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EFFECT OF ALKALI TREATMENT ON THE *IN VITRO* DIGESTIBILITY AND CHEMICAL COMPOSITION OF FIBROUS AGRICULTURAL RESIDUES.

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A study was carried out of the effects of sodium hydroxide on the chemical composition and *in vitro* organic matter digestibility (IVDOM) of different fibrous agricultural residues (FAR) and of various alkalis (NaOH, NH_4OH, $Ca(OH)_2$ and their combinations) on the IVDOM of maize cobs. The NaOH solubilises the hemicellulose and significantly increases the IVDOM of the FAR (18.3 ± 8.1 % with 60 g alkali/kg DM). The increase in the IVDOM is the result of the solubilisation as well as of the increase in the digestibility of the residual cell wall. The solubilised fraction is apparently not completely digestible. The increases in IVDOM showed a negative correlation (r = -.82) with the IVDOM in the untreated FAR and a positive correlation (r = .64) with the original cell wall content. The most effective alkali for improving maize cobs' digestibility was NaOH, followed by NH_4OH and, finally, $Ca(OH)_2$. The relationship between the chemical composition of the FAR and the response to alkali treatment is discussed.

Key words: Fibrous agricultural residues, alkali treatment, sodium hydroxide, ammonium hydroxide, calcium hydroxide, chemical composition, *in vitro* digestibility.

Fibrous agricultural residues (FAR) account for over 50% of the total organic matter generated by crop production. The majority of the material is either burned, produces contaminants or creates serious disposal problems. However, in recent years, FAR are being considered for use as feed, energy and/or fertilizers (Gonzâlez, 1981).

In Venezuela, the seasonality of the rainfall results in a scarcity of forage of sufficient quality and quantity to cover livestock requirements during the dry season. This situation means that FAR, which are available in the dry season, may be considered as potential feed stuffs for herbivores for strategic use to minimise the effects of the uneven distribution of forages throughout the year. However, biological, economic, technical and cultural factors have limited their use up to now as feed stuffs (Escobar and Parra, 1981).

Alkali treatment has been widely used to improve the feeding value of the FAR generated in temperate countries (Ololade et al 1970; Rexen et al 1076; Owen, 1979). The technical and economic possibilities of their use are also under investigation in India (Jackson, 1977).

The objectives of the present study were: 1) to make a preliminary evaluation of the effects of alkali treatment on the *in vitro* digestibility and chemical composition of various FAR produced in Venezuela and 2) attempt to determine the cause-effect relationships which explain the different responses to chemical treatment usually observed between different FAR.

Materials and Methods

Experiment 1: Samples weighing 200 grammes of the following FAR were used: sugar cane bagasse pith, sugar cane bagasse, bagasse pith with 25 % molasses, bagasse with 40% molasses, sorghum straw, maize cobs, *Paspalum fasciculatum* (green leaves, dead leaves, green stems, dead stems), pangola hay and *Rynchelytrum roseum*. The samples were put through a hammer mill with a 1 mm diameter screen and treated with sodium hydroxide (NaOH) at levels of 0, 20, 40, 60, and 80 g of alkali per kilogramme of dry matter (DM) using three replications per treatment. Samples were kept at ambient temperature with a ratio of 2:1 parts alkali solution to fibrous residue, during a period of 24 hours.

The treated material was then dried in a forced air oven (60° for 48 hours) and the following determinations carried out: cell wall constituents (CWC) and cell constituents (CC) according to the procedures of Van Soest and Wine (1967), acid detergent fibre (ADF), according to Van Soest (1967), and cellulose and lignin according to Van Soest and Wine (1968). The hemicellulose was determined as the difference between the CWC and the ADF. The *in vitro* digestibility of the organic matter (IVDOM) and of the cell wall (IVDCWC) was determined by the procedure of Tilley and Terry (1963) modified by Alexander and McGowan (1966). The in vitro digestibility of the CWC was determined for the bagasse pith, bagasse, sorghum straw, *Rinchelytrum roseum* and maize cobs.

Sub-samples of the bagasse pith were washed with water after the chemical treatment. The IVDOM and the dry matter loss due to washing were then estimated.

Experiment 2: Samples weighing 500 grammes of maize cobs were milled through sieves of 20 mm diameter and then given one of the following treatments, with three replications per treatment: 1) NaOH, 2) NH_4OH, 3) $Ca(OH)_2$, 4) NaOH (50%) + $Ca(OH)_2$ (50%), 5) $Ca(OH)_2$ (50%) + NH_4OH (50%), 6) Control. For all treatments the amount of alkali used was 60 g/kg DM, applied at the rate of 2 parts of alkali solution to one part of FAR.The treated materials were then ensiled in plastic cylinders for six weeks, dried at 60°C for 48 hours, milled through a 1 mm screen and then subjected to CWC and IVDOM determinations as described in Experiment 1.

The results of both experiments were subjected to an analysis of variance according to the method of Sokal and Rohlf (1979).

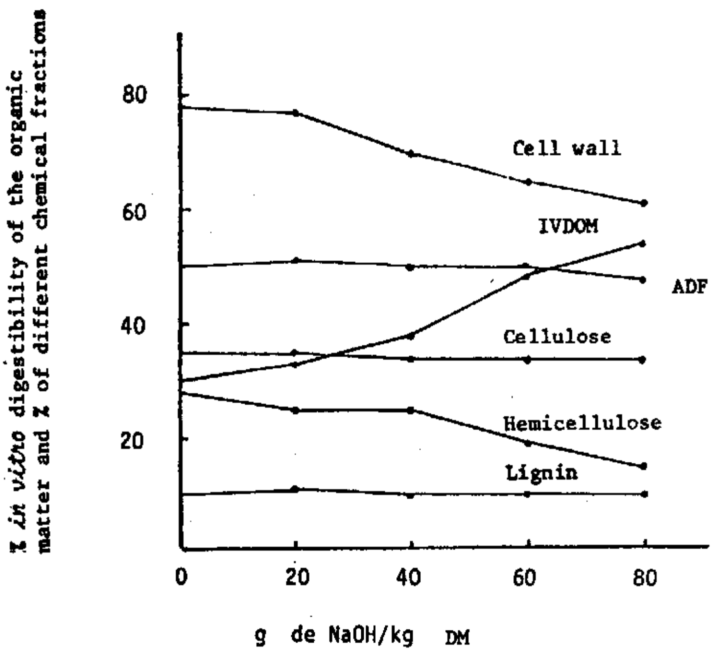
Results and Discussion

Figure 1 shows the mean changes in the IVDOM and the chemical composition of the FAR treated with differente levels of NaOH. The alkali reduced the CWC content, principally as a result of the solubilisation of the hemicellulose. The cellulose content was unchanged and the lignin content was only slightly reduced when alkali levels exceeded 60 g/kg DM.

The mean IVDOM of the FAR increased consistently as alkali levels rose at the rate of 4.5, 9.6, 18.3 and 23.5 percentage units for the treatments 20, 40, 60 and 80 g NaOH/kg DM, respectively. An increase in the efficiency of the reactive was observed up to the 60 g level, estimated in terms of the change in IVDOM/g de NaOH x kg DM.

Figure 1

Effect of NaOH on the chemical composition and *in vitro* *digestibility of 15 FAR*



As Table 1 illustrates, the effect of alkali on the IVDOM varied considerably between FAR. The size of the increase was very variable, ranging from 6 percentage units in the case of bagasse with molasses to 37 units in the case of the dead leaves of *Paspalum fasciculatum*. The higher IVDOM of the treated FAR was due not only to the solubilisation of the hemicellulose but also to the increase in the digestibility of the residual fibrous fraction. In Table 2 are presented the results of the solubilisation, the digestibility of the residual fibre and the combined solubilised cell wall and the digested residual cell wall, respectively.

The effect of NaOH on the solubilisation and digestibility of the residual fibre varied between the FAR studied. For instance, in the case of the bagasse pith, the effect on solubilisation was more important while in the case of the sorghum straw, the main effect of the alkali was on the digestibility of the residual fibre.

The effect of washing with water on the IVDOM of the bagasse pith treated with varying levels of NaOH is shown in Table 3. When the alkali levels exceeded 20 g/kg DM, practically all the cell contents plus the solubilised fraction were lost. This suggests that the IVDOM of the bagasse pith which was treated with more than 20 g NaOH/kg DM and then washed is equivalent to the IVDCWC. On the other hand, the IVDOM of the treated and washed bagasse pith was lower than that of the same material treated but unwashed at all levels of treatment. However, as the alkali levels rose, the differences became progressively smaller and were very small at the 80 g/kg DM level.

Table 1

Effect of NaOH on the in vitro digestibility (% OM) of fibrous agricultural residues

	g NaOH/kg DM				
	0	20	40	60	80
Bagasse pith	28.0	42 .1	46.7	58.0	62.0
Cane Bagasse	25.7	28.3	33.3	42.4	44.1
Bagasse + molasses[a]	58.9	58.8	63.7	65.3	65.0
Bagasse pith + molasses[b]	46.5	49.2	53.3	54.0	58.2
Sorghum straw	31.6	36.1	37.0	51.1	51.4
Maize cobs (white)	29.2	33.4	43.4	53.1	58.8
Maize cobs (red)	31.0	39.0	47.6	53.0	61.9
P. fasciculatum-stem (g)	49.5	47.4	50.4	55.9	59.7
P. fasciculatum-leaf (g)	29.0	28.0	37.0	52.6	64.3
P. fasciculatum-stem (dp)	24.1	27.3	33.6	40.3	48.8
P. fasciculatum-leaf (dp)	15.2	20.7	30.7	49.0	52.0
P. fasciculatum-stem (dg)	3.1	7.6	9.3	18.4	25.6
P. fasciculatum-leaf (dg)	9.0	7.5	14.2	29.7	41.1
R. roseum	17.8	24.5	32.7	38.2	42.4
Pangola hay	40.3	42.3	50.5	52.4	56.0
Mean ± s.d.	29.3±15.1	32.8±14.5	38.9±14.4	47.6±11.9	52.8±10.9

[a] 40% molasses

[b] 25% molasses

g: green

dp: dead on plant

dg: dead on ground

It seems clear from the results shown in Table 3 that the IVDCWC tends to be the same as the IVDOM. In other words, the IVDCWC reaches values similar to those of the in vitro digestibility of the cell contents + the solubilised fraction at the 80 g/kg DM level. This indicates that the digestibility of the cell contents (including the solubilised fraction) is considerably below that which is theoretically to be expected (approximately 100% of true digestibility). On the other hand, this may explain why the total IVDCWC, estimated as the sum of the solubilised and digested fractions (Table 2), reaches much higher values than the IVDOM, if it is erroneously supposed that the solubilised fraction is completely digestible.

The increases in the IVDOM of the FAR when treated with alkali show a high negative correlation with the IVDOM of the untreated materials (Figure 2). This has been reported previously for other residues (Owen et al 1973; Donefer, 1976; Thomas, 1978). Even though the FAR with lower initial digestibilities show a greater response to chemical treatment, their digestibility values after treatment do not necessarily reach satisfactory levels from the nutritional point of view.

Table 2

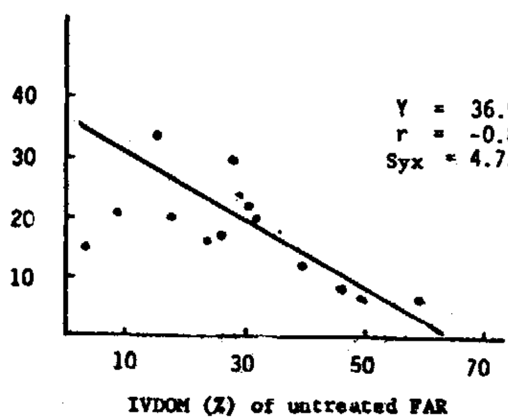
Solubilisation and digestion of the cell wall of fibrous agricultural residues treated with NaOH (g/100 g original cell wall)

Residue	Solubilisation (1) g NaOH/kg					Digestion (2) g NaOH/kg					Total (1 + 2) g NaOH/kg				
	0	20	40	60	80	0	20	40	60	80	0	20	40	60	80
Sugar cane bagasse	0.0	4.3	5.0	13.0	13.8	29.5	28.3	35.6	38.7	45.3	29.5	32.6	40.6	51.7	59.1
Sugar cane bagasse+molasses	0.0	0.0	3.5	11.2	10.8	28.5	31.1	33.7	42.8	48.3	28.5	31.1	37.2	54.0	59.1
Bagasse pith	0.0	13.2	14.3	25.6	29.3	39.9	40.3	54.9	57.6	60.0	39.9	53.5	69.2	83.2	89.3
Bagasse pith + molasses	0.0	1.5	4.3	10.2	12.6	38.9	41.5	45.3	47.0	54.5	38.5	43.0	49.6	57.2	67.1
Sorghum straw	0.0	0.0	0.0	10.7	8.8	35.3	45.5	50.2	58.9	63.8	35.3	45.5	50.2	69.6	72.6
R. roseum	0.0	4.4	9.3	13.4	21.8	19.7	29.2	36.7	43.3	43.1	19.7	33.6	43.0	56.7	64.9
Maize cobs	0.0	2.3	6.6	14.7	20.5	33.0	44.3	50.0	59.1	71.0	33.0	46.6	56.6	73.8	91.5

Table 3
Effect of washing with water on the in vitro digestibility of shredded cane bagasse treated with NaOH

Level of NaOH (g/kg DM)	Cell contents (% DM)	Losses from washing (% DM)	Digestibility (% OM)		
			Unwashed (1)	Washed (2)	Difference (1 - 2)
0	15.4	9.8	35.8	17.1	18.7
20	18.7	15.4	49.3	29.8	19.5
40	22.4	21.2	56.0	39.0	17.0
60	30.6	29.7	61.3	55.8	5.5
80	35.6	33.5	68.7	66.2	2.5

Figure 2
Relationship between the increase in digestibility following alkali treatment (60 g NaOH/kg DM) and initial digestibility of the FAR



It has been seen that the IVDOM rise is due to solubilisation and to an increase in the IVD of the residual CWC. Assuming that the cell contents have a true digestibility of 100% (Van Soest, 1976), it is logical to expect that the effect of the alkali on the IVDOM should be higher in those FAR which have a higher CWC (as % DM) and hemicellulose content (% of the CW).

The IVDOM of the untreated FAR show a negative correlation with the CWC, while the rise in IVDOM with alkali treatment as positively correlated with the CWC (Table 4). A higher CWC means that a greater fraction of the FAR is subjected to the beneficial effects of the NaOH, and this is reflected in a greater increase in the digestibility.

Since the hemicellulose is the fraction solubilised by the alkali, a significant positive correlation might be expected between the change in the hemicellulose content and the initial content of this same fraction (Table 4). However, the correlation between the increase in IVDOM and the initial hemicellulose content is very low. This is explained partly by the fact that the solubilisation is not the only component in the increased digestibility of the FAR.

Table 4

Linear regression and correlation coefficients between the digestibility and chemical composition of NaOH treated with FAR

Variables (Y)	Variables (X)	Intercept (a)	Slope (b)	Correlation Coefficient (r)	Standard Error (Syx)	No. of FAR (n)
IVDOM	CWC (% OM)	97.01	-0.83	-0.79**	7.40	13
Inc.IVDOM	CWC (% OM)	-11.25	0.38	0.64**	7.00	13
Dec.Hem	Hem (% DM)	- 2.34	0.39	0.78**	2.19	13
Inc.Hem	Hem (% CWC)	3.86	0.52	0.44	8.15	13

Inc.: Increase; D: Decrease (%) with treatment (60 g NaOH/kg DM). IVDOM: *in vitro* digestibility of organic matter; CWC: Cell wall constituents; Hem: hemicellulose; *P < .05; **P < .01

According to Tarkow and Feist(1969), a high xylose content is associated with an increased response to NaOH treatment. This indicates that the efficiency of the alkali is not only associated with the hemicellulose content, but also with the monosaccharide composition of that fraction of the material.

It is important to point out that the fibrous residue of legumes which have lower hemicellulose and cell wall contents and as well higher degrees of lignification than gramineous residues, show very limited responses to alkali treatment (Jackson, 1977).

The IVDOM and CWC of the maize cobs treated with different alkalis are shown in Table 5. The greatest increase in digestibility was obtained with NaOH, with NH_4OH in second place and the lowest change from $Ca(OH)_2$. With the combination of NaOH and $Ca(OH)_2$, an increase in the IVDOM was obtained which was equal to the mean of the two alkalis used separately. However, with $Ca(OH)_2$ + NH_4OH, the combined effect was less than the mean of the two alkalis acting separately.

With the exception of the NH_4OH, the increases in digestibility were correlated with the degree of solubilisation of the cell wall. A low cell wall solubilisation was also found for wheat straw when treated with NH_4OH by Solaiman et al (1979).

Table 5

Effect of different alkalis on the digestibility and cell wall content of maize cobs

Alkali	g alkali/ kg DM	Cell wall (% OM)	Solubilised[1] (% CWC)	IVDOM[2] (% OM)
NaOH	60	69[a]	22	52.8[a]
NH_4OH	60	82[b]	7	45.8[bc]
$Ca(OH)_2$	60	75[c]	15	40.5[cd]
NaOH + $Ca(OH)_2$	30 + 30	73[c]	17	48.5[b]
$Ca(OH)_2$ + NH_4OH	30 + 30	79[bc]	10	37.1[d]
Control	0	88[d]	0	30.3[e]

1) Percentage of the cell wall of the untreated maize cobs.

2) *In vitro* digestibility of organic matter.

Values in the same column accompanied by different letters are significantly different ($P < .05$)

The greater effectiveness of NaOH agrees with results reported in the literature (Goering et al, 1968; Chandra & Jackson, 1971; Wilkinson et al 1978). Although NH_4OH is less efective than NaOH in improving the FAR digestibilities, it has various advantages over NaOH since it provides additional nitrogen as the same time as it improves digestibility, does not produce contamination problems and does not require that the material be dampened very much, for treatment to be effective. It is of interest that the maize cobs treated with NH_4OH showed the lowest degree of fungus growth during ensiling, compared with the other treatments. These characteristics of the ammonification process indicate that NH_4OH is a treatment which merits greater research, especially in Venezuela where it is produced in considerable quantities, while NaOH is imported.

Conclusions

The increase in the digestibility of the FAR when treated with alkali is due to the solubilisation of the hemicellulose and to an increase in the digestibility of the residual fibrous action. The solubilised fraction apparently has a lower digestibility than the cell content of the untreated RAF.

At the 60 g NaOH/kg DM level, the increases in digestibility ranged from 6 to 37 percentage points, depending on the CWC, hemicellulose and initial digestibility of the FAR. The chemical composition and the IVDOM of the material can be used as a guide to the potential response to alkali treatment.

The most effective alkali for improving the digestibility of tropical residues is NaOH but NH_4OH offers various advantages, especially for use in Venezuela.

In general, the improvements obtained with NaOH treatment of FAR in the present study are of the same order as those reported for residues in temperate climates.

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