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Review: Biogas Production from Rice Straw

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ABSTRACT

Rice straw is a rice plant whose fruit (grain) has been removed, so only the stems and leaves are left. Rice straw is the largest among rice plant waste and has not been utilized as well. Utilization of rice straw waste is not optimal because its usually used for cattle feed and as organic fertilizer. Apart from being used as cattle feed and organic fertilizer, methane gas can still be used for alternative renewable energy sources such as biogas. Rice straw has a carbon-to-nitrogen (C/N) ratio content between 50-70. However, to achieve the optimum biogas formation, the substrate requires a C/N ratio of 20-30, therefore a combination of other waste mixtures, such as cow dung or waste that has a low C/N ratio content is usually carried out.

Keywords: *biogas, rice straw, anaerobic digestion, methane production*

1. INTRODUCTION

Rice Straw is a rice plant whose fruit (grain) has been removed, leaving only the stems and leaves which are the largest agricultural waste and have not been fully utilized due to technical and economic factors. Rice straw production varies, reaching about 12-15 tons per hectare in one harvest, or 4-5 tons of dry matter depending on the location and type of crop variety. Indonesia is the third largest rice producer in the world with 11 million hectares of area in Indonesia, which are planted as rice field and 63% of the rice area is irrigated (Tirtalistyani et al, 2022).

So far, the utilization of straw waste has not been optimal because rice straw is usually used for cattle feed, and as organic fertilizer, the other is left to decompose or burned which will then produce pollutants such as CO_2, NO_X, and SO_X which can damage the environment. The use of rice straw as animal feed material is experiencing obstacles in its utilization due to low crude protein levels and lignin, silica, and cutin bonds which are the cause of low digestibility when compared to forage feeds (Don Viet Nguyen et al, 2020).

Rice straw in Indonesia 36–62% is burned or returned to the ground as compost and is used as animal feed in the range of 31–39%, while the remaining 7-16% is used for industrial purposes. Several types of rice straw are available annually in sufficient quantities after harvest. However, rice straw is poor in nutritional content, as reflected by its low digestibility, high crude fiber content, and very low protein (Firdaus and Kamal, 2022).

Utilization of this straw other than as animal feed and organic fertilizer can still be taken from the methane gas as an alternative source of renewable energy. Biogas is a renewable energy that can be made from agricultural waste. Many types of research on making biogas from rice straw and animal dung have been carried out.

Biogas is a gas produced by anaerobic microbiology from organic waste (Khorsidi and Arikan, 2008). Biogas consists of a mixture of methane CH_4 (55-70%), CO_2 (25-50%), H_2O (1-5%), H_2S (0-0.5%), N_2 (0-5%) and NH_3(0 - 0.05%) (Deublein and Steinhauser, 2008). The decomposition of organic matter containing cellulose, hemicellulose, and lignin takes place very slowly.

2. RICE STRAW

2. 1 Rice Straws Contents

According to Amin et al. (2015), rice straw contains 8.26% crude protein, 31.99% crude fiber, 77% neutral detergent fibre (NDF), 57.91% acid detergent fibre (ADF), 23.05% cellulose, 19.09% hemicellulose, and 22.93% lignin.

Rice straw has a C/N content between 50-70. However, in the formation of biogas to achieve the optimum occurs on the substrate a C/N ratio of 20-30 is needed.

Table 1. Rice straws contents

Component	Value (%)
Water Rate	2.9
C/N ratio	64.86
Volatile Solid	81.63
Total Solid	97.1
Moisture	22
Components	14.5
Lignin	34
Cellulose	4.2
Free Nitrogen Extract	19.5
Ash	14
Silica	0.17
Calcium	0.10
Phosphorus	0.20
Potassium	0.11
Magnesium	0.02
Sulfur	0.05 (mg/kg)
Cobalt	0.50 (mg/kg)
Copper	0.4 (mg/kg)

Source: (Herawati and Wibawa, 2010)

2. 2 Mass Balance

In rice plants, there are several parts produced including straw, bran, and husks. Rice Straw produced from the rice plant is about 55.6% by weight of the total rice plant. While the rice grain produced in rice plants is around 44.4%. And from the grain, it can only produce about 65% by weight of rice and the rest is in the form of rice husks and bran (Nappu, 2013).

Table 2. Percentage of weight composition in rice plants

Component	Value (%)
Rice Straw	55.6
Grain	44.4
Rice	65
Husk and bran	35

According to IRRI (International Rice Research Institute) data, every 1 kg of White rice production yields rice straw ranging from 0.7 to 1.4 kg, depending on the variety, cutting size, and moisture content at harvest. Rice straw production in Indonesia reaches 2 to 3.9 tons of dry weight per ha per harvest, or about 4.0 to 7.8 tons per ha per year (Yasa, 2011). Along with the development of rice production, the potential for straw in Indonesia is very large and continues to increase by around 3.1% per year (Makharani, 2014). Based on data from Badan Pusat Statistik Kerangka Sampel Area (BPS KSA), rice production in 2021 will reach 31.68 million tons, an increase of 0.35 million tons from rice production in 2020 of 31.33 million tons, with a surplus for the current year to December reaching 1.65 million tons. So that in 2021, around 61.5 million tons of rice straw can be produced.

3. BIOGAS

3. 1 Definition of Biogas

Biogas is produced from the bacterial biomass degradation process under anaerobic conditions (Sindhu et al, 2019). There are three categories of biomass, namely:

a. Substrates of agricultural origin such as liquid fertilizer, feed waste, harvest waste, and energy crops;
b. Waste from private households and municipalities such as organic waste collected separately (in organic waste containers), market waste, expired food or food waste;
c. Industrial by-products such as glycerin, by-products from food processing, or waste from fat separators. Organic matter is converted into biogas by bacteria in several steps in an airtight digester. These bacteria are similar to those found in the stomachs of ruminants.

Like fossil natural gas, the main component of biogas that determines the energy content of the gas is flammable methane (CH_4). Depending on the digested substrate, the methane content of biogas fluctuates between 50% and 75%. Biogas is a mixture of several gases which is the result of the fermentation of organic matter under anaerobic conditions, which consists of a mixture of methane (50-75%), CO_2 (25-45%), and small amounts of H_2, N_2, and H_2S (Rambe et al., 2014).

Biogas is one of the alternative energy sources derived from biomass waste such as livestock manure, vegetable waste, fruit waste, and various other biomass sources. Various gas content contained in biogas is used by humans for their daily needs. The results of this biogas production can be used as a source of electrical energy generation and also as an alternative energy source to replace liquefied petroleum gas (LPG) for cooking needs. The greater the methane content of biogas, the greater the energy produced from the biogas.

3. 2 Stages of making biogas

In general, the biogas production procedure is carried out anaerobically and a series of complex material changes occur in it which consists of a four steps process, namely hydrolysis, acetogenesis, acidogenesis, and methanogenesis (Borja, 2011).

a. Hydrolysis
Hydrolysis is the first stage in biogas production. In this phase, insoluble compounds such as cellulose, protein, and fat which are complex biomass are broken down into monomers (water-soluble fragments) by exoenzymes (hydrolases) from facultative and obligate anaerobic bacteria (Deublein and Angelika, 2008). The bacteria that play a role in this hydrolysis process come from Proteobacteria (Deltaprobacteria, Gammaprobacteria), Clostridiales, Thermoanaerobacterial, Spirochaetales, and Tissierellia bacteria.
b. Acidogenesis
Acidogenesis is an advanced stage resulting from the hydrolysis stage by the action of acidogenic bacteria and fermentation. This stage leads to the formation of a mixture of organic acids, volatile fatty acids (VFA), alcohol, hydrogen, carbon dioxide,

ammonium, and others (Kumar, 2012). Simple sugars, amino acids, and fatty acids are degraded into acetate, carbon dioxide, hydrogen (70%), Volatile Fatty Acid (VFA), and alcohol (30%) (Megawati and Kendali, 2015). Bacteria that play a role in the process of acidogenesis are bacteria of the order Clostridiales, Petrotogales, and Bacilliales.

c. Acetogenesis
Acetogenesis is the stage of the transformation of acid produced from acidogenesis into acetate and carbon dioxide by the action of acetogenic bacteria (Kumar, 2012). VFA and alcohol are oxidized to methanogenic substrates such as acetate, hydrogen, and carbon dioxide. Hydrogen products increase the hydrogen partial pressure, this is considered a waste product of the acetogenesis process and inhibits the metabolism of acetogenic bacteria (Megawati and Kendali, 2015). Some of the bacteria that play a role in this acetogenesis process are Clostridia class bacteria such as Clostridium aceticum, natronincola, sporomusa ovata bacteria, and class 2 bacteria Holophagae.

d. Methanogenesis
Methanogenesis is the final stage of the biogas process, namely the transformation of acetate, hydrogen, and carbon dioxide into methane (Kumar, 2012). During methanogenesis, hydrogen is converted to methane. Methanogenesis is an important step in the whole process of anaerobic digestion because methanogenesis is the slowest biochemical reaction in the process. The process of methanogenesis is strongly influenced by operating conditions. Some examples that affect the methanogenesis process are the composition of raw materials, the ratio of food, temperature, and pH value. Digester overload, temperature changes, and the entry of large amounts of oxygen can result in the cessation of methane production (Megawati and Kendali, 2015). The bacteria that play a role in this methanogenesis process are bacteria of the order Methanobacteriales, Methanomicrobiales, Methanocellales.

3. 3 Factors influencing the production of biogas

Factors influencing the production of biogas, such as pretreatment process, substrate, temperature, pH, hydraulic retention time, C/N ratio, and microbial ecology.

a. Pretreatment Process
The pretreatment process can accelerate the degradation process of organic matter. Along with the acceleration of the degradation of organic matter, it will accelerate the biogas production process. Biomass containing lignocellulosic cannot be fermented in a biogas plant without pretreatment with heat or chemically.

There are so many types of pretreatment that can be done such as physical pretreatment, namely by reducing the size, heating the material, chemical pretreatment by adding chemical solution compounds, and biological pretreatment with the help of microorganisms. The advantages of pretreatment such as reduction of solids, deodorization, removal of pathogens, less energy use, and increase methane energy recovery (Mudhoo, 2012).

b. Substrate
The type and composition of the substrate directly affect the quality of the biogas produced. In the anaerobic process, measurements of COD and Total Volatile Solid are often carried out. Substrates with high water concentrations produce low yields of methane gas for COD and VS (Abbasi, 2012).

c. Temperature
The anaerobic digestion process is divided into several temperature conditions, such as psychrophiles (<20°C), mesophile (25-40°C), thermophile (46-60°C), and even in extra thermophile (>60°C) conditions (Kumar, 2012).

By increasing the temperature, it provides several advantages such as increasing the solubility of organic compounds that make them easily accessible to microorganisms, increasing the speed of chemical and biological reactions, increasing chemical-physical properties such as diffusivity of dissolved substrates, increasing the transfer rate of liquid to gas, accelerating the death rate of pathogenic bacteria and making a more energetic oxidation reaction at high temperature (Deublein, 2008).

d. pH
The pH level affects the activity of enzymes in microorganisms. The pH range accepted by the bacteria present in the process is 5.5 to 8.5 even though it is close to a neutral pH, increasing the possibility that methanogenic bacteria can function properly (Deublein, 2008).

e. Hydraulic Rentetion Time (HRT)
Hydraulic Retention Time is the average time used for the substrate to be in the digester (Deublein, 2008)

$$\boldsymbol{HRT} = \frac{\boldsymbol{V_R}}{\boldsymbol{V}} \qquad (1)$$

Where,
HRT = day
VR = digester volume (m^3)
V = feed volume per unit time (m^3/day)

f. C/N Ratio
The C/N ratio expresses the relationship between the amount of carbon and nitrogen in organic matter. A C/N ratio that is too low is at risk of inhibition by ammonia due to high nitrogen concentrations, a C/N ratio between 20-30 gives the best relative results (Zuliyana, 2015).

Ammonia is a source of nutrition for microorganisms but will be toxic to methanogenic microorganisms if there are high concentrations (Deublein, 2008).

g. Microbial ecology
The anaerobic digestion process requires a uniform rate of decomposition due to its sensitive

nature. If the hydrolysis process goes fast, acidification will occur and the pH will decrease so that the process will fail. Among the four processes, microbes in methanogenesis are the key to biogas production and are the most sensitive to changes in operating conditions during the production process (Deublein, 2008).

4. POTENTIAL RICE STRAW INTO BIOGAS

The existence of abundant rice straw and its utilization tends to be not optimal, namely, 36 – 62% is burned or returned to the ground as compost, 31 – 39% is for animal feed, and the remaining 7 – 16% is used for industrial purposes. Figure 1 shows a comparison of the potential emissions from open burning and anaerobic digestion of rice straw.

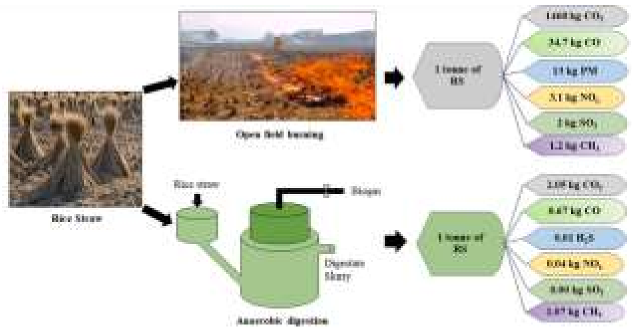

Fig. 1. Comparison of potential emissions from open burning and anaerobic (Kumar et al, 2021)

From Fig 1 it can be seen that the emissions from open combustion are much higher than that of anaerobic digestion. Although anaerobic digestion also has the potential to produce emissions, such as carbon monoxide (CO) gas. In the process of anaerobic digestion, CO is consumed and produced by bacteria methanogenic, acetogenic, and sulfate-reducing. This CO has formed abiotically from the substrate used in the anaerobic digestion process. In addition, this CO is also produced during the fermentation process of CH_4 and CO_2 from acetate.

Rice straw waste has the potential to be used as biogas through an anaerobic digestion process, as in the journal Dinuccio et al, (2010). The operating conditions used in this study are described in Table 3.

Table 3. Operating conditions of anaerobic digestion (Dinuccio et al, 2010)

Operating Conditions	
Temperature HRT	40 ± 2 °C
Biomass: Inoculum Ratio (digested slurry)	40 days
Temperature HRT	1:2
Size of rice straw	50-100 mm

Before the anaerobic process was carried out, and an analysis of the initial characteristics of rice straw was carried out. The characteristics of rice straw are described in Table 4.

Table 4. Characteristics of rice straw (Dinuccio et al, 2010)

Components	Value
pH	8.14
TS (%)	88.7
VS (% TS)	91.9
TN (% TS)	0.88
NDF (% TS)	78.4
ADF (% TS)	28
ADL (% TS)	8.33
HC (% TS)	50.4
CE (% TS)	19.6

* Notes: total solids (TS), volatile solids (VS), total nitrogen (TN), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), hemicelluloses (HC), and celluloses (CE).

In this study, the amount of methane was 195 L/Kg VS or 0,195 m^3/Kg VS.

In addition, to produce maximum methane, several methods were carried out, such as co-digestion and pretreatment. Shetty et al., (2016) has carried out the chemical pretreatment of rice straw. Table 5 showed the characteristics of the rice straw has used.

Table 5. Characteristics of rice straw (Shetty et al, 2016)

Components	Value
pH	7.5
TS (%)	90
VS (% TS)	77.5
TN (% TS)	0.56
ADL (%)	10
HC (%)	12
CE (%)	45

The operating conditions can be seen in Table 6.

Table 6. Operating conditions (Shetty et al, 2016)

Operating Conditions	
Temperature HRT	37°C
Biomass: Inoculum Ratio (cow dung)	40 days
Rice straw size	1:2
Temperature HRT	1 mm

Pretreatment was carried out, namely by soaking rice straw in 1% NaOH solution for 3 hours. Alkaline pretreatment degrades lignin by cleaving the side chains of esters and glucosides increasing the porosity of the substrate. This will increase the accessibility of the substrate to microbes and also reduce acetyl and some uronic acid substitutes, which are inhibitors of sugar degradation. In this study, the yield of methane was 303L/Kg VS.

In addition to pre-processing, another way to increase the yield of methane from straw is co-digestion. This method has been widely used, one of which is in the research journal Jingqing, Ye et al, (2013). The co-digestion of rice straw with kitchen waste and pig manure is carried out. Table 7 described the characteristics of the substrate and inoculum.

Table 7. Characteristics of substrate and inoculum (Jingqing Ye et al, 2013)

Characteristic	Unit	Digested sludge	Kitchen waste	Rice straw	Pig manure
Moisture content	%	95.72	79.77	6.28	72.84
Total solids (TS)	%(w)	4.28	20.23	93.72	27.16
Volatile solids (VS)	%(w)	2.95	18.16	83.18	20.12
VS/TS	%	69	90	89	74
pH	-	8.1	4.4	5.6	7.8
VFA	mg/L	2228	NA	NA	NA
$NH_4^+ - N$	mg/L	1668	NA	NA	NA
Lignin	%/TS	NA	NA	23.34	NA
Cellulose	%/TS	NA	NA	34.96	NA
TC	%/TS	NA	43.7	47	39.4
TN	%/TS	NA	3	1	2.3
C/N	–	NA	14.6	47	17.2
Calorific value	$kJ\ kg^{-1}TS$	NA	1.36×10^4	1.58×10^4	1.63×10^4

Anaerobic digestion was carried out in batches for 45 days at 37°C. The ratio of substrate and inoculum was varied. The results of this study obtained the optimum conditions at the ratio of KW/PM/RS = 0.4:1.6:1 with the amount of methane 383,9 L/Kg VS.

So, it can be concluded that the highest yield of methane was obtained by co-digestion. In addition, co-digestion is also considered to be more economical than pretreatment for lignocellulosic biomass. This is because co-digestion utilizes the diversity of bacteria and nutrients in some wastes to optimize the digestion process of rice straw.

5. CONCLUSION

Rice straw is a rice plant whose fruit (grain) has been taken, leaving only the stems and leaves which are the largest agricultural waste and have not been fully utilized due to technical and economic factors. Rice straw waste has the potential to be used as biogas through an anaerobic digestion process.

It can be concluded that the highest yield of methane was obtained by co-digestion. In addition, co-digestion is also considered to be more economical than pretreatment for lignocellulosic biomass. This is because co-digestion utilizes the diversity of bacteria and nutrients in some wastes to optimize the digestion process of rice straw.

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