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Research Article

Substitute Biogas Source for Sustainable Energy Generation: Advances in Insects Employment

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Abstract

The growing need for sustainable energy generation has sparked interest in exploring alternative biogas sources. In recent years, insects have emerged as a promising substitute for traditional feedstocks in biogas production due to their high protein and lipid content, rapid growth rate, and low environmental impact. This literature review aims to provide an overview of the advances in insect employment for sustainable energy generation. It presents a comprehensive analysis of the existing literature, highlighting the potential of insects as viable and renewable biogas sources, the challenges associated with insect rearing and processing, and the technological innovations in optimizing their utilization. The review also discusses the economic viability and environmental benefits of employing insects in biogas production and future research directions in this emerging field. The nutrient content of fermentable or biodegradable organic materials will serve as an ingredient in the production of biogas/biomethane. Nutrient-rich insect frass will eliminate the need for co-digestion with another feedstock, as previously examined. Currently, insect waste is not a familiar feedstock for biogas production, as its first utilization dates back to 2018, when 177-225 mL/g TS of biomethane was realized.

1. Introduction

Hitherto, hundreds of biodegradable matters have been explored for centuries to address energy deficits, with much significance attached to the possible reduction/elimination of greenhouse gas emissions via the anaerobic digestion technique. Erstwhile exploitation of these fermentable materials is still and all, not limited to sustainable energy and cleaner energy production alternative alone, but a major strategy to manage them when they eventually become waste. This is in addition to new feedstock discoveries such as fish wastes, placenta, urine, blood, pharmaceutical waste, press mud, mushroom, and insect breeding waste. In 2018, the first research on biogas generation from silkworm residue was carried out, which set the stage for future work [1]. Moreover, the efficacy of high-quantity bioenergy production using biogas lies in the ability of the feedstock taken to yield a considerable amount of gas that can be converted. Elissen, et al. [2] confirm that mono-digestion of insect frass (faeces from insects' larvae) will produce an enormous amount of methane/biogas.

Energy, fat, vitamins, minerals, and proteins required by anaerobic microorganisms to convert bio-degradable materials to biogas are also inherent in insects [3, 4]. Common examples that can be obtained in large numbers are houseflies, mealworms, crickets, termites, black soldier flies, grasshoppers, locusts, ants, cockroaches, and honey bees [5, 6]. According to literature, more than 75% of all animal species humans are familiar with are insects (> 1 million species) – out of which >2100 are edible (especially in Asia) [3]. Their roles in the eco-system are pollinating flowers, biological control, fertilizer production, food waste recycling, bioconversion of organic materials (e.g., faecal sludge), and some plastics [6-8]. Specifically, polypropylene, polystyrene, polylactic butadiene-styrene elastomer (SBR) rubber, polyethylene, and polyurethane can be consumed by Tenebrio molitor insect [9]. However, biowaste conversion using insects is considered more environmentally friendly than composting [5]. Insects also can destroy planted crops and stored grains. Apart from insecticides, about 3000 existing essential oils (biopesticides) have reportedly been utilized to control pests feeding on stored farm produce [10].

The increasing global demand for sustainable energy sources and the need to address environmental concerns have led to exploring alternative feedstocks for biogas production. Biogas, a renewable energy source primarily composed of methane (CH_4) and carbon dioxide (CO_2), is traditionally produced from organic materials such as agricultural residues, food waste, and sewage sludge. However, the availability and sustainability of these conventional feedstocks have become major concerns, necessitating the search for novel and sustainable alternatives. The primary objective of this literature review is to analyze and consolidate the existing research on the utilization of insects as a substitute biogas source for sustainable energy generation. By examining the scientific literature and relevant studies, this review provides a comprehensive overview of the advances, challenges, economic viability, environmental benefits, and prospects of employing insects in biogas production processes. This literature review focuses on recent studies conducted between 2010 and 2023, encompassing the latest field developments. The review covers various topics related to insects as biogas feedstock, including their nutritional composition, rapid growth, and reproduction, environmental benefits, challenges in rearing and processing, technological innovations, economic viability, market potential, environmental sustainability, and future research directions. The review structure follows a logical progression, highlighting key aspects and providing insights into the potential of insects as sustainable biogas sources.

2. Insects as Biogas Feedstock

Insects are rich in proteins, lipids, and other essential nutrients, making them a valuable alternative to conventional feedstocks for biogas production. Different insect species exhibit variations in their nutritional profiles, providing opportunities for tailored biogas production based on specific requirements and objectives. One of the key advantages of using insects as biogas feedstock is their rapid growth rate and high reproductive capacity. Insects have short life cycles and efficient conversion rates, enabling a continuous and sustainable biomass supply for biogas production. The utilization of insects in biogas production offers several environmental benefits. Insects can reduce organic waste, mitigate greenhouse gas emissions, and alleviate pressure on landfill sites. Additionally, insects require less land, water, and resources than conventional feedstocks, making them more environmentally sustainable.

2.1. Challenges in Insect Rearing and Processing

Selecting suitable insect species for biogas production involves considering factors such as nutritional content, growth rate, substrate preferences, and compatibility with the biogas production process. Various insect species, including black soldier fly (*Hermetia illucens*), mealworm (*Tenebrio molitor*), and cricket (*Acheta domesticus*), have shown promise in this regard. Efficient mass-rearing techniques are crucial for successfully integrating insects in biogas production. The development of scalable and cost-effective methods for insect rearing, including artificial diets, breeding systems, and optimal environmental conditions, poses challenges that require further research and optimization. The harvesting and processing of insects for biogas production involve various techniques, such as separation, drying, and fractionation. Each step presents its own challenges, including energy consumption, scalability, and the preservation of nutrient content. Addressing quality control and safety issues is crucial to guarantee the suitability of insects for biogas production. Factors such as contaminants, pathogens, and pesticide residues in the insect biomass must be carefully monitored and managed to maintain the integrity of the biogas production process and ensure the safety of the resulting biogas.

2.2. Technological Innovations in Insect Utilization

Pretreatment techniques play a vital role in enhancing insect biomass's digestibility and biogas yield. Mechanical, thermal, chemical, and biological pretreatment methods have been investigated to break down the complex structure of insects and improve their biodegradability. Various anaerobic digestion processes, including batch, continuous, and two-stage systems, have been explored for biogas production from insect biomass. Optimizing process parameters such as temperature, retention time, pH, and substrate concentration can enhance methane production and overall process efficiency. Co-digestion, combining different feedstocks, offers opportunities to optimize biogas production using insects. By co-digesting insect biomass with other organic materials, such as crop residues or food waste, synergistic effects can be achieved, improving biogas yield and nutrient recycling. The concept of insect biorefineries, where multiple valuable products are extracted from insects, is gaining traction. Biorefinery approaches aim to utilize biomass for biogas production and other valuable components such as proteins, lipids, chitin, and bioactive compounds, thereby maximizing insect-based systems' economic value and sustainability.

2.3. Viability of Biogas Production from Insect Frass

Availability and sustainability are not issues during biogas realization from insects, as they are found in all terrestrial habitats in the world and all climate zones [6]. Sampling as a monitoring technique can be used to determine the geographical spread of pests, especially in a continent like Europe, where its industry is multiplying [3, 11, 12]. Modes of its rearing include commercial big scale, large laboratory or small commercial scale and small laboratory scale as categorized by Halloran, et al. [6]. Lochynska and Frankowski [1] reported that, small-scale farmers may produce 250-300 kg of silkworm waste. Remains from fried grasshopper preparation for consumption in North-Eastern Nigeria is produced in large amount and might be an untapped bioenergy resource. Normally, insect breeding, spawns wastes (insect faeces mixed with feed remains) whose methane potential is identical to yields from manures, sewage sludge, and fruit and vegetable wastes [3].

Notably, under mesophilic conditions, silkworm waste generates 489.24 m^3/Mg TS of biogas, while silkworm excreta generates 331.97 m^3/Mg TS of biogas, according to a study conducted by Lochynska and Frankowski [1]. Black soldier fly larvae (*Hermetia illucens*), *Tenebrio molitor*, and *Gryllus spp*. Breeding wastes at initial pH of 7±0.2 and 37±1℃ has a biomethane potential of 177, 212, and 225 mL/g TS, respectively as reported by Bulak, et al. [3] after its experimentation in a 500 mL bioreactor. In another experiment carried out by Wedwitschka, et al. [13], anaerobic digestion of *Hermetia illucens* yielded 167±15 mL/gVS of specific methane. Once more, a high yield of biogas can be expected from *Hermetia illucens*, as exemplified in a study conducted by Yu, et al. [14], Win, et al. [15] and Zheng, et al. [16]. Correspondingly, according to Hol, et al. [17], adding *Hermetia illucens* larvae frass to cattle slurry biodigester will not lead to an increase in biogas production, but replacing cattle slurry with insect frass was observed to increase the volume of biogas generated.

3. Discussion

Based on the reviewed research, the following topics need to be carefully examined:

3.1. Economic Viability and Market Potential

The economic viability of insect-based biogas production depends on various factors, including insect-rearing costs, biomass conversion efficiency, market demand for biogas, and policy support. Cost analyses and economic feasibility studies are necessary to assess the competitiveness of insect-based systems compared to conventional feedstocks. Public perception, regulatory frameworks, and developing a sustainable insect supply chain influence the market potential for insect-based biogas production. Identifying niche markets, exploring co-products, and establishing collaborations among stakeholders can contribute to the commercialization and scalability of insect-based biogas systems. Effective policy support and regulatory frameworks play a crucial role in facilitating the adoption of insect-based biogas production. Policy incentives, research funding, waste management regulations, and sustainability certifications can provide the necessary impetus for the development and growth of the insect-based biogas industry.

3.2. Environmental Sustainability

Using insects in biogas production reduces organic waste, diverting it from landfills and minimizing methane emissions, a potent greenhouse gas. This waste-to-energy approach aligns with circular economy principles and promotes a more sustainable waste management system. Compared to conventional feedstocks, insects have a smaller ecological footprint due to their lower water and land requirements. Insect-based biogas production offers opportunities for resource-efficient systems, particularly in regions with limited water availability or land constraints. Insects possess the potential to facilitate a circular economy approach by converting organic waste into valuable biogas and co-products. Extracting proteins, lipids, chitin, and other valuable compounds from insects can contribute to developing a sustainable and resource-efficient bio-economy. By integrating insects into biogas production, valuable resources can be recovered, creating opportunities to produce animal feed, fertilizers, pharmaceuticals, and other high-value products.

4. Future Research Directions

Research focusing on the genetic improvement of insect species used as biogas feedstocks can enhance their growth rate, nutrient composition, and resistance to diseases and environmental stressors. Genetic selection, breeding programs, and genetic engineering techniques offer potential avenues for developing optimized insect strains for biogas production. Further research is needed to optimize insect rearing and processing techniques for higher biomass yields, improved cost-effectiveness, and enhanced nutrient retention. This includes exploring automated and scalable systems, identifying efficient and sustainable insect diets, and optimizing processing methods to minimize energy consumption and maximize resource recovery. Investigating the integration of insects into broader waste management systems is crucial. This involves assessing the compatibility of insect-based biogas production with existing waste treatment infrastructure and waste collection logistics and understanding the potential synergies and trade-offs between different waste management approaches. Comprehensive life cycle assessment (LCA) studies are needed to evaluate the environmental impacts of insect-based biogas production systems compared to conventional feedstocks. LCA can provide insights into resource use, energy consumption, greenhouse gas emissions, and other environmental indicators, enabling informed decision-making and policy development.

By conducting a thorough literature review, this paper aims to provide researchers, policymakers, and industry stakeholders with an up-to-date understanding of the advancements, challenges, and opportunities associated with employing insects as a substitute biogas source. The integration of insects in the biogas production can contribute significantly to sustainable energy generation, waste management, and the transition to a more circular economy. Further research and collaboration are essential to unlock the full potential of insects as a valuable resource for the renewable energy sector.

5. Conclusions

Insect waste utilization for sustainable energy generation through biogas production is gradually gaining recognition. Currently, *Tenebrio molitor*, *Gryllus spp*., silkworm waste, and *Hermetia illucens*, remain the few insects targeted previously for biogas/bioenergy generation, per the scope of the literature consulted. The study also demonstrates that insects, particularly black soldier fly larvae, have great potential as a sustainable material for biogas production. The results demonstrate that, despite appearing to be a challenging endeavor, attention must be devoted to breeding or rearing specific or various types of insects nature has provided to provide a significant number of feedstock for bioenergy generation. Unlike some feedstocks that must be co-digested to supplement missing nutrients for microorganisms' consumption, insect frass contains all the required nutrients. Future work might be interested in harnessing wastes from around 2100 edible insect species to supplement or use solely as an alternative bioenergy source.

Insects have emerged as a promising substitute biogas source for sustainable energy generation. Their high nutritional content, rapid growth rate, and low environmental impact make them an attractive alternative to conventional feedstocks. However, several challenges remain, including insect species selection, mass-rearing techniques, harvesting and processing methods, quality control, and safety considerations. Technological innovations, such as pretreatment methods and biorefinery concepts, offer opportunities to optimize insect utilization [18]. The economic viability and market potential of insect-based biogas production depend on factors such as cost-effectiveness, market opportunities, and policy support.

Furthermore, the environmental sustainability of insect-based systems contributes to organic waste reduction, resource efficiency, and the transition to a circular economy. Future research directions should focus on genetic enhancement, optimization of rearing and processing techniques, integration in waste management systems, and comprehensive environmental assessments. By addressing these challenges and advancing research in this field, insects can play a significant role in future sustainable energy generation and waste management systems.

Declaration of Competing Interest: The authors declare that they have no known competing of interest.

References

[1] M. Lochynska and J. Frankowski, "The biogas production potential from silkworm waste," Waste Management, vol. 79, pp. 564-570, 2018.

[2] H. Elissen, S. Hol, and R. van der Weide, "Methane production from insect, worm and mushroom waste streams and combinations," Stichting Wageningen Research, Wageningen Plant Research, Business Unit …2019.

[3] P. Bulak, K. Proc, M. Pawłowska, A. Kasprzycka, W. Berus, and A. Bieganowski, "Biogas generation from insects breeding post production wastes," Journal of Cleaner Production, vol. 244, p. 118777, 2020.

[4] I. G. Lopes, J. W. Yong, and C. Lalander, "Frass derived from black soldier fly larvae treatment of biodegradable wastes. A critical review and future perspectives," Waste Management, vol. 142, pp. 65-76, 2022.

[5] P. Adhikari, N. Aryal, A. Ghimire, and P. Khanal, "Sustainable biowaste recycling using insects," in Clean Energy and Resources Recovery: Elsevier, 2021, pp. 399-420.

[6] A. Halloran, R. Flore, P. Vantomme, and N. Roos, Edible insects in sustainable food systems. Springer, 2018.

[7] C. Lalander, S. Diener, M. E. Magri, C. Zurbrügg, A. Lindström, and B. Vinnerås, "Faecal sludge management with the larvae of the black soldier fly (Hermetia illucens)—From a hygiene aspect," Science of the Total Environment, vol. 458, pp. 312-318, 2013.

[8] T. T. Nguyen, J. K. Tomberlin, and S. Vanlaerhoven, "Ability of black soldier fly (Diptera: Stratiomyidae) larvae to recycle food waste," Environmental entomology, vol. 44, no. 2, pp. 406-410, 2015.

[9] P. Bulak, K. Proc, A. Pytlak, A. Puszka, B. Gawdzik, and A. Bieganowski, "Biodegradation of different types of plastics by tenebrio molitor insect," Polymers, vol. 13, no. 20, p. 3508, 2021.

[10] D. Dey and M. K. Gupta, "Use of essential oils for insect pest management-A review," Innovative Farming-An International Journal of Agriculture, vol. 1, no. 2, pp. 21-29, 2016.

[11] D. Dent and R. H. Binks, Insect pest management. Cabi, 2020.

[12] Y. Weinreis, C. M. Baum, and S. Smetana, "Insect production as a novel alternative to livestock farming: Exploring interest and willingness to adopt among German farmers," Sustainable Production and Consumption, vol. 35, pp. 28-39, 2023.

[13] H. Wedwitschka, D. Gallegos Ibanez, and D. R. Jáquez, "Biogas production from residues of industrial insect protein production from black soldier fly larvae Hermetia illucens (L.): An evaluation of different insect frass samples," Processes, vol. 11, no. 2, p. 362, 2023.

[14] Y. Yu, S. Wu, Y. Wu, and J. Zhang, "Biogas production from black soldier fly larvae and its frass: A review," Renewable and Sustainable Energy Reviews, vol. 134, no. 110248, 2020.

[15] S. S. Win, J. H. Ebner, S. A. Brownell, S. S. Pagano, P. Cruz-Diloné, and T. A. Trabold, "Anaerobic digestion of black solider fly larvae (BSFL) biomass as part of an integrated biorefinery," Renewable energy, vol. 127, pp. 705-712, 2018.

[16] L. Zheng, Y. Hou, W. Li, G. Yang, and Q. Li, "Biogas production from food waste by black soldier fly larvae (Hermetia illucens) and the improvement in biogas production from waste activated sludge," Waste Management, vol. 96, pp. 189-195, 2019.

[17] S. Hol, H. Elissen, and R. van der Weide, "Combined digestion of insect frass and cow manure for biogas production," Stichting Wageningen Research, Wageningen Plant Research, Business unit Open 2022.

[18] A. A. Siyal, R. Shamsuddin, M. Komiyama, M. D. Manogaran, and T. Soehartanto, "Control Strategies for Enhanced Biogas Production from Chicken Manure," ChemBioEng Reviews, 2023.