A MODEL TO OPTIMIZE ENERGY INTAKE OF RUMINANTS FROM BIOLOGICALLY TREATED CROP RESIDUES

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SUMMARY

The treatment of lignocellulosic crop residues by using fungi and its potential to enhance digestible energy intake by ruminant animals is discussed in order to prioritize further research. Losses of organic matter during solid state fermentation are inevitable and can reduce the energy content of fermented crop residues even when organic matter digestibility increases. This paper describes a conceptual model to optimize biological treatments of lignocellulosics and highlights the effect of treatment over time on the feeding value of fermented materials. Feeding value is defined as potential digestible organic matter intake, i.e. product of organic matter content, organic matter digestibility and intake. Two very different crop residues, i.e. rice straw and bagasse, and two sets of fermentation conditions, namely slow and fast growing, have been considered as case studies. It is concluded that organic matter losses are more serious with rice straw than with bagasse because of the higher ash content in rice straw. Also, it may be necessary to accept organic matter losses to achieve higher digestible organic matter intakes, when intake over time increases faster than the decrease in digestibility.

INTRODUCTION

Interest has been shown in recent years in the use of biological treatment procedures to improve nutritive quality of straws by adopting fungi in solid state fermentation systems (SSF) (Domsch *et al.*, 1981; Zadrazil and Brunnert, 1982; Agosin and Odier, 1985; Van der Meer *et al.*, 1986; Basuki and Wiryasasmita, 1987; Walli *et al.*, 1987; Gupta, 1988; Rai *et al.*, 1988; Singh *et al.*, 1989; Singh et *al.*, 1990 a, b; Singh, 1993). Fungi differ in their ability to alter the digestibility of lignocellulosics for ruminants. Few fungi have a positive effect, whereas most others show an adverse effect on the digestibility often depending on whether they are white rot, soft rot or brown rot fungi (Zadrazil, 1984; Kamra and Singh, 1987). Species such as *Stropharia rugosoannulata*, *Pleurotus* spp. and *Abotiporus biennis* S. can increase the *in vitro* digestibility of straw up to 30% (Kamra and Zadrazil, 1988; Badve *et al.*, 1987), whereas Rai et *al.* (1987), using fermented straw with *Coprinus fimetarius* as sole diet in goats, reported that *in vivo* digestibility of different nutrients either declined or remained equal with the

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control. They further indicated that the digestibility of fermented straw largely depends on OM losses during SSF. Most trials study only the effect of treatment on digestibility, but the nutritive quality is a combination of at least three factors: OMD, OM content and DMI. The effect of treatment on each of these factors is determined by the nature and duration of the treatment, the micro-organism and the original substrate. This paper discusses the relative importance of these aspects and their interrelation, in order to set priorities for further work. Other aspects of nutritive quality include the protein content and quality (Walli *et al.*, 1993; Gupta, 1988), and toxicity (Deodhar and Gupta, 1988) and are not discussed in this paper.

FACTORS AFFECTING SOLID STATE FERMENTATION AND THEREFORE NUTRITIVE VALUE

Amongst different processes, SSF is probably the most economical and practical method for large scale fermentation of biomass with micro-organisms. SSF is a process where an insoluble substrate is fermented with sufficient moisture but without free water. Changes in solid state fermentation affect the rate and species of microbial growth, as well as the quality of the final product. Following are few of major factors affecting SSF (Weiland, 1988).

Moisture content

The optimum moisture level in SSF depends on the nature of the substrate, the organism and the type the end product required. Ranges from 50-75% moisture have been reported as being optimal for various products in SSF carried out in the laboratory. A high moisture content of the SSF results in decreased porosity, gas exchange, oxygen diffusion, gas volume, but increased risk of bacterial contamination and enhanced formation of aerial mycelium. On the other hand, lower moisture levels lead to sub-optimal growth and less swelling of substrate. The moisture content of the substrate continues to change during the fermentation due to evaporation and metabolic activities. The maintenance of moisture content during fermentation depends on air circulation relative humidity, stack size etc.

Temperature

Temperature affects the rate of biochemical reactions during the fermentation process. Due to the heat produced during fermentation and because of the poor conducting properties of the substrate (crop residues), a rise in temperature is common. Differences between ambient and fermentation temperature should be recognised.

Exchange of gasses

Gas exchange between gaseous phase and solid substrate affects the process of fermentation. The gradients of oxygen and carbon dioxide concentration determine respiration rates, rates of biological activities and biological state of the system. Gas exchange is affected by the moisture content of the substrate. Excessive water hinders the exchange of gases and creates anaerobic conditions inside the substrate whereas insufficient water does not permit optimal fungal activity. The optimum level of solid : liquid ratio in solid state fermentation depends on substrate quality, particle size, water holding capacity of substrate and type of desired micro-organism (Zadrazil and Brunnert, 1981; Flegel and Meevootisom, 1986; Kamra and Zadrazil, 1987).

THE MODEL AND AIMS OF THE BIOLOGICAL TREATMENT

The prime aim of the many experiments with biological treatment of crop residues is often not well stated, but generally implies an increase of digestibility and/or protein content. However, for practical animal nutrition purposes, the goal should be well defined and could combine many factors, such as an increase in the intake of digestible nutrients by the animals. Other factors can be equally important and gains in one aspect are likely to cause a loss in other aspects. The nitrogen aspects of straw quality and their relation with digestible energy value of the straw are discussed by Walli *et al.* (1993) and toxicity by Deodhar and Gupta (1988). This paper will focus exclusively on the intake of digestible organic matter (DOMI), consisting of DMI, OMD and OM content of the fermented materials:

$$DOMI = OM * OMD * DMI \qquad (1)$$

A high DOMI requires one or more of the following factors:
- a high intake of fermented straw;
- reduced losses of organic matter;
- an increased OMD.

This means that maximization of DOMI can imply that a decrease of OMD or OM content is compensated by an increase in OMI.

Organic Matter Digestibility (OMD_t)

Not many *in vivo* digestibility values of fungal treated straws are available, hence the digestibility values used for our model have to be derived from *in vitro* values. The digestibility of straws in SSF change with time, expressed in our model as OMD_t. Generally at the beginning of the fermentation, the OMD of the substrate will decrease because the easily solubilized substances are used by the fungi. In the following stage, substrate polymers could be decomposed and sugars and other components of the substrate could be liberated. As a result the digestibility might

increase after an initial decrease (Zadrazil and Brunnert 1982; Badve *et al.*, 1987), though not necessarily returning to the same level.
The change in OMD depends on the fungal species, duration of fermentation period, temperature, water/air ratio and gas composition in the substrate, on the preparation, bulk density and the composition of the substrate.
In the calculations two situations have been considered: one in which the fungus will not decompose polymers, resulting in an ever decreasing OMD ("fast growing", e.g. *Coprinus* spp.), and one fungus which can decompose polymers, resulting in an increased OMD after an initial dip ("slow growing", e.g. *Pleurotus* spp.).

Organic matter content (OM_t)

Our model uses OM content in dry matter (OM_t) on the basis of literature data, by recalculating them from ash contents and DM losses (the DM loss can be supposed to consist entirely of OM loss). The OM_t is assumed to decrease linearly as the fermentation period progresses. OM decreases because the micro-organisms consume organic constituents for own metabolism. As a result of the OM loss, the ash content of fermented/spent rice straw can increase up to 30-33% or even further (Langar and Bakshi, 1986; Gupta *et al.*, 1988; Basuki and Wiriyasasmita, 1987). A general formula for organic matter content overtime is

$$OM_t = OM_o + bt \qquad (2)$$

Where:
OM = organic matter, kg/100 kg dry matter,
t = time after inoculation of fungus (days),
b = organic matter loss (% per day).

Two types of crop residues have been considered in the case study, i.e. a high and a low ash containing material (rice straw and sugarcane bagasse). The corresponding intial OM contents (OM_o) are 80% and 98% of rice straw and sugarcane bagasse respectively.
In our calculations of Tables 1 and 2, "t" ranges from 0 to 25 days ("fast growing") and 0 to 50 days ("slow growing) and b = 1.4 respectively 1 % for the "fast growing" and "slow growing" situation.

Dry Matter Intake

The total amount of DOM at time "t" is the product of OMD_t and OM_t:

$$DOM\% = OM\% * OMD\% \qquad (3)$$

This DOM may be used to estimate the economic value from the nutritive value by comparing with other feeds as done by Schiere *et al.* (1987). DOM is approximately the same as TDN, if the feeds

Table 1   Change over time in DOM and necessary change of DMI (to obtain at least an equal DOMI) of rice straw and bagasse as affected by fermentation by "fast growing" and "slow growing" fungi

Particulars	Fermentation periods				
"Rice straw-fast growing fungus"					
OM loss (%)	0	10	20	30	40
OM (%)	80	78.3	76.2	73.7	70.6
OMD (%)	50	47.0	44.5	42	40
DOM (%)	40	36.8	33.9	30.9	28.2
Δ DMI (%)	-	8.7	18	29.2	41.6
"Rice straw-slow growing fungus"					
OM loss (%)	0	10	20	30	40
OM (%)	80	78.3	76.2	73.7	70.6
OMD (%)	50	43	50	53	52
DOM (%)	40	33.7	38.1	39.1	36.7
Δ DMI (%)	-	18.8	5	2.49	
"Bagasse-slow growing fungus"					
OM loss (%)	0	10	20	30	40
OM (%)	98	97.8	97.5	97.2	96.7
OMD (%)	50	43	50	53	52
DOM (%)	49	42.1	48.8	51.5	50.3
Δ DMI (%)	-	16.5	0.5	-4.9	-2.6

Note: assumptions based on Rai et al. (1989) and Singh et al. (1989) for rice straw and on BIOCON (1988) for bagasse

Table 2   Animal performance on biologically treated straw.

Source	Animal species	Treatment	OM (%)	OMD (%)	DMI (g/d)	DOMI (g/d)
RICE STRAW						
Rai et al. (1987)	Goat	UTS[1]	76.6	65.6	551	281
		FTS[2]	67.5	55.9	750	282
Rai et al. (1989)	Goat	UTS[1]	77.4	64.5	652	320
		FTS[2]	70.2	66.2	1073	5003
Singh et al. (1990c)	Goat	Control	79.4	71.5	?	747
		FTS[2]	72.2	60.2	?	582
WHEAT STRAW						
Walli et al. (1987)	Goat	UTS[1]	85.0	48.4	445	183
		FTS[2]	80.0	46.3	550	204
Chaudhary et al. (1988)	Heifer	Control	82.6	53.5	4190	1860
		FTS (Spent)	78.2	49.5	4320	1700
		UTS[1]	87.6	61.6	4280	2300

[1] urea treated straw; [2] biologically treated straw after urea pre-treatment; [3] Interrelated with a higher intake of molasses of the FTS group

are of low fat content such as poor quality crop residues and fodder.

However if an increase in intake of digestible nutrients is the objective of the research, due attention should be given to the effect on DMI. In Table 1 the necessary increase in DMI is calculated to achieve at least a similar DOMI as with non-fermented crop residues (assuming a DMI of the original substrate of 6 kg). If higher increases in DMI can be achieved, this will result in a higher DOMI and, probably, a higher animal production. Actual DMI values are scarce but few are given in Table 2.

The calculations

The combined effect of changes in OM_t and OMD_t as affected by time (t) on DOM and necessary change in DMI is calculated for three situations (Table 1):
- a high ash substrate (rice straw) with a "fast growing fungus" (*Coprinus*),
- a high ash substrate (rice straw) with a "slow growing fungus" (*Pleurotus*),
- a low ash substrate (bagasse) with a "slow growing fungus" (*Pleurotus*).

The objective of these calculations is to prioritize further research on this subject by an assessment of:
- the impact of OM% of the original substrate,
- the relative importance OMD and DMI.

RESULTS AND DISCUSSION

In the case of "fast growing fungus" on rice straw, a decrease in OMD from 50 to 40%, combined with an OM loss of 40%, leads to a DOM decline from 40 to 28.2%. This decline is both an effect of the fermentation of the soluble parts and of the inability of fungi to break down the lignocellosic structure, resulting in both a lower OMD and a lower OM%. This means that the OM losses aggravates OMD losses. The OMD would have to increase from 50 to 56.7 to compensate the OM losses.
Also in the case of the "slow growing fungus" the DOM decreases from 40 to 39.1% after 30 days due to the OM losses, even though the OMD was assumed to increase from 50 to 53% after 30 days. This means that in high ash containing substrates like rice straw it is unlikely that DOM will be increased even if OMD is increased, due to the large impact of OM losses. Similar OMD and DOM patterns have also been shown by Schiere *et al*. (1987).
In low ash containing substrates like bagasse, the effect of OM losses on DOM is less severe. In the case of an increased OMD ("slow growing fungus"), the DOM increased from 49 to 51.5% after 30 days, even though the OM losses were assumed to be 30%.
The increased OMD is of importance because crop residues are a potential source of energy for ruminants. However the intake of energy (= DOMI)is not only dependent on OMD and OM but also on DMI. Calculating the necessary increase in DMI in order to have an equal DOMI as compared with the non-fermented substrate, it revealed that the DMI is to be increased by 41.5% in the case of "rice straw-fast growing fungus", while it might be decreased by 4.9% in the case of "bagasse-slow growing fungus".

This indicates that the scope in substrates like rice straw for fungi positively affecting the digestibility is limited due to the high effect of OM-losses on DOM, unlike substrates like bagasse where this effect is much smaller. It also indicates that the usefulness of biologically treated straw should not be evaluated on the basis of OM loss and digestibility alone, but that the DMI is an important parameter which should be taken into account also before drawing conclusions about the effectiveness of straw fermentation.

LIMITATIONS

Changes of DOMI over time are generally not studied through *in vivo* feeding trials, though the optimization of the process urgently requires such data. Some data of *in vivo* trials with straw are given in Table 2. These trials confirm that DOM is decreased due to OM-losses and decreased (or at best equal) OMD, while in some cases a higher DMI outweigh this lower DOM. Also little information is available on (a) potential (combination of) fungi that can effectively increase DOMI in non-sterile SSF, while toxicity due to contamination with other fungal strains warrants caution for the application under field conditions.

CONCLUSIONS

The focal point for evaluation of fermented straw should be the absolute DOMI rather than the OM losses or OMD alone, if increasing the intake of digestible nutrients is the aim of biological treatment. In that case fungal strains should be selected that increase DOMI, where a loss in digestibility can be compensated by an increase in DMI or *vice versa*. For optimization of the process (if at all possible) one has to know changes of DOMI components over time, which requires experiments at different treatment duration.

The results available in literature so far, mainly focussing on OMD and OM-losses, are not encouraging for the biological treatment from a ruminant nutrition point of view. However, little information on changes over time and DMI are reported. The results of the modeling, based on this limited information, suggest that the low ash containing roughages are better suited for fungal treatment than high ash containing material, while DMI appears to be of overriding importance.

REFERENCES

Agosin, E., and Odier, E., 1985. Solid state fermentation, lignin degradation and resulting digestibility of wheat straw fermented by selected white rot fungi. Appl. Microbiol. and Biotechnol. 21: 397-403.

Badve, V.C., Nishal, P.R., Joshi, A.L., and Rangnekar, D.V., 1987. Studies on the use of lignocellulose degrading fungi to improve the nutritive value of sugarcane bagasse and sorghum straw, pp. 112-125. In: Kiran Singh, T.W. Flegel and J.B. Schiere (eds): Biological, chemical and physical treatment of fibrous crop residues as animal feed. Proceedings of an International Workshop held on 20-21 January 1987 in New Delhi, India.

Basuki, T., and Wiryasasmita, R., 1987. Improvement of the nutritive value of straw by biological treatment, pp. 86-105. *In:* *M. Soejono, A. Musofie, R. Utomo, N.K. Wardhani and J.B. Schiere (eds): Crop-residues* for feed and other purposes. Proceedings on bioconversion project II Workshop held on 16-17 November 1987 in Grati, Indonesia.

BIOCON 1988, Progress Report, April 1987 - October 1988. Bioconversion of Agricultural Wastes, Uruli Kanchan Centre. BAIF, Pune.

Chaudhary, R.B., Tiwari, A.D., and Singh, M., 1988. Effect of feeding urea and fungus spent straw on nutrient utilization in cross-bred growing heifers, pp. 133-134. In: Kiran Singh and J.B. Schiere (eds): Fibrous crop residues as animal feed. Proceedings of an International Workshop held on 27-28 October 1988 at the National Dairy Research Institute, Southern Regional Station, Bangalore, India.

Deodhar, A.D., and Gupta, B.N., 1988. Toxicological Aspects of biologically treated cereal straw, pp. 125-132. In: Kiran Singh and J.B. Schiere (eds): Fibrous crop residues as animal feed. Proceedings of an International Workshop held on 27-28 October 1988 at the National Dairy Research Institute, Southern Regional Station, Bangalore, India.

Domsch, K.H., Ferranti, M.P., and Theander, O., 1982. Improved utilization of lignocellulosic materials for animal feed. Proceedings of a OECD/COST Workshop held on 30 September - 2 October 1981 in Braunschweig.

Gupta, B.N., 1988. Development and concept of Karnal process for fungal treatment of cereal straws, pp. 46-56. In: Kiran Singh and J.B. Schiere (eds): Fibrous crop residues as animal feed. Proceedings of an International Workshop held on 27-28 October 1988 at the National Dairy Research Institute, Southern Regional Station, Bangalore, India.

Gupta, B.N., Rai, S.N., Walli, T.K., and Singh, K., 1988. Evaluation of fungal treated rice straw at different fermentation periods in relation to dry matter intake and nutrient utilization in goats. Indian J. Anim. Nutr. 5: 273-279.

Flegel, T.W., and Meevootisom, V., 1986. Biological treatment of straw for animal feed, pp. 181-191. In: M.N.M. Ibrahim and J.B. Schiere (eds): Rice straw and related feeds in ruminant rations. Proceedings of International Workshop held on 24-28 March 1986, Kandy, Sri Lanka.

Kamra, D.N., and Zadrazil F., 1987. Influence of gaseous phase, light and substrate pretreatment on fruit body formation, lignin degradation and in vitro digestion of wheat straw fermented with Pleurotus spp. Agicultural Wastes 18: 1-18.

Kamra D.N., and Zadrazil, F., 1988. Microbiological improvement of lignocellulosics in animal feed production - a review, pp. 56-63. In: F. Zadrazil and P. Reiniger (eds): Treatment of lignocellulosics with white rot fungi. Proceedings of a EEC-workshop held on 21-23 October 1986 in Braunschweig.

Kamra, D.N., and Singh, R., 1987. Microbiological treatment of ligno-cellulosic by-products for animal feeding, pp. 260-268. In: U.B. Singh (ed.): Advanced Animal Nutrition for Developing Countries. Indo-Vision Pvt. Ltd. Ghaziabad.

Langar, P.N., and Bakshi, M.P.S., 1986. Evaluation in vitro of volvariella harvested spent rice straw. Agricultural Wastes 15: 309-311.

Rai, S.N., Walli, T.K., and Gupta, B.N., 1987. Investigations on fungal treatment of rice straw and its evaluation as sole feed for cross-bred goats, pp. 88-102. In: Kiran Singh, T.W. Flegel and J.B. Schiere (eds): Biological, chemical and physical treatment of fibrous crop residues as animal feed. Proceedings of an International Workshop held on 20-21 January 1987 in New Delhi, India.

Rai, S.N., Singh, Kishan, Gupta, B.N., and Walli, T.K., 1988. Microbial conversion of crop residues with reference to its energy utilization by ruminants - an overview, pp. 66-74. In: Kiran Singh and J.B. Schiere (eds): Fibrous crop residues as animal feed. Proceedings of an International Workshop held on 27-28 October 1988 at the National Dairy Research Institute, Southern Regional Station, Bangalore, India.

Rai, S.N., Walli, T.K., and Gupta, B.N., 1989. The chemical composition and nutritive value of rice straw after treatment with urea or Coprinus fimetarius in a solid state fermentation system. Anim. Feed. Sci. and Technol. 26: 81-92.

Schiere, J.B., Oosting, S., and Mulyaningsi, N., 1987. Biological treatment of straw from an animal nutrition point of view, pp. 68-87. In: Kiran Singh et al. (eds): Proceedings of 1st Indo-Dutch Project Workshop on Biological, Chemical and Physical treatment of fibrous crop residues as animal feed, ICAR, New Delhi.

Singh, R., 1989. Proceedings National Seminar on Biotechnology of Lignin Degradation held on 20-21 December 1989. Indian Veterinary Research Institute, Izatnagar-243122, India.

Singh, K., Rai, S.N., Singh, G.P., and Gupta, B.N., 1989. Solid state fermentation of urea-ammonia treated wheat and rice straws with Coprinus fimetarius. Indian J. Microbiol. 29: 371-376.

Singh, K., Rai, S.N., Neelakantan, S., and Han, Y.W., 1990a. Biochemical profiles of solid state fermented wheat straw with Coprinus fimetarius. Indian J. Anim. Sci. 60: 984-990.

Singh, K., Rai, S.N., Flegel, T.W., and Neelakantan, S., 1990b. Solid substrate fermentation of ground and unground wheat straw with Pleurotus ostreatus. Indian J. Anim. Sci. 60: 1230-1234.

Singh, G.P., Gupta, B.N., Singh, and Kishan, 1990c. Effect of microbial treatment of paddy straw on chemical composition and nutrient utilization in cross-bred goat. Indian J. Anim. Nutr. (in press).

Walli, T.K., Rai, S.N., Singh, G.P., and Gupta, B.N., 1993. Nitrogen status of biologically treated straw and its N-utilization by animals. In: Kiran Singh and J.H. Schiere (eds): Proceedings International Workshop, National Dairy Research Institute, Karnal, Haryana-India, 4-8 February, 1991.

Walli, T.K., Gupta, B.N., and Rai, S.N., 1987. Feeding trials with urea treated and fungal treated wheat straw, pp. 103-111. In: Kiran Singh, T.W. Flegel and J.B. Schiere (eds): Biological, chemical and physical treatment of fibrous crop residues as animal feed. Proceedings of an International Workshop held on 20-21 January 1987 in New Delhi, India.

Weiland, P., 1988. Principles of solid state fermentation, pp. 64-76. In: F. Zadrazil and P. Reiniger (eds): Treatment of lignocellulosics with white rot fungi. Proceedings of a EEC-workshop held on 21-23 October 1986 in Braunschweig.

Zadrazil, F., and Brunnert, H., 1981. Investigation of physical parameters important for the solid state fermentation of straw by White-rot fungi. Eur. J. Appl. Microbiol. and Biotechnol. 11: 183-188.

Zadrazil, F., and Brunnert, H., 1982. Solid state fermentation of lignocellulose containing plant residues with Sporotrichum pulverulentum Nov and Dichomitus squalens (Karst) Reid Eur. J. Appl. Microbiol. and Biotechnol. 16: 45-51.

Zadrazil, F., 1987. White rot fungi and mushrooms grown on cereal straw: aim of the process, final products, scope for the future, pp. 55-62. In: J.M. Van der Meer, B.A., Rijkens and M.P. Ferranti (eds): Degradation of lignocellulosics in ruminants and in industrial processes. Proceedings of a Workshop held on 17-20 March 1986 in Lelystad, the Netherlands. Elsevier Applied Science, London, U.K.

Zadrazil, F., 1984. Microbial conversion of lignocellulose into feed, pp. 276-287. In: F. Sundstøl and E. Owen (eds): Straw and other fibrous by-products as feed. Elsevier Science Publishers BV, Amsterdam, The Netherlands. Developments in Animal and Veterinary Sciences 14, ISBN 0-444-42302-8, 604 pp.