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Role of Green Nanotechnology to Manage the Agricultural and Food Waste via Advanced Anaerobic Digestion Technology

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ABSTRACT

Energy crisis and environmental pollution are serious problems of sustainable development in the world. The problem is acute in developing economies like India, where there is significant pressure on available natural sources of energy. One of effective approaches to solve these energy problems is developing biomass energy such as biogas and biofuel. Biogas production is a well-established conversion technology i.e., anaerobic digestion, to obtain energy from biomass that is alternative to fossil fuel. Nanotechnology can contribute to the improvement of biogas production through the use of nanocatalysts. These catalysts can enhance bioconversion strategies, facilitate better breakdown of substrates, and optimize output delivery. Generally, nanoparticles can be prepared through a variety of chemical and physical methods, some of which can be expensive and potentially hazardous to the environment. These methods often involve the use of toxic chemicals that pose various biological risks. This may be the reason for the increasing interest in the biosynthesis of nanoparticles through a green route, which avoids the use of toxic chemicals. Such environment friendly processes are gaining momentum. Therefore, in this article, the green synthesized plant derived various metal nanoparticles which can be used for enhancement of biogas production from cattle dung, will be discussed.

Keywords Anaerobic digestion, Bioconversion, biogas, Fossil fuel, Nanoparticles.

INTRODUCTION

In recent years, we are facing several problems due to the growing energy demands diminishing supplies of fossil fuels and global warming. The problem is particularly severe in developing economies like India, where there is significant pressure on the available natural sources of energy. Meeting the daily life requirements in such circumstances is a critical challenge, there is an urgent need to search an alternative fuel which is renewable, cost effective, eco-friendly and has fewer greenhouse gases emission (Malik and Sangwan 2012). Biogas production is a well-established method conversion technology

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i.e., anaerobic digestion (AD) to obtain energy from biomass that is alternative to fossil fuel (Wang *et al.* 2016). Anaerobic digestion (AD) is widely recognized as one of the most important techniques for converting organic wastes into renewable energy in the form of methane carbon dioxide and other trace element (Holm-Nielsen *et al.* 2009, Feng *et al.* 2014). In this context, nanotechnology has gained significant potential with a wide range of technological, chemical, and engineering applications. Nanoparticles (NPs) hold commercial value due to their versatile physico-chemical properties. Different NPs such as metal NPs, nanofibers, nanotubes and nanosheets have been reported for using in biofuel production (Adelere and Lateef 2016). Nanotechnology has vital potential to achieve low cost and more efficient process for biofuel production. Nanomaterials have been developed to enhance biofuel production by harnessing their unique properties. It has played a crucial role in the design, synthesis, and characterization of various new energy materials and catalysts for bioenergy and biofuel production from renewable resources. NPs are prepared/synthesized by different methods viz., physical, chemical and biological. Physical and chemical methods are costly and produced toxic chemicals which are hazardous to the environment and responsible for various biological risks. In this context, the biological methods are potential for the synthesis of NPs in the ecofriendly manner by using nanotechnological approaches. Nanoparticles (NPs) possess multifunctional properties and find interesting applications in various fields including medicine, nutrition, and energy (Chandran *et al.* 2006). NPs biostimulate the methanogenic archea and increase their activity (Abdelsalam *et al.* 2016). Use of biological agents such as microorganisms, plant extract or plant biomass could be an alternative to chemical and physical methods for the eco-friendly production of nanoparticles (NPs) (Mohanpuria *et al.* 2008). In recent years, synthesis of metallic NPs like iron, silver, gold, copper, titanium, platinum, zinc and thallium has wide range of applications due to easily reproducible, large surface area, easily available. Biologically synthesized NPs process is called green synthesis concept with some challenges in the process. Therefore, it is dire need to search biological methods which could be an alternative of traditional chemical and physical methods for the biosynthesis and production of metal nanomaterials in a safe, clean, non-toxic and eco-friendly process. Green biosynthesis of NPs is low cost, easy to reproduce, easily available, environmentally friendly, non-toxic and can easily be produced commercially. These green synthesized NPs act as reducing, capping and stabilizing agents as compared to physical and chemical method which are expansive and release the toxic compound that have negative effects on the human health and environments. Biosynthesis of NPs using plants could be providing more compatible NPs than traditionally synthesized methods that might have undesirable effects in industrial products. (Veeramanikandan *et al.* 2017) Plant-derived biologically synthesized nanoparticles (NPs) have gained significant importance in recent times. This is because plant extracts contain abundant natural compounds, including alkaloids, flavonoids, saponins, steroids, tannins, and other nutritional compounds.

These compounds are obtained from various parts of plants, including leaves, stems, roots, shoots, flowers, barks, and seeds. They serve as both reducing and stabilizing agents in the bio-reduction reaction for the synthesis of metallic nanoparticles (NPs). Plants have been successfully utilized in the synthesis of various environmentally friendly nanoparticles, such as iron, cobalt, copper, silver, gold, palladium, platinum, zinc oxide, and magnetite (Mohamed and Nageh 2015). Green synthesis is not only able to reduce environmental impact but attractive enough if they are intended for invasive applications in bioenergy and biofuel production. It can be efficient alternative to produce large quantities of NPs that are easy, eco-friendly, non-toxic, simpler and less expensive. NPs that are easy, eco-friendly, non-toxic, simpler and less expensive methods for synthesis of NPs which have lesser detrimental effects on health and environment. Currently, iron based NPs have gained more interest due to cost effective, easily available and their properties possessed are similar to the other metallic NPs (Mody *et al.* 2010). *Azadirachta indica,* commonly known as neem, nimtree, or Indian lilac, is a tree belonging to the family Meliaceae. It is native to the Indian sub-continent, i.e. India, Nepal, Pakistan, Bangladesh, Sri Lanka and Maldives. It is typically grown in tropical and semi-tropical regions. It has contained various phytochemicals such as

carbohydrates, alkaloids, steroids, phenols, saponins and flavonoids (Kumar *et al.* 2017). The bioreduction of silver NPs from *Azadirachta indica* is a green synthesis method that exhibited a good antibacterial activity. The advantage of using neem leaves for the bioreduction of metal ions is the easy availability of neem leaves throughout the year. Similarly, Murraya koenigii, commonly known as curry tree, sweet neem, kadipatta, or curry vepila, is a tropical to sub-tropical tree in the family Rutaceae that is native to India. It has an antioxidant activity due to high concentrations of carbazoles, a water-soluble heterocyclic compound (Rai *et al.* 2008) which acts as a stabilizing agent and reducing agent for the reduction of metal ions. Green synthesis of iron oxide NPs were extracted from *Phyllanthus niruri* leaves and characterized by different techniques (VG and Prem 2018).

The use of iron NPs has proven attractive due to the NPs' abundance, non-toxicity and cost effectiveness. The addition of iron nanoparticles (NPs) as an additive or catalyst to a co-digestion system can significantly increase biogas production and enhance chemical oxygen demand removal compared to the control. This leads to an increase in the microbial activity of the co-digestion system compared to the control (Joo *et al.* 2018). Impact of synthesized iron oxide and titanium dioxide NPs on biogas production was studied by Farghali *et al.* (2019). Many attempts have been made by scientists for generation of biogas from different lignocellulosic plant materials and many researches are being done for enhancement of biogas production using plant derived NPs some of which will be discussed in this article.

Anaerobic digestion

The world is facing several problems due to growing energy demands and depletion of fossil fuels resources. There is a dire need to explore cost effective and renewable energy sources. In these regards, biogas is an alternative and sustainable source of energy, that could be used as a low-cost fuel and produced through anaerobic digestion (AD) of organic matter such as animal manure (cattle dung), sewage, and municipal solid waste. Anaerobic digestion is highly interesting, as it can replace fossil fuels in power and heat generation and used as feedstock for production of various value-added products (Weiland 2010). Anaerobic digestion of organic materials to biogas is a complex microbiological process which requires the combined activity of several groups of microorganisms with different metabolic capacities and growth requirements. To achieve a stable and efficient biogas production process, it is essential to fulfill the growth requirements of all microorganisms involved. In this regard, nanotechnology can play a crucial role in enhancing biogas production. By utilizing nanocatalysts, it can ensure more efficient bioconversion strategies, improve substrate breakdown, and optimize the delivery of output (Chandran *et al.* 2006). The use of biological agents such as microorganisms, plant extracts, and plant biomass provides an eco-friendly alternative to chemical and physical methods for the production of nanoparticles (NPs) (Mohanpuria *et al.* 2008).

Plant-derived nanostructures and nanoparticles (NPs) have diverse functional applications in various fields such as energy, healthcare, food and feed, cosmetics, biomedical science, drug-gene delivery, and environmental health. It is essential for researchers to recognize that plants serve as cost-effective, sustainable, and renewable platforms, making them ideal sources for the production of natural nanoparticles (Adelere and Lateef 2016). The green synthesis of nanoparticles (NPs) offers several advantages over chemical and physical methods. It is a safe, simple, and cost-effective approach that often yields more stable materials. Additionally, green synthesis does not require high temperatures, pH levels, energy inputs, pressure, or the use of toxic chemicals (Forough and Farhad 2011, Ahmed *et al.* 2016). Plants have been successfully utilized in the synthesis of various environmentally friendly nanoparticles (NPs) including cobalt, copper, silver, gold, palladium, platinum, zinc oxide, and magnetite (Mohamed *et al.* 2015). Some organic materials can serve as the sole substrate for digestion, while others require co-digestion with complementary substrates to create favorable conditions for microbial growth (Mata-Alverez *et al.* 2014). However, the addition of additives such as iron, trace metals, or buffering chemicals may be necessary in specific processes to maintain adequate microbial activity and prevent process collapse (Romero- Guriza *et al.* 2016). Now days, a large number of plant

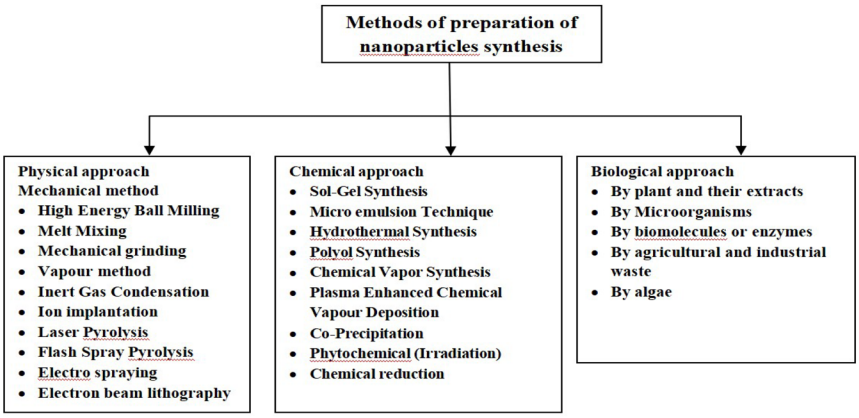

Fig. 1. Overview on different type of synthesis methods to produce variety of nanoparticles..

extracts are used for NPs synthesis.

Synthesis of nanoparticles

NPs, which have unique properties due to their size, distribution, and morphology, are critical components of any nanotechnology. Currently, various physical, chemical, biological methods are used for synthesize of variety of nanoparticles (Fig. 1) (Dhand *et al.* 2015).

Advantages of plant based nanoparticles

Plant-based synthesis of NPs is in contrast faster, safer and lighter; works at low temperatures; and requires only modest and environmentally safe components. Plant-based NPs have gained significant attention due to the increasing interest in environmentally conscious products. In addition, the synthesis of nanoparticles (NPs) using plants offers various other advantages. These include the use of safer solvents,

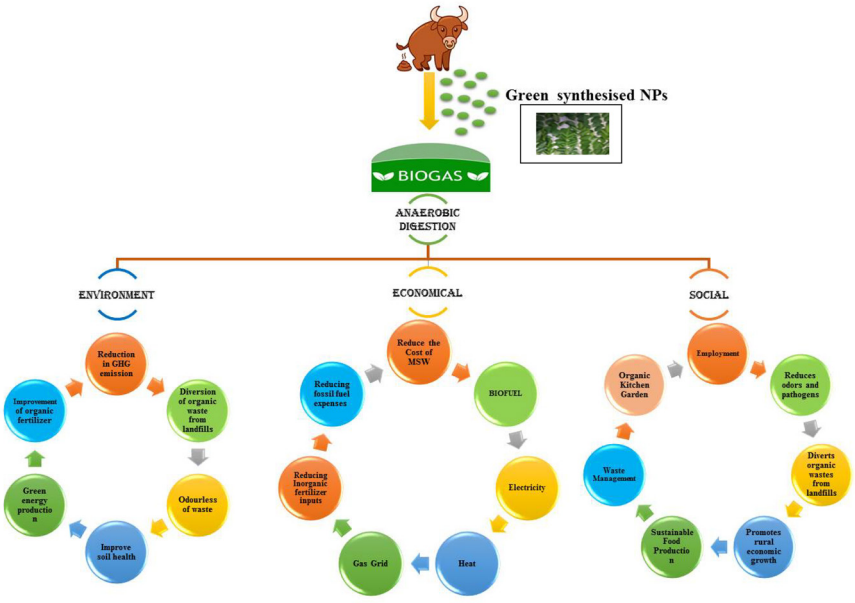

Fig. 2. Advantages of green synthesized NPs.

Table 1. Studies showing effect of different metal nanoparticles on waste management.

Sl. No.	Substrate	NPs	Experimental conditions	Interpretation	Reference
1	Municipal solid waste + Cow dung	ZnO	15-60 mg/kg ZnO NPs+250 ml batch digestor, 60 days at 35 ± 2 °C	ZnO showed inhibitory effect on microbial richness anaerobic digestion of the municipal solid waste.	Eduok *et al.* (2015)
2	Organic waste	Fe_3O_4	100ppm Fe_3O_4 (7 nm), 60 days at 37^0C	Methane content and biogas production increased by 234% and 180% respectively as Fe plays a vital role in electron transport, methane and hydrogen production rates increase and bacterial growth was stimulated by enzymatic action.	Ma *et al.* (2015)
3	Seed sludge from beer industry	IONPs	IONPs and multiwall carbon nanotubes, 96 h	IONPs at concentration of 750 mg/L and MWCNTs at concentration of 1500 mg/L induced faster substrate utilization and biogas production rates than the control	Ambuchi *et al.* (2016)
4	Organic fraction of the municipal solid waste e.g. food waste	Fe_3O_4	50 mg/l, 75 mg/l, 100 mg/l, and 125mg/l at 37 ± 0.5°C	Iron oxide nanoparticles at 75mg/l yielded maximum methane content.	Ali *et al.* (2017)
5	Anaerobic digestion process of digested slurry	$CoCl_2$, and $NiCl_2$	0.5, 1.0, and 2.0 mgl^{-1} concentrations of Co and Ni	The addition of 1.0 mg l^{-1} cobalt and 2.0 mg l^{-1} nickle nanoparticles significantly increased the biogas production by 1.64 and 1.74 times and methane yields by 1.86 and 2.01 times as compared to the control, respectively.	Abdelsalam *et al.* (2017)
6	Anaerobic digestion of the Cattle dung	IONPs	Various concentration of IONPs (9, 12, 15, 18, 21 mg/L)	Methane and Biogas production increased by 25.5% and 27.6%, respectively at 18 mg/L IONPs as compared control.	Singh *et al*. (2022)

reduced reliance on hazardous reagents, milder reaction conditions, feasibility, and their adaptability for medicinal, surgical, and pharmaceutical applications (Fig. 2).

Application of nanoparticles in biogas production

The application of nanoparticles in biogas production is significant. Anaerobic digestion is recognized as a crucial process for converting organic waste into valuable by-products. This biogas is suitable for energy production, aiding in the replacement of fossil fuels.Various attempts have been made to enhance biogas production by stimulating microbial activity using different biological additives under optimized conditions. In this direction, different NPs were used as an additive for biogas production. NPs are ideal in a diversity of areas such as energy, agriculture, medical, electronic and commercial products due to their unique physico-chemical characteristics (e.g., size, specific surface area, surface structure, solubility and catalytic properties). Although there are many

chemical and physical methods also produce pure, well-defined NPs successfully but their methods were potentially dangerous to the environment and quite extensive. Use of plant extracts can be an economically viable alternative to physical and chemical method for the preparation and production of NPs in an eco-friendly manner. There are many studies in which effect of green synthesized metal NPs on anaerobic digestion of cattle dung has been reported which are shown in Table 1.

CONCLUSION

The supplementation of cattle dung with plant-based metal nanoparticles has shown to enhance biogas and methane production, particularly during both summer and winter seasons. Green-synthesized iron nanoparticles have demonstrated the capability to effectively biostimulate methanogenic bacteria, thereby increasing their activity and promoting enhanced biogas production.

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