Enhancing Paddy Straw Potential as an Efficient Substrate for Biogas Production by Various Pretreatments

Karamjeet Kaur[1] and Urmila Gupta Phutela[2]

[1,2]School of Energy Studies for Agriculture, College of Agricultural Engineering and Technology, Punjab Agricultural University, Ludhiana-141004, Punjab, India

Abstract: Paddy straw has high holocellulose content but the lignin complex and silica incrustation shield the microbial action for biogas production. So, the paddy straw needs to be pretreated in order to enable cellulose to be more accessible to the microbial/enzymatic attack. The various pretreatment methods are being exploited to enhance paddy straw digestibility like physical, chemical and biological methods. The physical pretreatment requires high energy and corrosion resistant high-pressure reactors which increase the need of equipment and cost of pretreatment. The chemical pretreatments can be detrimental to the methanogens apart from generating acidic or alkaline water which needs pre-disposal treatment to ensure environment safety. Thus, an alternative approach is microbial/ enzymatic pretreatment to increase digestibility of paddy straw. Advantages of biological pretreatment include low cost, low energy requirement and mild environmental conditions. Several pretreatment studies conducted at Biogas Laboratory, SESA, PAU are summarized in this paper which showed that 1kg of untreated paddy straw can produce 180 liter biogas.

Keywords: Paddy straw, Pretreatment, Chemical, Biological, Enzymatic

Food, fuel and fertilizer are main problems faced by the developing countries. As far as fuel is concerned, the rural population is still heavily dependent on the traditional fuels such as firewood, animal wastes and agricultural residues. Energy sources can be broadly classified into two categories: non-renewable energy sources which are very costly and limited in nature. *e.g.* oil, coal, electricity; and renewable energy sources which are cheap and unlimited in nature. *e.g.* biomass, solar, wind, animal and human waste. There is large unutilized energy potential in the lignocellulosic biomass and paddy straw is one of the most abundant lignocellulosic wastes.

Biomass statistics depicts that world's annual production of straws and stover is 2,000 and 3,000 million tons; Asia's annual production of straws and stover is over 800 million tons; Asia's rice straw generation is over 300 million tons (90 per cent of the total world production); India's annual production of rice is 96.4 million tons [1]; and annual paddy straw generation is 96.4-144.6 million tons (@1-1.5 kg straw/kg grain harvested) [2]. Most of the paddy straw is burnt in the field after harvesting of crop because other disposal methods have number of problems associated with them like residues takes a long time to decompose in ***in situ*** incorporation; collection and storage of residues remain a practical problem. So, an alternative use of paddy straw is to utilize it for biogas production. Biogas is a mixture of methane, carbon dioxide, hydrogen sulphide and hydrogen. And the uses associated with biogas technology are smokeless fuel generation (*i.e.* biogas), decrease in deforestation, decline in environmental pollution, generation of cheap source of power for lighting, heating, running engine, irrigation pumps *etc.*

Paddy straw can be a good substrate for biogas production. But the problem associated with its efficient utilization is its structural composition *i.e.* lignin and silica which hinders the paddy straw digestibility. Therefore, paddy straw needs to be pretreated in order to enable cellulose to be more accessible to methanogens for biogas generation. Various pretreatment options are available to enhance paddy straw digestibility. These include concentrated acid, dilute acid, alkali, hydrogen peroxide, wet oxidation, steam explosion, ammonia fiber explosion (AFEX), CO_2 explosion and organic solvent treatments. In each option, the biomass is reduced in size and its physical structure is opened. Each pretreatment method offers distinct advantages and disadvantages.

Physical and chemical pretreatment of lignocellulosic biomass is an expensive procedure in terms of cost and energy. Several white rot fungi have the ability to delignify kraft pulp. Their lignin-degrading capacity is attributed to extracellular oxidative enzymes that function together with low molecular weight cofactors.

The degradation of lignin by the white rot fungus *Phanerochaete chrysosporium* is catalyzed by extracellular peroxidases (lignin peroxidase and manganese peroxidase) in a H_2O_2-dependent process. If the lignin is even partially removed by the chemical or biological means or if its relationship with the polysaccharides is modified well, the polysaccharide becomes much more susceptible to the enzymatic degradation [3]. Pretreatment with *Pleurotus* sp. leads to decrease in acid detergent fibre, neutral detergent fibre and hemicellulose content of rice straw [4].

In Biogas Lab, SESA, PAU various trials were run for biogas production from paddy straw. In PAU trial 1, chopped paddy straw was mixed with cattle dung and fed into the conventional biogas plants. But the problem faced in biogas production was that of the formation of scum layer of paddy straw at the top because of it being light in weight. In PAU trial 2, chopped paddy straw was mixed with cattle dung @ 1:3 (w/w dry weight basis), filled in PVC sacs and the sacs were loaded manually into the biogas digester. Here, the problem faced was this that the gas did not recover. In PAU trial 3, ground paddy straw was mixed with cattle dung @1:15 (w/w) and fed into the biogas digester. In this case, the problem arose was of the flow of slurry which resulted in the choking of the plant.

Thus, it was concluded that pretreatment of paddy straw is a very important step towards its effective utilization as lignin and silica pose problem in its digestion. So, various paddy straw pretreatment methods were tried at Biogas Laboratory, SESA, PAU to enhance its digestibility which are briefed below:

1. **Chemical Pretreatment:** Different chemicals like NH_3, Na_2SO_3, Na_2CO_3 and NaOH along with 60 min microwave pretreatment were tried to enhance paddy straw digestibility and around 60.9 % enhancement in biogas production was achieved in case of NaOH pretreatment. Since chemical pretreatment was associated with problems like disposal of alkaline waste water obtained from the washing of pretreated paddy straw, so biological pretreatment was tried to overcome the lacunae of chemical pretreatment.
2. **Biological Pretreatment:** Biological pretreatment have been tried with various mesophilic cultures like *Pleurotus florida* MTCC 142 (30d pretreatment period), *Coriolus versicolor* MTCC 138 (10d pretreatment period) and *Fusarium* sp. (10d pretreatment period) which showed 24.7, 19.4 and 17.2 % decrease in lignin content of paddy straw that ultimately led to 15.4, 26.2 and 53.8 % increase in biogas production.
3. **Enzymatic Pretreatment:** Enzymatic pretreatment with the enzyme extract of *Coriolus versicolor* MTCC 138 for 48 h has also been tried which led to 27.5% decrease in lignin content and 47.6 % increase in biogas production.

Amongst all the different pretreatments, biological pretreatment was concluded to be the simplest, economic and environment friendly method for enhancing paddy straw digestibility and biogas production.

Pleurotus ostreatus and *Sporotrichum pulverulentum* inoculated paddy straw is more digestible with significant reduction in lignin resulted from the utilization of cell wall constituents by the fungi [5]. *Phanerochaete chrysosporium* pretreated the cotton stalks have been found to result in significant decrease in lignin *i.e.* 19.38% and 35.33% for submerged and solid state cultivation, respectively [6]. Lignin biodegradation by different microorganisms has been widely studied and it has been shown that inoculation with lignin-degrading microorganisms can accelerate the composting process and improve compost quality [7].

Table 1. Effect of different pretreatment on lignin and silica content of paddy straw and biogas production

Type of Pretreatment	Lignin (%)	Silica (%)	Biogas (l/kg PS)
Control (Untreated paddy straw)	9.3	10.2	180

Chemical + 60 min microwave	NH_3	6.6	11.6	260.5 (44.7 ↑)
	Na_2SO3	6.9	8.6	265.0 (47.2 ↑)
	Na_2CO_3	5.5	5.0	277.9 (54.4 ↑)
	NaOH	4.0	2.0	289.6 (60.9 ↑)
Biological	*Pleurotus florida* MTCC 142	7.0	15.0	207.7 (15.4 ↑)
	Coriolus versicolor MTCC 138	7.5	8.9	227.2 (26.2 ↑)
	Fusarium sp.	7.7	8.8	276.8 (53.8 ↑)
Enzymatic	*Coriolus versicolor* MTCC 138	6.74	8.51	265.7 (47.6 ↑)

**PS: Paddy Straw, values in the parentheses indicate percent increase in biogas production as compared to control*

REFERENCES

[1] Anonymous (2010) Ministry of Agriculture, 1/5/2010.

[2] *Maiorella BL Ethanol.* In: Moo-Young M (ed) *Comprehensive Biotechnology 1985;* vol *3* Pergamon Press, New York pp. *861–914.*

[3] Kirk TK In: Nicholas DD (ed.) Wood determination and its prevention by preservative treatments, 1984; University Press, New York Syracuse pp. 149-181.

[4] Jafari MA, Nikkhah A, Sadeghi AA and Chamani M *The effect of Pleurotus spp. fungi on chemical composition and in vitro digestibility of rice straw.* Pak J Biol Sci 2007; 10: 2460-2464.

[5] Kahlon SS and Dass SK *Biological conversion of paddy straw into feed.* Biol Wastes 1987; 22: 11-21.

[6] Shi J, Shivappa RRS, Chinn M and Howell N *Effect of microbial pretreatment on enzymatic hydrolysis and fermentation of cotton stalks for ethanol production.* Biomass Bioener 2009; 33: 88-96.

[7] Lopez MJ, Vargas-Garcia MDC, Suarez-Estrella F, Moreno J *Biodelignification and humification of horticultural plant residues by fungi.* Int Biodeterior Biodegrad 2006; 57: 24–30.