PROCESSING CELLULOSIC CROP RESIDUES FOR RUMINANT FEED*

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Summary

This paper reviews the methods available for processing underutilised crop residues such as bagasse, through t use of NaOH and NH_3, into nutritionally improved feed components for ruminants.

This positive effect of NaOH and NH_3 on the *in-vitro* dry matter digestibility of rice hulls, bagasse and cane tops is shown using experimental data.

1. INTRODUCTION

Cellulosic residues such as rice and wheat straw, corn stover and sugar cane bagasse are potential sources of ruminant feed, as ruminant animals are uniquely adapted to utilise the cellulose in high fibre roughages. World production of residues was conservatively estimated as 1000 million metric tons annually, by Rexen[1]. Most of this material is either destroyed or grossly under-utilised, particularly in the developing countries. In the Caribbean, there is very limited usage of such materials.

As a source of ruminant feedstuff, cellulosic residues are quite variable, but they are generally of poor quality. Such materials are low in crude protein, have low digestibility, and low levels of voluntary intake. Even with minimum utilisation, it is necessary to supplement cellulosic residues with proteins, energy, minerals and vitamins. However, supplementation alone can not overcome such problems as low voluntary intake. Processing of such residues is therefore a pre-requisite for their increased utilization.

2. THE NATURE OF CELLULOSIC RESIDUES

The low nutritive value of crop residues can be attributed to the low digestibility of the largely carbohydrate fraction of such materials. This fraction in the straw from cereals generally consists of 40-45% cellulose and 15-20% lignin[2] . . . . From a feeding viewpoint, three fractions of this ligno-cellulosic complex can be identified[3], viz:-

(i) Lignin, which is essentially unavailable

(ii) Hemicellulose and some cellulose, that are readily digested by the rumen micro-organisms

(iii) The remaining cellulose fraction that resists bacterial action, but which is potentially available through special processing.

The unavailability of the entire cellulosic fraction for rumen digestion has been attributed to the action of lignin [4]. Because of its close physical and/or chemical association with cellulose, it acts as a barrier which impedes the microbial degradation of this product. As the lignin content of forage plants increases with maturity, changes in this constituent have been considered as a partial explanation for the poor feeding value of mature forages.

3. MECHANICAL PROCESSING METHODS

Grinding of cellulosic residues followed by pelleting is a mechanical method of improving the feeding value of

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residues. Grinding reduces the particle size and increases the surface area of the roughage and therefore enhances the rate of microbial digestion and the rumen turnover rate[3]. This results in an increase in intake. On grinding roughages, the metabolizable energy of the feed is used with greater efficiency as mastication and heat are reduced. As a consequence, the net energy value per unit of dry matter consumed is increased[5].

The intake of cellulosic residues may also be improved by mechanically blending with a more palatable feedstuff. Osuji[6] reported the use, in Jamaica, of a commercial bagasse/molasses formula (Pimola) consisting of 65% molasses, 33% bagasse pith and 2% urea. Bagasse and bagasse pith are good carriers of molasses, and palatability can be increased up to 55% by the addition of molasses. In Denmark the use of a roughage feed called Strawmix, consisting of 50-55% chopped straw, 20% molasses and 17-22% special high protein concentrate with trace elements and minerals is commercially available. Processing plants for producing such pelleted feeds are also marketed.

Steam-pressure treatment of cellulosic residues can also be used to improve the digestibility of such materials. Steam treatment of ground grass straw for three (3) minutes at a pressure of 28kg/cm^2 improved the *in-vitro* dry matter digestibility of such straw by more than 50%[7]. Donefer[8], using temperatures and pressures in excess of 160^{o}C and 6kg/cm^2 respectively, demonstrated that this technique can markedly increase the *in-vitro* dry matter digestibility of wood, straw and sugar-cane bagasse. The effect of steam treatment appears to be a solubilisation of cellulose and hemicellulose and the freeing of digestible matter from lignin.

4. CHEMICAL TREATMENT OF CELLULOSIC RESIDUES

Two chemical processing methods for improving the nutritive value of cellulosic crop residues have been principally used. Either sodium hydroxide or ammonia (anhydrous of aqueous ammonia) have been used.

4.1 Sodium Hydroxide Treatment

NaOH treatment of straw was carried out in Germany before 1900. Homb et al[9], and Jackson[10] have reviewed the development of such processing methods. The original wet method (Beckmann) of straw processing entails the soaking of straw for 18-20 hours in a 1.5% solution of NaOH. Eight to ten litres of solution per kg of dry straw is recommended for effective soaking, and therefore 12-15kg NaOH/100kg of straw dry matter is therefore needed. At the end of the soaking period, the NaOH solution is drained off and the straw is washed by fresh water for a further 18 hours. This method is found to be very effective in increasing the digestibility of straws, and the data of Fingerling et al. as cited by Homb et al.[9] are given in Table 1. The effectiveness achieved in this process is at the expense of high levels of NaOH (12-15% on a straw dry matter basis), and washing after treatment is necessary to remove the excess alkali. The disadvantages of this method are the high alkali, labour and water requirements, dry matter losses of up to 25% and the short storage life of the treated straws.

More recently, the development of dry methods for the chemical processing of straw has been reported. The quantity of NaOH applied is limited to that amount which will not affect the animal adversely, and is usually 5% NaOH on a straw dry matter basis[10]. At this level, washing and the subsequent significant losses in dry matter are avoided. However, when compared to wet methods, improvements in digestibilities are lower. In the dry process, the effect of NaOH on cellulosic residues is influenced by the following factors, level of NaOH, reaction time, process temperature and the moisture content of the material. Ololade et al[11] working with NaOH treated barley straw, obtained higher dry matter digestibilities (untreated 38%, maximum treated, 82%) with increasing levels (up to 12%) of NaOH and increasing temperatures (maximum 130^{o}C). Phoenix et al.[12] also investigated factors affecting the reaction between NaOH and barley straw and found that increasing levels of NaOH up to 10%, increasing temperatures and increasing moisture content all had positive effects on the initial rate and the extent of the time-dependent reaction. Ololade et al.[11] found substantial improvements in dry matter digestibilities within twenty-four hours at 23^{o}C, while at higher temperatures (60-100^{o}C), the reaction is practically completed in minutes.

4.2 Ammonia Treatment

Ammonia has been applied on cellulosic crop residues to improve the digestibility of such residues. Ammonia has the advantage that considerable amounts of nitrogen can be incorporated into the treated straw in a form in which it could be used as a source of non-protein nitrogen (NPN) by ruminant animals. It has the disadvantage that the improvement in *in-vitro* digestibility is not as great as when stronger bases such as NaOH are used[13]. Sankat and Bilanski[14] ammoniated covered stacks of corn stover on the field, and using a 3% level of NH_3 (on a dry matter basis), the crude protein content of the corn stover increased from a level of 5.3% (untreated) to 10.0% (treated), and the *in-vitro* digestibility of dry matter increased from 51% (untreated) to a level of 62% (treated).

5. ALKALI TREATMENT OF BAGASSE AND CANE TOPS

Bagasse and cane tops are the two most potentially available residues in Trinidad as well as in the other sugar producing countries of the Caribbean. Current research at U.W.I., is aimed at determining the effect of alkali treatment on such residues, the parameters which influence any such reaction, and methods for handling and processing the residues. The results of recently conducted experiments to determine the effect of NaOH and NH_3 on bagasse, cane tops, and rice hulls (at 25% moisture content, wet basis) are shown in Figure 1,2 and 3 respectively. The treatments were manually carried out on small samples of such residues, and after treatment, samples were stored in plastic bags under room conditions for various time intervals. *In-vitro* dry matter digestibility were determined by the method of Tilley and Terry[15]

Results indicate that NaOH is more effective that NH_3 in improving the digestibility of such residues, and that such improvements are most pronounced in residues of reduced quality. From the experimental data obtained, the magnitude of the reaction between NaOH and the residues did not change significantly after twelve (12) hours, but with NH_3 some changes were noted within three (3) and twenty-one (21) days.

6. INDUSTRIAL AND FARM SCALE METHODS FOR PROCESSING RESIDUES

The dry process for NaOH treated straws described previously has been incorporated in industrial processing plants. The unit operations in such plants vary, depending upon the product to be manufactured, e.g.

(1) The production of NaOH-treated straw pellets only, with or without molasses. Such pellets can be later incorporated into complete ruminant diets using the facilities of existing feed mills.

(ii) The production of a complete ruminant diet based upon NaOH-treated straw and containing molasses, other feed ingredients, urea, vitamins and minerals. An elementary process flow chart for such a plant is shown in Figure 4.

Alternatively NaOH treated straws can be manually prepared at the farm for direct use, by spraying a dilute solution of NaOH with a watering can. The material should be turned with a hay fork to ensure uniform wetting. Jackson[10], suggested the use of 200l of solution per 100kg. of straw. This material can be fed with other feed ingredients after twenty-four hours, but longer storage is recommended as the level of unreacted alkali is reduced.

For large on-farm processing, NaOH treated straw (4-5kg NaOH/100 kg straw) can be prepared by tractor PTO driven machines, at the rate of four tons/hr. In such mobile machines bales of straw are shredded and chopped, then mixed with the NaOH solution in a special mixer ensuring even mixing and adequate penetration of the alkali. The treated straw is then blown into storage. It can be used in three days, but longer storage is recommended to maximise the digestibility of the straw (a temperature rise occurs within the stored straw, enhancing the extent of the reaction), and also to reduce the sodium level.

On farm processing with NH_3 can be achieved by covering stacks or bales of straw with polyethelene plastic sheets, sealing such sheets to the ground by sand, and injecting anhydrous ammonia into the stack with an injection probe[14]. A Danish straw process has also been developed for this operation, and straw treatment takes place within a 24-hour period. In a sealed chamber, ammonia is recycled for fifteen (15) hours at a temperature of 95^{o}C and this is followed by four (4) hours of reaction time and four (4) hours of aeration. The organic matter digestibility of barley straw treated in this manner was approximately doubled.

7. CONCLUSION

Alkali treatment of cellulosic crop residues can significantly improve the digestibility of such material, and therefore increase their usage in ruminant feeds. In Trinidad and Tobago, bagasse has considerable potential for being commercially processed in this manner as it is available in large quantities at fixed locations. Cane tops may also be processed, but for this to be commercialised a system has to be implemented for its harvesting, collection and transportation from the fields to the processing plant.

Current research indicates that NaOH is faster acting and more effective than NH_3 when applied to bagasse and cane tops under similar processing conditions. However the use of NH_3 in processing crop residues for feed in Trinidad and Tobago may be rationalised principally on the basis of its local manufacture and availability.

8. ACKNOWLEDGEMENTS

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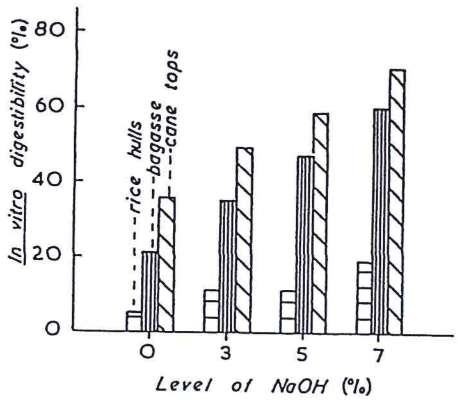
REFERENCES

1. REXEN, F.P., "Utilisation of Cellulose rich by-products", In DANSTRAW — Technical Bulletin of the Danish Straw Technology Association, 1980, pp. 4-13.
2. FRANK, G. "The importance of Structural Roughage, rich in crude fibres, as a component in compound feed milling," Amandus Kahl Nachf., Hamburg, 1977.
3. DINIUS, D., "Cellulosic wastes as ruminant feed", Proceedings of the 1975 Maryland Nutrition Conference for Feed Manufacture, University of Maryland, 1975, pp. 100-104.
4. VAN SOEST, P.T., "Composition, maturity, and the nutritive value for forages", In "Cellulases and their Applications", R.F. Gould (Editor), Advances in Chemistry Series 95, American Chemical Society, Washington, D.C., 1969, pp. 262-277.
5. GREENHALGH, J.F.D., and WAINMAN, F.W. "The nutritive value of processed roughages for fattening cattle and sheep," Proc. Br. Soc. Animal Production, 1972, pp 61-72.
6. OSUJI, P.O.,"Agro-Industrial by-products and animal feeding in the Caribbean Region", Wld. Rev. Anim. Prod.,. Vol. XVIII, No. 1, 1982.
7. GUGGOLZ, J., KOHLER, G.O., and KLOPFENSTEIN, J., "Composition and improvement of grass straw for ruminant nutrition.", J. Anim. Sci. 1971, 33, 151-156.
8. DONEFER, E., "Physical treatment at commercial and farm level", FAO Technical Consultation on New Feed Resources, FAO, Rome, 1976.
9. HOMB, T., SUNDSTOL, F., and ARNASON, J., "Chemical treatment of straw at commercial and farm level", FAO Technical Consultation on New Feed Resources, FAO, Rome, 1976.
10. JACKSON, M.G., "Treating straw for animal feeding", FAO Animal Production and Health, Paper No. 10, FAO, Rome, 1978.
11. OLOLADE, B.G., MOWAT, D.N., and WINCH, J.E., "The effect of processing methods on the *in-vitro* digestibility of sodium hydroxide treated roughage", Can. J. Anim. Sci., 1970, Vol. 50, 657-662.
12. PHOENIX, S.C., BILANSKI, W.K., and MOWAT, D.N., "*In-vitro* digestibility of barley straw treated with sodium hydroxide", Trans. of the ASAE., 1972, 15, 1091-1093.
13. COXWORTH, E., "A review of previous studies on ammonia treatment of straw and other low quality forages to improve digestibility and nutritive value and incorporate non-protein nitrogen", Saskatchewan Research Council Saskatoon, Canada, 1976, pl.
14. SANKAT, C.K., and BILANSKI, W.K., "Ammoniation of corn stover stacks to improve feed value", Can. Agric. Eng., 1980, 22, 77-80.
15. TILLEY, J.M.A., and TERRY, R.A., "A two-stage technique for the *in-vitro* digestion of forage crops", J. Br. Grassland Soc., 1963, 18, 104-111.

TABLE 1

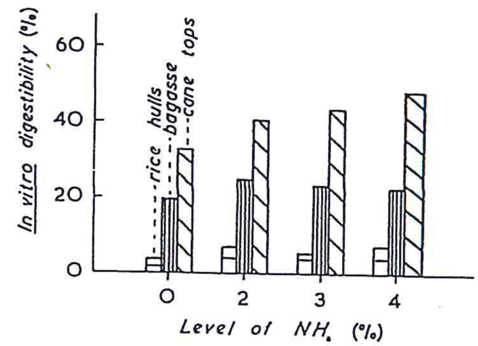
DIGESTION COEFFICIENTS OF ORGANIC MATTER IN STRAW AFTER TREATMENT WITH INCREASING AMOUNTS OF NaOH(9).

NaOH TREATMENT	DIGESTION COEFFICIENT
Untreated straw	45.7%
2kg NaOH per 100 kg straw	46.3%
4" " " " "	50.2%
6" " " " "	61.1%
8" " " " "	66.1%
10" " " " "	66.2%
12" " " " "	71.2%



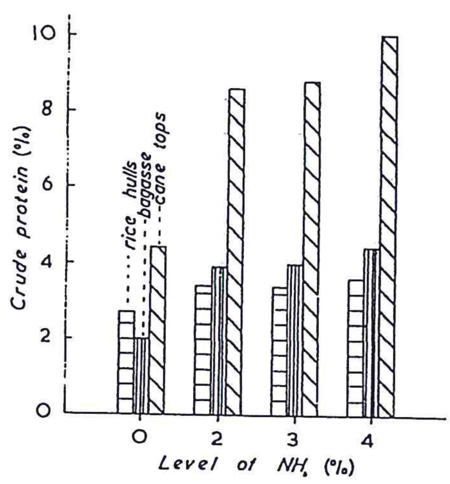
The effect of NaOH on the *In-vitro* Dry Matter Digestibility of Residues at 25% moisture content (wet basis) and after 24 hours.

FIGURE 1



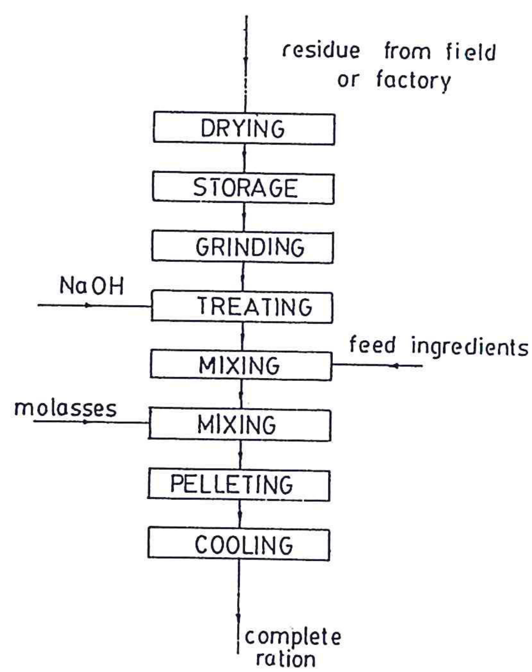
The effect of NH_3 on the *In-vitro* Dry Matter Digestibility of Residues at 25% moisture content (wet basis) and after 7 days.

FIGURE 2



The effect of NH_3 on the crude protein content of residues at 25% moisture content (wet basis) and after 7 days.

FIGURE 3



A process flow chart for processing cellulosic residues in a complete ruminant diet.

FIGURE 4