An Overview on the Emerging Role of Insects in the Circular Economy of India

Sunil Kamlakar Anand
Department of Zoology, J.S.M. College, Alibag

***Abstract*—The circular economy is increasingly recognized as a sustainable development model that emphasizes efficient resource utilization and waste reduction. In India, insects are gaining attention for their potential to advance circular economy practices by delivering ecological services and economic benefits in waste management, agriculture, and food security. This review analyses the emerging contributions of insects to India's circular economy, focusing on their roles in organic waste recycling, bio-conversion processes, and as alternative protein sources. The paper synthesizes recent research and field applications, addresses current challenges and future prospects, and proposes strategies for incorporating insect-based solutions into India's sustainability agenda. This overview aims to inform policymakers, researchers, and industry stakeholders about the potential of insects to strengthen India's sustainable and resource conscious circular economy.**

***Index Terms*—Circular Economy, Insects, India, Organic Waste Management, Sustainable Agriculture, Bio-conversion, Alternative Protein, Resource Recycling.**

I. INTRODUCTION

India is facing serious environmental and resource challenges due to rapid population growth, urbanization, and expanding industrial and agricultural activities. The traditional linear economic model where resources are extracted, used, and then discarded has led to high levels of waste, resource depletion, pollution, and greenhouse gas emissions. These problems underline the need for sustainable development approaches that reduce environmental impact while supporting economic progress.

The circular economy (CE) offers a practical alternative to this linear system. It aims to minimize waste, improve resource efficiency, and restore natural ecosystems by promoting recycling, reuse, and material recovery (Geissdoerfer et al., 2017). Since India's waste is largely organic, adopting circular economy principles can greatly enhance sustainable waste handling and resource recovery.

Insects are increasingly being recognized as effective biological agents that can help achieve circular economy goals. India's diverse insect species, favorable climate, and large amounts of agricultural residues and organic waste create ideal conditions for insect-based solutions. Many insects can convert organic waste into useful products such as protein rich biomass, organic fertilizers, and other bio-resources (Kumar et al., 2021).

Species like black soldier fly larvae (Hermetia illucens), mealworms (Tenebrio molitor), crickets, and earthworms are particularly efficient in waste conversion, nutrient recycling, and producing sustainable feed and food (Makkar et al., 2014; Surendra et al., 2016). These organisms not only reduce waste but also generate economic benefits, making them well suited for circular economy systems.

Concerns about the environmental impact of conventional livestock have increased interest in alternative protein sources. Edible insects are considered sustainable because they need less land, water, and feed, and produce fewer greenhouse gases compared to traditional livestock (Van Huis et al., 2013; Halloran et al., 2017). In India, some tribal and rural communities traditionally consume insects, but this practice is not common in mainstream diets.

Although research and pilot projects show promise, large scale adoption of insect based circular economy practices in India is still limited. Key challenges include unclear regulations, technological gaps, weak market development, and low social acceptance (Shah et al., 2021). Overcoming these barriers is

essential to fully realize the potential of insects in promoting sustainable development.

This paper provides a comprehensive overview of the emerging role of insects in India's circular economy by reviewing current research, applications, and policy considerations. It highlights key benefits, identifies challenges, and suggests possible pathways for integrating insect-based solutions into India's sustainability agenda.

II. MATERIALS AND METHODS

This study is based on a detailed review of existing literature related to insect-based applications in circular economy systems. A systematic search was conducted using academic databases such as Scopus, Web of Science, and Google Scholar. Publications from 2010 to 2023 were considered to include recent developments and emerging trends.

Search terms included combinations of keywords such as "insects," "circular economy," "India," "organic waste management," "bio-conversion," "vermiproducts," "entomophagy," and "sustainable agriculture." The review included peer-reviewed journal articles, government reports, institutional publications, conference papers, and documented case studies.

Studies focusing on insect mediated waste recycling, nutrient recovery, soil improvement, alternative protein production, and relevant policy frameworks were prioritised. The collected information was analysed qualitatively to identify major themes, benefits, challenges, and policy implications. A multidisciplinary approach combining environmental science, entomology, agriculture, and socio-economic perspectives was adopted to provide a comprehensive understanding.

III. RESULTS AND DISCUSSION

India produces large amounts of biodegradable waste from households, markets, farms, and food industries. Poor disposal practices lead to growing landfills, methane emissions, and pollution. Insects, especially black soldier fly larvae (BSFL), offer an effective solution for managing this waste through bio-conversion.

BSFL can process a wide range of organic materials, reducing waste by 50–70% and producing protein-rich larvae and nutrient-rich compost (Surendra et al., 2016; Chakraborty et al., 2020). Several Indian startups and pilot projects have shown that BSFL based systems are both technically and economically viable (Kaur et al., 2022).

Other native insects also help break down agricultural residues and organic matter. Combining insect-based systems with existing municipal and farm waste management practices can improve resource recovery and support decentralized circular economy models.

Soil degradation and excessive use of chemical fertilizers are major challenges for sustainable farming in India. Vermicomposting, which uses earthworms to turn organic waste into nutrient-rich compost, is a proven circular economy practice.

Vermicompost improves soil structure, boosts microbial activity, and increases nutrient availability, leading to better crop yields (Suthar, 2010; Singh et al., 2019). Encouraging small farmers to adopt vermicomposting can reduce dependence on chemical fertilizers and lower costs. When combined with insect-based feed production, it can create integrated circular bioeconomy systems that benefit agriculture and rural livelihoods.

Protein deficiency is a concern in India, especially among low-income groups. Traditional livestock farming requires large amounts of land, water, and feed, and has a high environmental impact. Edible insects provide a sustainable alternative because they are rich in protein, essential amino acids, vitamins, and minerals (Rumpold & Schlüter, 2013).

Some Indian communities already consume insects, showing cultural acceptance. Expanding insect farming for food and feed can improve food security and reduce environmental stress (Mishra et al., 2021). However, scaling up requires better hygiene standards, processing technologies, supply chains, and consumer awareness.

Several barriers limit the adoption of insect-based circular economy practices in India:

Regulatory gaps: No clear policies for insect farming and use.

Technology limitations: Need for cost-effective and standardized rearing and processing methods.

Social acceptance: Low awareness and cultural perceptions hinder adoption.

Market constraints: Lack of strong value chains and quality standards.

To overcome these challenges, India needs supportive policies, research funding, startup incentives, and awareness programs. Existing government initiatives on organic farming and waste management can provide a foundation for integrating insect-based solutions (FAO, 2013; Ministry of Agriculture & Farmers Welfare, 2020).

IV. CONCLUSION

To fully realise this potential, coordinated efforts are required across research institutions, government agencies, industry, and society. Strengthening regulatory frameworks, investing in scalable technologies, and increasing public awareness will be critical for mainstreaming insect based circular economy practices.

By integrating insects into waste management, agriculture, and food systems, India can move towards a more resource efficient, environmentally sustainable, and inclusive development pathway, while contributing to global goals related to climate action, biodiversity conservation, and food security.

REFERENCES

[1] S. Chakraborty, R. Kumar, and A. Singh, "Black soldier fly larvae for organic waste management: A review," Waste Management, vol. 105, pp. 176–186, Jul. 2020. doi: 10.1016/j.wasman.2020.02.019.

[2] FAO, Edible insects: Future prospects for food and feed security, FAO Forestry Paper 171. Food and Agriculture Organization of the United Nations, 2013. [Online]. Available: http://www.fao.org/3/i3253e/i3253e.pdf.

[3] M. Geissdoerfer, P. Savaget, N. M. P. Bocken, and E. J. Hultink, "The Circular Economy – A new sustainability paradigm?" Journal of Cleaner Production, vol. 143, pp. 757–768, Dec. 2016. doi: 10.1016/j.jclepro.2016.12.048.

[4] A. Halloran, N. Roos, J. Eilenberg, A. Cerutti, and S. Bruun, "Life cycle assessment of edible insects for food protein: A review," Agricultural Systems, vol. 162, pp. 1–10, Jan. 2017. doi: 10.1016/j.agsy.2017.01.019.

[5] P. Kaur, S. Singh, and N. Sharma, "Black soldier fly larvae for sustainable organic waste management in India," Journal of Environmental Management, vol. 304, p. 114209, Jan. 2022. doi: 10.1016/j.jenvman.2021.114209.

[6] A. Kumar, A. K. Patel, and S. Prasad, "Circular bioeconomy in India: Role of insects and microbial technologies," Bioresource Technology Reports, vol. 15, p. 100753, 2021. doi: 10.1016/j.biteb.2021.100753.

[7] H. P. S. Makkar, G. Tran, V. Heuzé, and P. Ankers, "State-of-the-art on use of insects as animal feed," Animal Feed Science and Technology, vol. 197, pp. 1–33, Jul. 2014. doi: 10.1016/j.anifeedsci.2014.07.008.

[8] S. Mishra, S. P. Singh, and V. Kumar, "Prospects of edible insects as alternative protein in India," Food Science and Human Wellness, vol. 10, no. 3, pp. 205–215, Sep. 2021. doi: 10.1016/j.fshw.2021.05.003.

[9] Ministry of Agriculture & Farmers Welfare, Government of India, National Policy on Organic Farming, 2020. [Online]. Available: https://agricoop.nic.in/sites/default/files/NationalPolicyonOrganicFarming-2020.pdf.

[10] B. A. Rumpold and O. K. Schlüter, "Nutritional composition and safety aspects of edible insects," Molecular Nutrition & Food Research, vol. 57, no. 5, pp. 802–823, May 2013. doi: 10.1002/mnfr.201200735.

[11] S. A. Shah, J. Johnson, and M. Ali, "Challenges and opportunities for insect farming in South Asia," Journal of Insects as Food and Feed, vol. 7, no. 3, pp. 349–363, 2021. doi: 10.3920/JIFF2020.0071.

[12] R. Singh, S. Yadav, and D. Singh, "Vermicomposting and its role in sustainable agriculture in India," Environmental Science and Pollution Research, vol. 26, no. 13, pp. 13002–13013, May 2019. doi: 10.1007/s11356-019-04542-y.

[13] S. Suthar, "Vermicomposting of vegetable-market solid waste using Eisenia fetida: A comparative study of bioconversion and nutrient recycling," Ecological Engineering, vol. 36, no. 3, pp. 376–383, Mar. 2010. doi: 10.1016/j.ecoleng.2009.09.004.

[14] K. C. Surendra, R. Olivier, J. K. Tomberlin, R. Jha, and S. K. Khanal, "Bioconversion of organic wastes into biodiesel and animal feed via insect larvae: A review," Renewable and Sustainable

Energy Reviews, vol. 79, pp. 147–158, Nov. 2017. doi: 10.1016/j.rser.2017.05.047.

[15] A. Van Huis, J. Van Itterbeeck, H. Klunder, E. Mertens, A. Halloran, G. Muir, and P. Vantomme, Edible insects: Future prospects for food and feed security, FAO Forestry Paper 171, 2013. [Online]. Available: http://www.fao.org/3/i3253e/i3253e.pdf.

[16] F. Verneau, F. La Barbera, M. Amato, V. Carfora, and L. Cenci, "Circular economy and edible insects: Consumer acceptance and potential barriers in Italy," Sustainability, vol. 8, no. 5, p. 476, May 2016. doi: 10.3390/su8050476.

[17] X. Zhao and J. Zhang, "Application of black soldier fly larvae in organic waste management and bioenergy production: A review," Renewable Energy, vol. 149, pp. 179–190, Apr. 2020. doi: 10.1016/j.renene.2019.11.027.