulosan, the furfuraldehyde-yielding substances and 'other carbohydrates'.

The cellulose contents of the straw were also determined by the method of Kürschner & Hanak [1930]. It will be seen from Table 2 that this method gives a lower yield of crude cellulose than Norman & Jenkins's [1933] method, owing to the loss of a considerable part of the cellulosan fraction.

Table 2. *Cellulose contents of untreated straw and straw pulp.
Comparison of methods (as percentage dry matter)*

	Untreated straw		Straw pulp	
	N. and J.*	K. and H.†	N. and J.	K. and H.
Crude cellulose	54.21	39.45	63.87	52.18
True cellulose	35.28	35.00	43.78	43.81
Pentosan	18.93	4.45	20.09	8.37

* Norman & Jenkins's method.

† Kürschner & Hanak's method.

Digestibility

The faeces of the sheep were analysed in the same way as the straws. It is interesting to note that the crude fibre in the faeces of the sheep receiving untreated straw consisted of 86% cellulose (almost entirely true cellulose) and 14% lignin, whereas in the case of the straw-pulp faeces the crude fibre contained 60% true cellulose and 40% lignin. These proportions are quite different from those found in the fibres of the original materials fed and show the unreliability of the crude fibre digestibility figures. It follows, therefore, that the digestibility value for the N-free extractives are also unreliable.

The average digestibility coefficients are given in Table 3 and the values for the individual sheep in the Appendix. The digestibility of the crude protein was ignored since this constituent forms a very small part of the whole.

Table 3. *Average digestibility coefficients of the straw constituents*

Constituent	Untreated straw	Straw pulp	Constituent	Untreated straw	Straw pulp
Dry matter	47.8	63.8	Lignin	10.2	-0.5
Organic matter	51.8	68.5	Crude cellulose	62.4	87.7
			True cellulose	62.1	86.7
Ether extract	43.7	40.9	Pentosans in cellulose	63.2	89.7
Fibre	60.3	81.0	Furfuraldehyde	51.2	84.2
N-free extractives	46.8	63.1	Other carbohydrates	67.0	76.9

It is clear that the alkali treatment raised the digestibility of most of the constituents. The digestibilities of the true cellulose and pentosans in cellulose run parallel and therefore, the sum of these constituents, namely the crude cellulose, only need be considered. Its digestibility was raised from 62.4 to 87.7% by the treatment. The furfuraldehyde-yielding substances also increased markedly in digestibility. The 'other carbohydrates' showed a less marked increase, as might be expected from the nature of this fraction. The average digestibility of the lignin in the untreated straw was 10.2%, the range in the individual sheep being 4.4-16.6%. In the straw pulp a figure of -0.5%, or total indigestibility was obtained, the range being -9.1 to 6.4%. It can only be assumed that the treatment with alkali removed a part of the lignin which possessed some slight digestibility. It must be remembered, however, that the determination of lignin cannot be considered altogether reliable and appreciable errors could be introduced in this way.

DISCUSSION

During the passage of straw pulp through the sheep, approximately 70% of the dry matter and 90% of the cellulose were digested. This was quite efficient digestion and it occurred in a probable maximum of 3½ days. It seems unlikely that the food remained in the rumen for more than 2-2½ days. It is generally thought that in ruminants practically all the cellulose digestion or fermentation occurs in the rumen and the work of Trautmann & Asher [1939] certainly confirms this. The present work therefore cannot support McAnally's view that wastage by too rapid passage through the rumen might occur with straw pulp. It is interesting to note that McAnally obtained a figure for the digestibility of true cellulose of 88.8% by suspending straw pulp in the rumen for 7 days. This is very close to the value of 86.7% obtained for complete digestion in the present work. This also suggests that McAnally's technique gives a rate of digestion which is considerably slower than that occurring normally in the rumen.

The lignin appears quite indigestible in straw pulp and this does not agree with McAnally's findings. She obtained 70% digestibility of this constituent in the rumen and two possible explanations of the difference might be put forward. Either the lignin is considerably digested or rendered soluble in the rumen and then later deposited in

some other part of the alimentary tract, or the difficulty in dealing with small quantities of material in the rumen fistula has introduced some error.

The digestibility data, which are typical of many obtained at Jealott's Hill, clearly show the benefit derived from the alkali treatment of straw. The increase in digestibility has the effect of approximately doubling the feeding value of good wheat straw to the ruminant.

SUMMARY

The digestibilities of straw constituents in wheat straw and wheat straw treated with sodium hydroxide solution (straw pulp) have been determined on sheep.

The alkali treatment results in a marked increase in the digestibility of all constituents except lignin. The lignin was totally indigestible.

Owing to the high digestibility of the major straw-pulp constituents, it is unlikely that any wastage occurs owing to too rapid passage of the material through the rumen.

The inadequacy of the conventional feedingstuffs analysis is discussed briefly.

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APPENDIX

Digestibility coefficients

Sheep ...	7	8	9	10	11	12	Average
Untreated straw:							
Dry matter	43.7	47.1	47.0	47.5	49.0	52.4	47.8
Organic matter	48.0	50.7	51.1	51.0	53.3	56.6	51.8
Ether extract	36.4	59.3	43.5	47.7	34.9	40.2	43.7
Crude fibre	57.8	58.6	55.5	60.2	63.1	66.3	60.3
N-free extractives	42.3	46.2	46.9	45.7	48.0	51.6	46.8
Lignin	4.4	13.9	10.5	6.0	9.8	16.6	10.2
Crude cellulose	60.0	60.4	59.9	62.4	64.9	67.0	62.4
True cellulose	59.9	59.6	60.2	62.2	63.9	66.5	62.1
Pentosans in cellulose	60.3	62.0	59.4	62.9	66.7	67.9	63.2
Furfuraldehyde	45.3	55.3	56.5	50.0	45.2	54.8	51.2
Other carbohydrates	60.6	60.4	69.7	66.8	71.2	73.3	67.0
Straw pulp:							
Dry matter	66.5	61.1	61.5	60.0	67.3	66.1	63.8
Organic matter	71.4	65.3	65.8	64.9	72.6	70.9	68.5
Ether extract	49.2	40.3	25.6	33.9	50.0	46.1	40.9
Crude fibre	83.6	77.0	80.2	78.3	83.9	82.9	81.0
N-free extractives	66.1	61.9	58.9	59.2	67.4	65.1	63.1
Lignin	4.4	-1.1	-9.1	-6.1	6.4	2.8	-0.5
Crude cellulose	90.6	84.1	86.0	85.0	90.6	89.7	87.7
True cellulose	89.7	82.5	85.0	84.3	89.9	88.7	86.7
Pentosans in cellulose	92.6	87.1	88.0	86.5	92.3	91.8	89.7
Furfuraldehyde	84.3	81.2	83.8	85.4	85.2	85.0	84.2
Other carbohydrates	75.9	77.3	81.4	68.8	81.6	76.2	76.9