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Review Article

A review on waste-to-energy by anaerobic digestion: A sustainable approach for the agriculture waste management and energy production

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Abstract

To manage enormous amounts of lignocellulosic waste and meet the world's energy demand. The production of biogas from agricultural wastes represents an efficient and sustainable option. Lignocellulosic biomass is a renewable, environmentally friendly, and sustainable source of biofuels that has the potential to replace fossil fuels. In order to generate biogas, lignocellulosic biomass must be treated for recalcitrance due to the presence of cellulose and hemicellulose, and to its crystallinity, which minimizes the availability of fermentable sugars. To reduce the complexity of lignocellulosic biomass and for enhancing the yield, various pre-treatment is required. This review comprises the harmful effect of agriculture waste, the types of agriculture waste generated, and its utilization for energy production by using the pre-treatment technique.

Keywords: Agriculture waste; Waste management; biogas production; Lignocellulosic biomass; pre-treatment

1. Introduction

The human population has grown four times just in the past century. In order to feed the expanding population, there is ongoing pressure on food production, which is partly the consequence of improved agricultural and industrial processes (Turmel et al., 2015). Air pollution caused by agriculture waste and from conventional fossil fuel are two major problems in current scenario. Despite tremendous socioeconomic and technical advancement, about one-fourth of people worldwide still utilize conventional fuels for residential consumption, such as natural gas, kerosene, biomass waste, firewood, coal, and animal dung. Conventional energy sources adversely harm the environment as, it produce numerous forms of pollution. There are several factors supporting a huge interest in renewable energy and a shift away from traditional energy sources in the modern world. Conventional energy sources have several drawbacks mentioned above as well as some others are dependence on fossil fuel, wasted heat, high oil prices and once exhausted, do not replenish themselves. Thus there is a need to identify alternative energy sources before all of the fossil fuel stocks are exhausted since fossil fuel reserves are being exploited quickly to meet the rising energy demands. Apart from conventional sources of energy, solid waste also contributes to harm and degrade the environment. Each year, enormous amounts of agricultural waste are produced due to extensive production of agriculture crops and livestock (Gadde et al., 2009). If waste biomasses are not managed properly, then these wastes may cause many serious environmental issues. Agriculture wastes were traditionally burned or left in the fields, however burning of wastes causes major soil and air pollution. For the disposal of agricultural residues, several methods have been used (Iqbal et al., 2020). The agriculture residue is contained high amount of silica which is not suitable to feed the animals. Therefore, proper disposal of these wastes are very crucial. Waste to energy (WTE) is a promising alternative energy source that is both environmentally and economically sustainable. In order to utilize waste to produce energy, anaerobic digestion (AD) is supposed to be one of the worthwhile and cost effective techniques. Anaerobic digestion is a biological process that decomposes organic material without the use of oxygen to generate biogas, which is predominantly composed of methane. Microorganisms play a key role in the digestion, which includes processes like acidogenesis, methanogenesis, and hydrolysis. This review comprises the problems caused by agriculture residue and sustainable approach for its management and energy production.

2. Types of Agriculture waste and its utilization for energy production by anaerobic digestion

Due to rapid urbanization and industrialization huge amount of agriculture waste generated to fulfill the surging demand of people. Wastes produced by agriculture are referred to as agricultural wastes. They are produced through a variety of processes and activities as raw materials, byproducts, or finished goods. The materials are considered waste and dumped because it can no longer be utilized.

2.1 Crop residues

The world's food supply is mostly dependent on agricultural produce. Modern farming techniques and the cultivation of crop types with high yields were sparked by the growth in the human population. Although the production of food grains increased, so did the production of crop residues such as stalks, stubbles, leaves, seed pods, etc (Prasad et al., 2020). In rural areas, crop residues are utilized as animal feed and cooking fuel, however a sizeable portion of the crop residues are still left on the field or farm. Disposing of crop residues appropriately is a major challenge (Kumar et al., 2016; Prasad et al., 2020). Therefore anaerobic digestion is supposed to be a cost-effective and easy way to optimize crop waste biomass. Crop residues are hard to digest due to recalcitrant structure thus prior anaerobic digestion of crop residues pre-treatment is required. The complexity of crop residues is reduced by different pre-treatment methods.

2.2 Fruit waste

The Food and Agriculture Organization of the United Nations reports that the global production of fruits reached one billion tonnes in 2017, (Lucarini et al., 2021). Production and consumption of fruit produces fruit waste in large amount. According to reports, one of the main causes of the generation of fruit waste is fruit injury, bruising, and over-ripening during fruit transport and storage. The huge amount of fruit consumption generates enormous amount of waste which is a part of municipal solid waste and generally disposed to a landfill. Anaerobic biological techniques can be used to transform fruit waste into biogas in order to make use of this invaluable natural resource. Zeynali et al. (2017) investigated the methane yield of fruit and vegetables waste were 396 mL/g VS. The AD of fruit and vegetable waste is recommended as the best waste management method since it will minimize the amount of garbage going to the landfill, produces energy in the form of biogas, and it has a positive economic impact (Morales-polo et al., 2019).

2.3 Agriculture processing waste

In 2018, there was a roughly USD 974 billion global demand for packaging. Asia had the biggest demand, with 40%, followed by North America with 21% (Essuman et al., 2018). Food packaging plays a significant functions in the preservation and protection of food during production, transportation and storage. If the packing is inadequate or destroyed mechanically, food can be damaged physiologically, chemically, and physically. Packaging also serves as a vital marketing and communication tool for consumers. It's crucial to discover more environmentally friendly substitutes because of the issue of microplastics polluting the environment on a global scale as well as the vast amounts of food waste and by-products produced by the food industry (Bayram et al., 2021).

2.4 Animal waste

Environmental effects of livestock production and waste management are a growing subject of public and economic concern (Innes, 2000). Methane and pathogen emissions, as well as nutrient runoff to water bodies, are all caused by livestock waste (manure), which has a negative impact on the air and water quality and eventually cause eutrophication, algal blooms and hypoxia. One of the primary factors affecting water quality is nutrient pollution (Sampat et al., 2018). Animal manure and other waste materials with an organic composition can be used as feedstocks for waste-to-bioenergy conversion processes, enabling farmer's access to new markets for their current waste products. Consequently, the treatment of livestock manure has the potential to change from a liability or cost component into a profit center (Cantrell et al., 2008). Livestock waste-to-energy (WTE) is a special kind of energy source that can be used to meet the world's present energy needs as well as to contribute with the current issues with waste management (Owusu and Banadda, 2017). The animal waste degraded effortlessly during anaerobic digestion; therefore, no pre-treatment will be required. Anaerobic digestion of livestock waste is a cost effective technique which has potential to fulfill the surging demand of energy and optimize the animal waste.

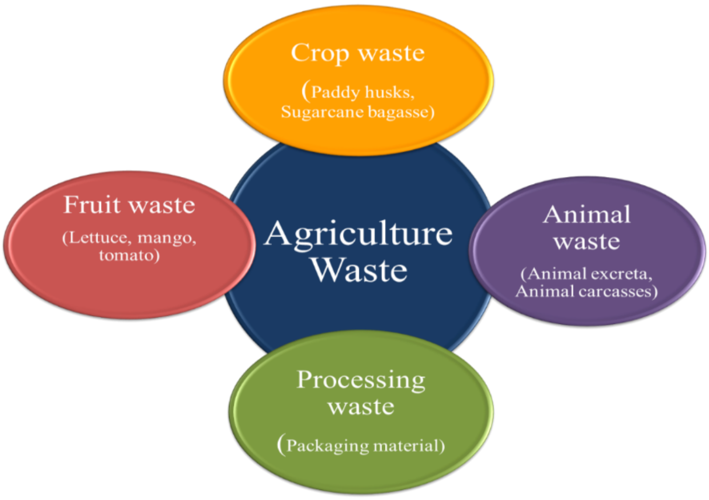

Fig. 1. Types of agriculture waste

3. Composition of agriculture waste

Agriculture waste mainly referred to as lignocellulosic biomass and is made up of complex molecules including cellulose, hemicellulose, lignin and certain extractives, primarily protein and soluble carbohydrates (Fu et al., 2021). In general, cellulose dominates hemicellulose and lignin in agricultural wastes. A polysaccharide called cellulose is made of a long chain of glucose molecules joined together by (1–4) glycosidic linkages. A macromolecule with a lower molecular weight than cellulose called hemicellulose contains many sugars including xylose, mannose, galactose, rhamnose, and arabinose (Momayez et al., 2019). The most complex component of lignocellulose is lignin, an amorphous three-dimensional biopolymer formed by the disordered polymerization of phenyl propane monomers replaced with methoxy or hydroxy groups (Ma et al., 2019). Lignin incorporates cellulose and hemicellulose by crosslinking through covalent and hydrogen bonds to produce "Lignin-Carbohydrate Complexes," which are hydrophobic three-dimensional structures (LCC) (Rodriguez et al., 2017; Hu et al., 2016). The amount of biomass in lignocellulosic material affects how easily it can be broken down. High lignin materials have low digestibility and high hydraulic retention time, whereas high sugar materials have low hydraulic retention time and high digestibility (Awogbemi and Kallon, 2022)

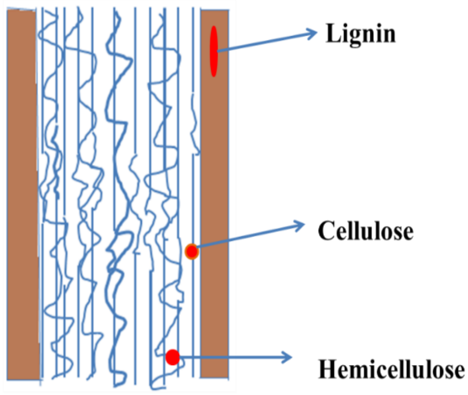

Fig. 2. Structure of lignocellulose

4. Pre-treatment of agriculture waste to reduce the recalcitrant structure

4.1 Various types of pre-treatment for lignocellulosic biomass

It is difficult to convert biomass during anaerobic digestion because of the complicated structure of lignocellulose, which prohibits microbes from efficiently digesting plant cell walls (Kanaujia and Singh, 2022). Lignin is found in lignocelluloses which form a protective barrier that inhibits fungus and bacteria from destroying plant cells for use as fuel. The breakdown of cellulose and hemicellulose into their respective monomers (sugars), which microbes may use, is necessary for the conversion of biomass to fuel (Kumar et al., 2009). Therefore, pre-treatment is required to reduce the complexity of lignocellulosic biomass for anaerobic digestion. Physical, chemical, biological, and combined pre-treatment are the major types of pre-treatment methods that can be used. Table 1 shows the methane yield of different types of agriculture waste by applying various pre-treatment methods.

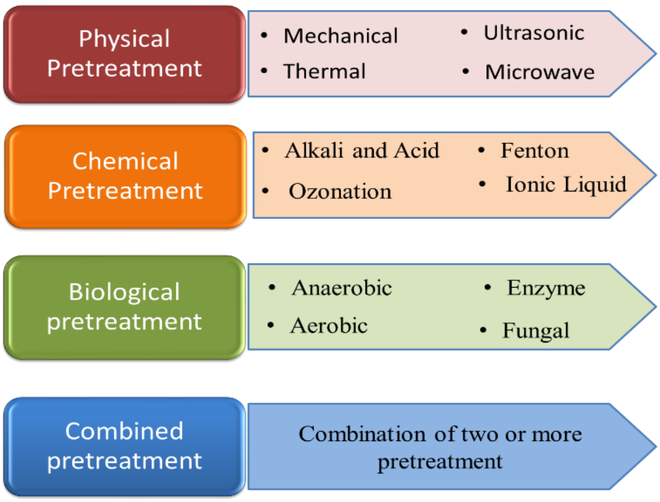

Fig. 3 Different types of pre-treatment methods

4.1.1 Physical Pre-treatment

Physical pre-treatment includes mechanical, ultrasonic, thermal, and microwave pre-treatments (Amin et al., 2017). Physical preparation that alters the biomass's specific surface area, particle sizes, crystallinity index, or degree of polymerization. Since, no chemicals are used during physical pre-treatment, less waste and reaction inhibitors are produced (Je̜drzejczyk et al., 2019). The structure of lignocellulosic structures can be partially destroyed by grinding (size reduction). The effects of grinding directly influence the degree of polymerization, porosity, surface area and reduced the substrate's crystallinity and its surface area (Kainthola et al., 2019). Mechanical pre-treatment is among the physical pre-treatments that are frequently used for waste materials, including agricultural residues and residues generated from the forestry (Amin et al., 2017). Dai et al. (2019) reported that particle size decrease might facilitate hydrolysis more effectively. Mshandete et al. (2006) suggested that particle size reduction stimulates substrate usage, which results in improved biogas production. In physical pre-treatment, ultrasonic pre-treatment is quite effective. Ultrasonic pre-treatment enhanced the delignification of lignocellulose, which may improve hydrolysis yield of cellulose (Bussemaker and Zhang, 2013).

4.1.2 Chemical Pre-treatment

Chemical pre-treatment is the process of modifying the physical and chemical properties of lignocellulosic biomass using chemicals like acids, bases, and ionic liquids (Zhen et al., 2014). A successful biological conversion of lignocellulosic biomass into biofuels or biochemicals required chemical pre-treatment. High lignin concentration and lignocellulosic biomass resistant characteristics are key factors affecting bioconversion for effective pre-treatment, especially as lignin is known to be effectively solubilized by alkaline solutions (Bharadwaj et al., 2022). The part is subdivided into four major groups: ionic liquid pre-treatment, ozonation, Fenton process, alkali and acidic pre-treatments (Atelge et al., 2020). There have been reports that some chemicals, including acids, alkalis, organic solvents, and ionic liquids, significantly alter the native structure of lignocellulosic biomass (Agbor et al., 2011).

Table 1 Utilization of different types of agriculture waste by anaerobic digestion at various conditions

Substrate	Condition	Yield	References
Rice straw	Pretreated with white rot fungi	240 L/Kg VS	Lianhua et al. (2010)
Mixed fruit and vegetable waste	Digester of 200 liter at ambient temp. (27-31˚C)	0.387 L CH_4/g VS	Sitorus et al. (2013)
Wheat straw	Wheat straw pretreated with 1% urea	305.5 L/Kg VS	Yao et al. (2017)
Cow dung	Diluted cow dung with tap water with ratio 1:1	0.15 L/Kg VS_{added}	Abubakar and Ismail. (2012)
Rice straw	Pre-treatment of 4% of H_2O_2	327.5 ml/g VS	Song et al. (2012)
Corn Stover	Pretreated by 4%CH3COOH, at 25°C for 7 days	145.1 mL/g VS	Song et al.(2014)
Sunflower straw	Hydrothermal pre-treatment at 180°C for 60 min	406.9 mL/g VS	Hashemi et al. (2019)

4.1.3 Biological Pre-treatment

In anaerobic digestion, fungal, microbial consortia, and enzymatic pre-treatment have received a lot of attention in the biological pre-treatment process to increase biogas generation (Zheng et al., 2014). The microbial degradation of lignin in fungus has been extensively investigated, whereas bacteria have received very less attention (Mishra et al., 2018). Microorganism used in biological pre-treatment disrupts lignocellulose extracellularly by secreting hydrolases (Sharma et al., 2019). White-rot fungi are recognized as the most effective among all fungal strains used to produce biogas from lignocellulosic biomass (Sun and Cheng, 2002). Biological pre-treatment, which is controlled by microorganisms and/or enzymes, is carried out under moderate environments (around ambient temperature and pressure), demanding less energy and chemical input and producing less inhibitor. However, some features of biological pre-treatment still need to be improved to make it a viable alternative to thermochemical pre-treatment, including incubation duration and overall effectiveness (i.e., sugar yield).

4.1.4 Combined Pre-treatment

A combination of two or more pre-treatment methods is designed to overcome the numerous drawbacks of single pre-treatment methods, combining pre-treatment techniques results in higher sugar production efficiency, a shorter processing time, and less inhibitor formation (Mood et al., 2013). Over the past few years, a number of combinations have been used to pre-treatment of lignocellulosic biomass. Combining two or more pre-treatment techniques was proven to be more successful than using just one (Kumari and Singh, 2018). Pre-treatment techniques that combine physical and chemical characteristics are most frequently used. This combined pre-treatment can accomplish the objective of mutually trying to make up for the imperfection and subsequently improving the pre-treatment effectiveness (Yu et al., 2019).

5. Conclusion

The huge amount of agriculture waste produced which adversely effected the environment. Utilization of agriculture waste through anaerobic digestion is a promising technique. It optimizes the waste in sustainable way. Agriculture waste is hard to digest due to complex structure of biomass. Therefore, pre-treatment is significant part of anaerobic digestion of biomass. According to a study of the literature on pre-treatments for agricultural biomass, the success of pre-treatment depends on the properties of feedstocks, particularly the proportions of lignocellulosic biomass. A harsher pre-treatment, such as alkali, thermal, and thermochemical techniques, is needed for larger amounts of lignocelluloses. If these techniques are not used correctly, they could have adverse effects on anaerobic digestion. Proper anaerobic digestion of agriculture waste is a profitable option in order to manage huge amount of waste and producing energy from the waste biomasses.

Author contribution

Nikita Kanaujia: Conceptualization, Writing – original draft. Jiwan Singh: Supervision, review & editing.

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Conflict of Interest

The author declare, there is no conflict of interest between them.

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