



## Utilization of Organic Substrates for Biogas Production

Jeniffer Christeena Masih<sup>1</sup>, Sourabh<sup>2</sup>, Swati Sindhu<sup>1\*</sup> and R. C. Anand<sup>1</sup>

<sup>1</sup>Department of Microbiology, CCS Haryana Agricultural University, Hisar, Haryana, India.

<sup>2</sup>Department of Horticulture, CCS Haryana Agricultural University, Hisar, Haryana, India.

### Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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### ABSTRACT

**Problem:** The major problems in the present world include global warming and climate change which adversely affect the environment. There is, therefore, a need to reduce Green House Gas (GHG) emissions by replacing the fossil fuels with renewable energy resources like biogas. Biogas can be generated from various organic waste products or industrial byproducts and used as a renewable and ecofriendly fuel.

Biogas is also used to provide the energy requirements in rural areas while its byproduct can be used as manure for crop plants as highly rich in nutrients. Indirectly biogas production leads to waste reduction which may be hazardous for the public health. However, there are some obstacles in optimised biogas production. One major problem is limited availability of suitable organic substrates for biogas production.

**Objective:** Hence, there is a need for new proficient substrates which can improve or enhance the progress of the biogas industry all over the world. The performance of the anaerobic digestion processes is highly reliant on the feedstock characteristics as well as on the activity of the microorganisms involved in different degradation steps.

**Methodology:** The information related to various aspects of biogas production was retrieved from the several scientific databases such as Google Scholar, PubMed, Science Direct, Scopus, Medline,

\*Corresponding author: E-mail: [swati3357@gmail.com](mailto:swati3357@gmail.com);

and AGRICOLA, etc. here we include the data from ninety nine papers to compile this manuscript.  
**Summary:** This review presents an overview of the biogas production and discusses different possible organic substrates used for the biogas production which can be informative towards biogas economy.

*Keywords: Biogas; substrates; microorganisms; ecofriendly; organic waste; fermentation.*

## 1. INTRODUCTION

Biogas is produced by anaerobic digestion which involves the natural breakdown of organic matter in the absence of oxygen into a methane rich gas (biogas) via the complex and successive interactions of various kinds of microorganisms including hydrolytic, fermentative, acidogenic, and methanogenic bacteria [1]. It is the only process which can generate energy from wet material and provide a large part of energy needs [2]. Biogas is produced under strict anaerobic conditions by acting on biodegradable materials such as animal excreta, kitchen waste, sewage sludge, municipal solid waste, spice residues, market wastes, organic residues from food industry. It is an odourless and colourless gas that burns with clear blue flame similar to that of LPG gas [3]. Biogas generating plants have been in use from long times in England, India, Taiwan by using cow manure and municipal waste as a substrate. Experiments on biogas technology in India began in 1937. Floating drum type biogas plant known as Gobar Gas Plant was designed firstly by Jashu Bhai Patel in 1956 [4].

Agricultural residues represent the most important energy sources readily available in rural areas as plant residues normally have a high content of cellulose, which has combustion energy of 15 KJ/g. In different studies, many different agricultural wastes were used for the production of biogas. The application of anaerobically digested cow dung effluent improved the physiochemical properties of sandy soil [5]. The canteen residual wastes rich in organic constituents considered for biogas generation provided a high gas yield of 0.981 m<sup>3</sup>/kg volatile solids (VS) with a methane content of 50% [6]. Ranade et al. [7] studied anaerobic digestion of vegetable market waste in laboratory scale biogas plant of floating dome design and obtained maximum production rate of 17.5 l/d. Dhala and Rajor [8] reported that cabbage waste, with 5% cow dung, produce 8.5 l/d gas/kg dry weight with CH<sub>4</sub> content of 55%. Biogas production varies depending upon type of substrate, nutrient composition, Ph and CN ratio.

The carbon/nitrogen ratio (C:N) also affects the process of anaerobic degradation, C:N ratio (25-32:1) was observed to be favorable for anaerobic digestion [9]. At higher loading rate slurry being acidic which, negatively affected biogas production. Anaerobic digestion of rice straw alone is inefficient because of inefficient level of nutrients and minerals required for bacterial growth in rice straw. Rice straw can be mixed with other wastes to improve its digestion capacity by microbes during biogas production [10]. The digested slurry can be used as a manure and soil conditioner thus sustaining the crop yield without increasing the pollution due to excessive use of the chemical fertilisers. The objective of this review was to present an overview of the biogas production and discuss different possible organic substrates used for the biogas production.

## 2. MICROBIOLOGY OF BIOGAS PRODUCTION

Methanogenesis is the production of biogas (methane) by specific group of microorganisms known as methanogens. Organisms capable of producing methane have been identified only from the domain Archaea, a phylogenetically distinct group from both eukaryotes and bacteria, although many live in close association with anaerobic bacteria. The production of methane is an important and widespread form of microbial metabolism. In most environments, it is the final step in the decomposition of biomass. This process of anaerobic degradation requires a coordinated action of different groups of microorganisms with different metabolic capacities. The conversion of organic matters into biogas is divided in three different stages: hydrolysis, acid formation, and methane production. These different stages are collaborative in nature where the products of one stage microbes will be the substrates for another group. The process profits efficiently if the degradation rates of the different stages are in balance [11].

Methanogens share the properties of strict anaerobiosis and the ability to reduce carbon dioxide with molecular hydrogen to produce methane. Some have the additional properties of forming methane from simple substrates such as formate, methanol, methylamine or acetate [12]. Methanogenic bacteria influence the overall anaerobic metabolism of organic compounds towards complete dissimilation to methane and carbon dioxide. Anaerobic degradation of substrates tends to shift from the formation of hydrogen, carbon dioxide, and mixed organic end products to the formation of acetate, methane and carbon dioxide. The acetate formed may then be again converted by acetate utilising methanogens to produce more methane and carbon dioxide [13]. *Methanosarcina* commonly found in sewage sludge is also important methane producing bacterium. It has also been found in aquatic sediments and observed in large numbers in some mesophilic digesters [14]. Zeikus [15] concluded that at least three groups of bacteria viz. hydrolytic fermentative, syntrophic acetogenic and methanogenic bacteria are involved in the production of methane from wastes. Propionate degrading bacterium *Syntrophobacter wolinii* in co-culture with *Methanobacterium hungatei* has been reported from anaerobic sewage sludge digester [16]. According to Ramasamy [17] *Ruminococcus flavefacience*, *Eubacterium cellulosolvens* and *Clostridium cellulovorens*, *Clostridium thermocellum*, *Bacteroides cellulovorens*, and *Acetivibrio cellulolyticus* were some of the other important fermentative bacteria present in cattle dung fed anaerobic digesters. The pathways of methane formation, CO<sub>2</sub> fixation, and ATP synthesis are highly conserved among the different H<sub>2</sub> utilising (hydrogenotrophic) methanogens [18].

The methanogenic bacteria include *Methanobacterium*, *Methanobacillus*, *Methanococcus* and *Methanosarcina*. Methanogens can also be divided into two groups: acetate and H<sub>2</sub>/CO<sub>2</sub> consumers. *Methanosarcina* spp. and *Methanotherix* spp. (*Methanosaeta*) are considered to be important in both groups of anaerobic digestion. Kumar et al. [19] investigated the emission of methane. They concluded that it has more than 20 times the global warming potential of carbon dioxide and that the concentration of it in the atmosphere is increasing with one to two per cent per year. Thomsen et al. [20] found that increasing oxygen pressure during wet oxidation on the digested bio-

waste increased the total amount of methane yield.

Methane producing archaea naturally combine the processes of methanogenesis and autotrophic growth under highly variable conditions with respect to the supply and concentration of their energy source [21]. Kaparaju and Angelidaki [22] reported the use of *Methanosarcina* as inoculum for biogas production at 55°C. Demirel and Scherer [23] have reported that both acetotrophic and hydrogenotrophic methanogens are involved in conversion of particulate biomass to methane and these are essential for last step of methanogenesis. Victor et al. [24] showed that *Lactobacillus* can be used as a better enhancer for more biogas production with short term of period compared with control condition, though other tested organism of *E. coli* also act as a modest range enhancer of biogas production and utilising additives of these two bacterial strains as the experimental wastes for biogas production, it was observed that the tremendous biogas production takes place within a short period of time.

### 3. SUBSTRATES FOR BIOGAS PRODUCTION

There is a wide variety of substrates like animal wastes, agricultural wastes (crop residues, weed biomass), industrial wastes, municipal wastes and vegetable wastes that have been tried for biogas production. Mixed inoculum (dung and poultry wash) was found to be best for biomethanation.

Vegetable wastes generated largely in markets were disposed in municipal landfill or dumping sites [25]. To avoid all of these, vegetable wastes could be used as a good substrate for biogas production. Vegetable wastes due to high biodegradable nature and high moisture content (75-90%) seemed to be a good substrate for bio-energy recovery through anaerobic digestion process [26]. Pretreated sawdust and rice straw were found to be good substrates for biomethanation. Among different feed stocks, *Spirogyra* (algae), *Ipomea* and water hyacinth were most effective whereas *Jatropha gossypifolia* and *Parthenium* sp. were the least effective for biogas production [27]. Anaerobic digestion of organics will proceed best if the input material consists of roughly 8% solids [28]. The isolates from buffalo, pig and paper mill wastes appear to be most effective. According to [29] food waste

contained well balanced nutrients for anaerobic microorganisms.

### 3.1 Animal Wastes

Animal wastes need to be treated as a valuable resource which can be used as a basis for biogas production. Kumar and Biswas [30] reported that besides the cattle dung, excreta of other animals can also be used for biogas production. A mixture of coir pith and cattle waste at 3:2 ratio gave a better output of biogas among other combination with 80-85% methane content [31]. Nagamani and Ramasamy [32] studied biogas production from cattle dung at different temperatures and observed that although biogas production was higher at 55°C but the process was unstable due to higher production of volatile fatty acids and specific microbial consortia was needed for biomethanation. Desai and Madamwar [33] reported biogas production of 2.2 l/l/d from poultry waste, cattle dung and cheese waste mixed in ratio of 2:3:1 at loading rate of 6 g TS/l/d at 40°C. Broughton et al. [34] stated that anaerobic digestion of sheep tallow with high lipid content was amenable to mesophilic digestion in batch system. Magbanua et al. [35] reported higher yield of biogas (30-35 l/kg) from a mixture of poultry waste and hog waste (2:1 ratio) as compared to each waste alone. Al Masri [36] tried different combinations of sheep and goat waste and olive cake and obtained good biogas production with combination of sheep waste and olive cake. Carrasco et al. [37] studied the capability of dairy cow waste for biogas production and found that cow's wastes are more reactive than other animal's wastes suggested it as a good substrate over other animal wastes.

Yadvika et al. [38] reviewed the effect of retention time and temperature on biogas production from cattle dung using different techniques and reported 35 l/kg biogas at mesophilic temperature at a retention time of six weeks. Masse et al. [39] obtained good yield of methane from swine manure slurry and reported 0.23 l/kg of TS added within 5 weeks of digestion period at 35°C. Kalia and Kanwar [40] studied biogas production from different ratios of cattle dung and sheep droppings and reported maximum methane content from 25:75 (w/w) ratio of sheep dropping and cattle dung as compared to cattle dung alone. Llama and cow manure were tested for biogas production, yield was 49.6-131.3 litres CH<sub>4</sub>/kg VS and 35.6-84.1 litres CH<sub>4</sub>/kg VS at 35°C respectively. Llama manure is best substrate for biogas production

because of high VS, N and P [41]. Fernandez et al. [42] reported that fats from animal and vegetable origin were almost completely degraded in high percentage in co-digestion with simulated organic fraction of municipal solid waste, confirming that anaerobic digestion of lipids is possible.

Ojolo et al. [43] reported the average biogas production equal to 0.0318, 0.0230 and 0.0143dm<sup>3</sup>/day, respectively from a comparative study of poultry droppings, cow dung and kitchen wastes. It was concluded that the wastes can be managed through conversion into biogas. Different animal manures have different potential of methane production. Kusch et al. [44] studied biogas production by use of dung from horse stable straw bedding at mesophilic range of temperature, methane yield reported was 170 litres CH<sub>4</sub>/kg VS. In view of the needs for environmental management, waste recycling and alternative energy resources, there has been on-going work on biogas production with a locally fabricated digester in Akwa Ibom State of Nigeria. The first result exhibited that 0.032 m<sup>3</sup> of biogas was produced from 180 litres of poultry manure mixed with same volume of moisture in 16 days.

Using the same concentration of cow dung in a repeat experiment, 0.015 m<sup>3</sup> of biogas was produced in 7 days [45]. Sangeetha et al. [46] studied the biogas production from poultry waste and the mixture of poultry and fish waste. Fish wastes have high content of organic carbon and ammonia nitrogen for methane production and it was also found that the poultry wastes produced more biogas than poultry droppings.

### 3.2 Agricultural Wastes

Crop residues from farming represent a large unexploited energy potential that could be harnessed by the production of methane-rich biogas through anaerobic digestion. Hill and Roberts [47] using semi- continuous digesters, showed that methane production could be increased by adding chopped field crop residues, barley straw, rice hulls or rice straw to fresh dairy manure. Maximum gas production was observed with barley straw, followed by rice straw and methane generation was maximal when the ratio of non-lignin carbon to nitrogen ratio of these feed stocks was around 30:1. Ghosh and Das [48] studied anaerobic fermentation of mixture of water hyacinth, algae, cattle dung and untreated rice husk and reported that biogas was improved

and the biogas effluent was rich in N, P, and K as compared to cattle dung alone. Studies with various materials, such as crop straw, manure mixtures, delignified straw, cellulose and other agricultural substrates such as green leaves, grasses, apple wastes, animal wastes and oil cakes, have shown the potential substrates for biogas production [49].

Alkali treated (1% NaOH for 7 days) plant residues (lantana, wheat straw, apple leaf litter, peach leaf litter) when used as a supplement to cattle dung resulted in almost two fold increase in methane production [50]. Anaerobic digestion of a mixture of fruit and vegetable solid wastes was studied at laboratory scale, using digesters operated in the mesophilic range and biodegradation was achieved around 75% in two weeks [51]. Somayaji and Khanna [52] reported that addition of rice or wheat straw to cattle dung slurry increased daily gas production from 176 to 331 l/kg total solids with 100% rice straw and 194 l/kg total solids with 40% wheat straw. Sahota and Singh [53] reported that addition of rice husk soaked in water at 20% level to cattle dung digester increased gas production. Hutnam et al. [54] used sugar beet pulp for biogas production and reported 0.117 l/l/day biogas in 45 days. Parawira et al. [1] used solid potato waste alone and in combination with sugar beet leaves for biogas production and found that biogas production increased with increased concentration of potato waste.

Mahnert et al. [55] studied co-digestion of grasses with cattle slurry in 60:40 ratio and reported 75- 80% more biogas production with methane content 59-63% as compared to when used alone. Biogas production from ley crops sugar beet tops was studied by Svensson et al. [56] and reported high methane yield of gas with a generation of nitrogen rich slurry from that substrate. The C/N ratio is an important factor for anaerobic digestion and it varies from substrate to substrate. It was reported that C/N ratio of about 15 was recommended for treating the mixture of onion juice and aerobic sludge [57]. Diaz et al. [58] reported that the highest biogas producers were rice with inoculum of matooke (African bananas) and both these were rich in carbohydrates and less fats. Due to rich carbohydrates, they produced the highest biogas in their experiment because carbohydrates are rapidly digestible. Pang et al. [59] reported that there was 27.3-64.5% increase in biogas yield from rice straw during anaerobic digestion through pretreatment with 6% sodium hydroxide.

Ayu and Aryati [60] used cassava starch effluent as a substrate for biogas production with ruminant bacteria as biocatalyst using anaerobic digester in which the pH (6.8 to 7.2) was maintained to get maximum yield. Lei et al. [61] found that rice straw particles can be used as substrate along with acclimated sludge and different levels of phosphate under room temperature conditions. Adebayo et al. [62] reported that co-digestion of cattle slurry with maize stalks at ratios 3:1, 1:1 and 3:1 at mesophilic temperature gave biogas yields of 0.426, 0.385 and 0.391m<sup>3</sup>/kgoDM, respectively while the methane yields were 0.297, 0.270 and 0.262m<sup>3</sup> CH<sub>4</sub>/kgoDM, respectively. Chandratre et al. [63] analysed five agriculture wastes samples for biogas production at laboratory scale and observed that wheat stalk, soybean straw and black grams stalk has potential for bio-energy production. Legume straw of black gram, red gram and wheat stalk can act major sources of glucose and carbon as found to be high in total carbohydrate content in comparison to soybean straw and groundnut shells.

### 3.3 Industrial Wastes

A number of industrial wastes are available for anaerobic digestion. Balasubramanya et al. [64] developed a batch fermentation method to process this type of material for the production of biogas. The willow dust treated with sodium hydroxide (1% w/w) and inoculated with slurry from anaerobically digested willow-dust followed by fermentation reported the production of 17 m<sup>3</sup> biogas from 100 kg capacity biogas plant in one month. Boopathy et al. [65] reported 55-60% methane production using distillery wastewater (3.5 g COD/l/d) and found that the performance of the experimental unit was as good as with those of other types of reactors treating organic waste waters. Ranade et al. [66] reported biogas production of 35l/kg in 20 days of hydraulic retention time with 48% reduction in VS from waste of biscuit and chocolate industry.

Borja et al. [67] carried out anaerobic digestion of waste from wine distillery in semi-continuous, well- stirred fermentor with microorganisms immobilised on sepiolite support. Substrate concentration equal to or lower than 3.6 g COD/l within the reactor resulted in a methane production rate that was first-order with respect to biodegradable substrate concentration. The apparent rate constant was proportional to the volatile suspended solids concentration and product yield coefficient was 0.285 litres CH<sub>4</sub>/g

COD. Joseph and Sharda [68] studied effect of organic feeding rate on biogas production from tomato processing waste. They reported increased biogas production from 0.42 m<sup>3</sup>/kg of volatile solids (VS) added as organic feeding rate increased from 0.5 to 2.9 kg of VS/m<sup>3</sup>/d. The anaerobic digestion of distillery waste has become an attractive method for its management. In India, the amount of distillery waste generated in urban areas ranged from 400-600 g per capita/d as reported by Metcalf [69] that biogas production of 30 litres g/kg COD from sea food processing industry with average 60-65% methane content. A good yield of biogas (19 m<sup>3</sup>/kg) with 52-55% methane from spent tea leaves was reported by Ergurder et al. [70].

Ahmed et al. [71] reported gas production of 2.02 l/l/d at an organic loading rate of 12.6 g COD/l/d from waste palm oil mill processing system at a temperature of 55°C in 35 days of retention time. Choorit and Wisarwan [72] studied anaerobic digestion of palm oil mill of effluent at different temperatures and reported gas production 3.73 l/l/d with methane content of 69.53% at 55°C. Bayret al. [73] studied anaerobic digestion of two groups of industrial by-products, slaughter house and rendering wastes, and pulp and paper industry wastewater sludge which found to be feasible. The methane yields of 170–240 dm<sup>3</sup> kgVSfed<sup>-1</sup> were obtained from the pulp and paper mill wastewater sludge. Dere et al. [74] suggested cotton waste as a good substrate for biogas production.

### 3.4 Municipal Wastes

Municipal solid wastes such as fruit and vegetable wastes, leaf litter, paddy straw, cane bagasse, cane trash and paper are generated in large quantities and their use for biogas production has become a major interest of waste management worldwide. The study of anaerobic digestion of a mixture of paper, kitchen food waste and sewage sludge at pilot scale was conducted by Oleszkiewick and Hector [75] and biogas production of 140 m<sup>3</sup>/ton of TS was reported. Converti et al. [76] studied biogas production from the mixture of sewage sludge and hydrolysed agricultural wastes and reported 5.6 mmol/dm<sup>3</sup> methane at an organic loading rate of 4.6 g COD m<sup>3</sup>/d. Volumetric biogas production about 0.35 l/l/d from municipal solid wastes in a batch fermenter reactor in 35 days time at 46°C was reported by Nouike and Mizuno [77]. Rani [78] studied biogas production from dairy effluent and reported that 0.25 m<sup>3</sup> biogas/g

of TS added with 60-65% methane content at 35 days retention time at ambient temperature.

Murphy and Keogh [79] used municipal wastes to generate CH<sub>4</sub> enriched biogas and utilised the gas for combined heat and power generation and for transport fuel. The addition of iron hydroxide and iron-reducing bacteria into a reactor for anaerobic processing of sulfate-containing waste water was shown to decrease sulfate reduction and sulfide concentration, while increasing the total organic carbon and methane production [80]. Igoni et al. [81] studied the effect of total solids concentration of municipal solid waste on the biogas production in an anaerobic continuous digester and reported the total solid (TS) concentration of the waste influence the pH, temperature and effectiveness of the microorganism's decomposition process. Elango et al. [82] reported enhanced biogas production by addition of domestic sewage to municipal solid waste. The maximum biogas production of 0.36 m<sup>3</sup>/kg/d was observed at the organic feeding rate of 2.9 kg VS/m<sup>3</sup>/d. The maximum reduction of total solids was 87.6 and 88.1% respectively with methane content 68-72%. Ferrer et al. [83] investigated the effect of a low temperature pre-treatment (70°C) on the efficiency of thermophilic anaerobic digestion of primary and secondary waste sludge. Biogas production increased up to 30% both in batch tests and in semi-continuous experiments.

Sagagi et al. [84] studied biogas production from fruits and vegetables waste materials and their impact on plants as fertiliser. It has been observed that the highest weekly individual production rate is recorded for the cow dung (control) slurry with average production of (1554 cm<sup>3</sup>), followed by pineapple waste (965 cm<sup>3</sup>) and orange waste (612 cm<sup>3</sup>). All the substrates were found to be good materials for biogas production and their spent slurries can be used as a manure for plants. According to Voegeli et al. [85] the methane in biogas produced from food waste was 56.8%. Azlina et al. [86] used leachate from municipal waste as feed into one litre digester which was carried out in batch mode and the amount of biogas detected was 1.2 to 1.5 ml/ml leachate/day. Ofoefule et al. [87] created a difference in anaerobic digestion by using paper waste with the blend of cow dung. Retention period of 43 days were used and the amount of biogas produced was 9.34 dm<sup>3</sup>/kg slurry. Retention time selected was twenty days for the digestion to take place. Food waste from both domestic and commercial sources has been

targeted for biogas production because of its high biochemical methane potential [88]. Imasuen et al. [89] carried out anaerobic digestion of fresh maize leaves at mesophilic temperature ( $28 \pm 2^\circ\text{C}$ ) for a period of 20 days. The digester with 1:5 biomass: Water mix had significantly high performance compared to others and a maximum of 520 ml biogas was obtained. Banks et al. [90] reported that the stable digestion is possible at the high ammonia concentrations associated with food waste by selective trace element addition and suggested that on-farm co-digestion of source segregated domestic food waste was the most effective means of making cattle slurry digestion economically viable, with associated benefits in greenhouse gas reduction and nutrient management. Rico et al. [91] observed that methane potential of sludge samples was influenced by solid waste content. Sludge samples from fat separator reached specific methane productivities of 350 and 388 L CH<sub>4</sub> kg<sup>-1</sup> VS (10.5 and 24.1 L CH<sub>4</sub> kg<sup>-1</sup> sludge), while biological sludge yielded only 125 L CH<sub>4</sub> kg<sup>-1</sup> VS (12.6 L CH<sub>4</sub> kg<sup>-1</sup> sludge). Mehta et al. [92] characterised compost, paddy soil, landfill waste and kitchen waste to develop the microbial inoculum for the improvement in biogas production from cattle dung under semi-continuous digestion system. The maximum biogas production (144.2 litres) was observed on supplementation of cattle dung with kitchen waste and no increase with supplementation of paddy soil. Dere et al. [74] evaluated biogas production from different organic wastes and observed that kitchen waste has high calorific and nutritive value to methane producing microbes and resulted in enhanced methane production. Ravi Agrahari and Tiwari [93] also observed that the kitchen waste is the best alternative for biogas production in a community level biogas plant.

#### 4. DIFFERENT STIMULANTS AS SUBSTRATA

Different stimulants were also used along with organic substrates for the biogas production. Vikram et al. [94] studied the effect of several salts, FeCl<sub>3</sub>, NiCl<sub>2</sub>, CoCl<sub>2</sub>, CuCl<sub>2</sub>, and ZnCl<sub>2</sub>, on anaerobic digestion of water hyacinth-cattle dung. Among the salts studied, FeCl<sub>3</sub> caused a more than 60% increase in gas production with a high methane content. Preeti Rao et al. [95] observed that when 50 mM FeSO<sub>4</sub> was added to cow dung and poultry litter waste which were processed in daily-fed batch digesters, digesters

subsequently unfed showed a faster conversion of substrate and overloaded digesters stabilised within 48 h. Early stabilisation of digesters was achieved by adding 20 or 50 mM FeSO<sub>4</sub> though the latter concentration was faster. Ghosh and Bhattacharyya [96] studied the biomethanation of white and brown rotted rice straw and tested their efficiency. Rice straw was treated with white rot fungus *Phanerochaete chrysosporium* (PC) and brown rot fungus *Polyporus ostreiformis* (PO). VFA (Volatile Fatty Acid) production also increased in PC and PO treated straw compared to control straw which were 76.73 and 30.69%, respectively. Reduction of COD was also been found during biomethanation. The rate of reduction of COD during the initial period of digestion was 59.01, 55.55 and 26.00% in PC-treated, PO-treated and control straw, respectively after 21 days of digestion.

Vidhya et al. [97] attempted to study the effect of caffeine and saponin on anaerobic fermentation of food waste to examine their potential influence on biogas production at 8% total solids (TS) content. Addition of caffeine at 50, 100, and 150 ppm to the food waste on the first day resulted in biogas production in 24 hours which normally comes on 4<sup>th</sup> day. Ranjeet et al. [98] studied the collected inocula from four different sources such as Jajmau tannery waste (ITW) treatment plant, Jajmau municipal waste treatment (IMW), Unnao distillery (IDW) and a batch reactor, in which the sludge of a field scale biogas reactor was added to cow dung slurry to develop inoculum (IBS). According to Getachew and Berhanu [99] the fruit wastes are ideal candidates for anaerobic digestion because they contain high levels of easily biodegradable materials.

#### 5. CONCLUSIONS

Biogas production by using microbes provides an ecofriendly approach of renewable energy production. The production of biogas is largely depends to a largely depends on the nature and cost of the substrate. Substrate selection is a critical factor in determination of biogas production. So, its selection is an important step which results in enhancement of biogas production. Organic substrates like agricultural wastes, municipal, industrial wastes are proving cheap and easily available substrates they can enhance the biogas production and quality along with the reduction of hazardous waste products. The purpose of this review is to overview of biogas production from different type of organic waste products which can be informative toward biogas economy.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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