Sustainable Management of Agro-Industrial Waste through Bioplastics Production: A Review of Recent Developments

Suneetha T. B[1], Malvika kandpal[2], Salma Praveen[3], Mohd Gulfishan[4], Himshikha Gusain[5], Ajmat Jahan[6], Naveen Kumar[7*]

[1]Department of Biotechnology, Acharya Institute of Technology – 5601073
[2]School of Education, Shri Guru Ram Rai University, Dehradun
[3]Department of Botany, Maya Devi University, Dehradun, Uttarakhand, 248011
[4]School of Agriculture & Technology, Maya Devi University, Dehradun, Uttarakhand, 248011
[5]Department of Forestry and Natural resources, School of Agriculture and Allied sciences, HNB Garhwal University, Srinagar Garhwal, Uttarakhand-246174
[6]Department of Botany, AMU Aligarh
[7]Department of Microbiology, Maya Devi University, Dehradun, Uttarakhand, 248011
*Corresponding Author: Dr. Naveen Kumar, E-mail: naveenbhadani12@gmail.com

Abstract
The excessive generation of agro-industrial waste and the escalating global plastic pollution cause immense environmental and economic problems. This chapter summarizes the current status of global bioplastic production and focuses on agri-food waste streams as feedstock for polymerization and also on recent initiatives both private/industrial funded and by India supporting the development of using agro-waste for bioplastics. Key technologies, feedstocks, challenges, and future directions will be discussed. Case studies from India will be presented including a PLA plant, biocomposite companies that use agro-waste products, and government policy support mechanisms. The chapter will close by considering scalable opportunities and barriers, particularly in the context of India.

Keywords: Bioplastics, Agro-industrial waste, Circular bio-economy, Waste valorization

Introduction

The global reliance on petrochemical-derived conventional plastics has created a unique environmental challenge. The non-biodegradable characteristic of plastics leads to massive landfill accumulation and massive ecosystem devastation, particularly in aquatic sites as these wastes can accumulate away from our eyes [1]. The global pollution problem and the limited supply and volatile price of fossil fuels have sparked a need for a more sustainable production of materials. A viable solution is the idea of a circular bioeconomy, which promotes bioplastics - polymers that are either bio-based, biodegradable, or both - as replacements for conventional plastics [2].

While plastics produced from fossil fuels are consumed in great quantities in present-day economies, they have significant and harmful consequences on global environments as a result of their lack of biodegradability, loss into microplastics, greenhouse gas (GHG) emissions, and accumulation as trash on land and in the ocean. Agricultural, food processing, sugarcane milling, fishery, distilling, and other agro-industrial operations generate waste, processes byproducts, and residuals in large amounts, e.g., fibrous residuals (straw, husks, and bagasse), fruit and vegetable peels, pulp and peel, processing effluents, as well as waste from animals or seafood. Utilizing waste as a feedstock for bioplastics offers two advantages which are reducing environmental pollution and producing value-added products.

Bioplastics such as polyhydroxyalkanoates (PHAs), polylactic acid (PLA), and thermoplastic starch have advantageous end-of-life options and reduce the overall carbon footprint of material usage. Unfortunately, high production costs, primarily driven by expensive, purified feedstocks (for example, glucose and sucrose) are significant barriers to commercial feasibility and widespread adoption of these biopolymers [3].

One possible approach to this challenge is to use agro-industrial waste, which is both strategically and economically smart. The agricultural and food processing industries produce vast quantities of byproducts—whey, lignocellulosic residues (straw, stover), fruit pomace, and molasses—most of which are mostly disposed of by burning, dumping, or repurposing into low-value animal feed, sometimes simply to avoid secondary environmental pollution. Not only does this approach address the urgent challenge of waste management, it also significantly reduces the total costs associated with bioplastics, as high-value biopolymer precursors can be derived from relatively abundant, inexpensive agricultural byproducts.

While recent advances in pretreatment, microbial fermentation, enzymatic hydrolysis, composite/biocomposite design, and material finishing practices (mechanical strength, barrier properties, biodegradability, etc.) have contributed to the feasibility of agricultural food waste biopolymer conversion, numerous issues remain. These include feedstock supply volatility, pretreatment and downstream processing costs, scalability, commercialization and regulatory acceptance, and cost and performance competition with petroplastics. The next sections explore the current landscape of bioplastic production in India and globally, specific pathways from agricultural waste to biopolymers, and associated industrial initiatives funded by or engaging these pathways.

Current status of bioplastic production

Global developments: The European Bioplastics association states that global bioplastics installed production capacity rose to approximately 2.18 million tonnes in 2023, and it will reach ~7.43 million tonnes by 2028. It is anticipated that PLA (polylactic acid) will consume ~43.6% of this capacity by 2028 (https://www.sustainableplastics.com/news/balrampur-chini-mills-build-indias-first-industrial-bioplastics-plant?utm_source=chatgpt.com) . Feedstock materials commonly include corn starch, sugarcane, cassava, vegetable oils, but increasingly non-food biomass (lignocellulosic waste, agricultural residues, fruit & vegetable peels, seafood shells, etc.). Certain bioplastics; PLA, PBS, PBAT, PHA, are commercially produced; others are still developing and are in pilot/startup/academic stages. Performance (mechanical, barrier, thermal) and cost remain key determinants. Many governments are providing incentives for bioplastics, via subsidies, government grants for R&D, or regulating single use packaging. In India, the recent policy announcements and investments indicate increasing government support.

In the past decade, global bioplastic production has increased tremendously, driven by rising environmental awareness and demand for sustainable alternatives to traditional, petroleum-based plastics. Recent analysis by European Bioplastics (2024) indicates the total global production capacity of bioplastics reached 2.47 million tonnes in 2024, and will exceed 5.7 million tonnes by 2029, which is approximately one percent of global plastics production. While this share may be small, it represents a strong upward trajectory supported by industry investment and government regulation to move to biobased materials [4].

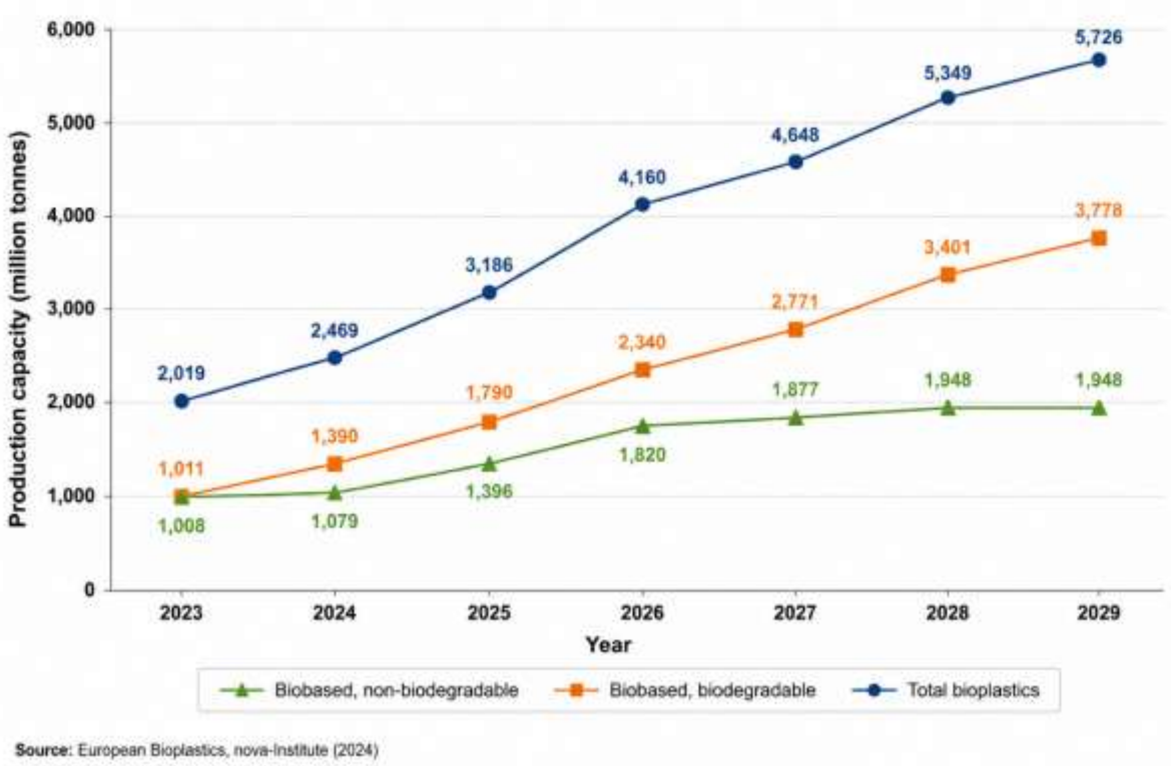

Figure 1: Global production capacities of bioplastics 2024-2029 [4]. (Source European Bioplastics, nova institute, (2024)

Bioplastics cover the broad spectrum of polymers that include not only bio-based non-biodegradable bioplastics such as bio-polyethylene (bio-PE), bio-polyethylene terephthalate (bio-PET) but cement-based biodegradable polymers such as polylactic acid (PLA), polyhydroxyalkanoates (PHAs), polybutylene succinate (PBS) and starch-based plastics [5]. Cost-effectiveness and commercial readiness have propelled PLA and starch blends into the most secure market position, whereas PHAs have begun to enter the packaging and biomedical applications with their full biodegradability attribute [6].

In terms of geographic distribution, Asia has the largest global capacity for bioplastic production, accounting for more than 50% of capacity, primarily driven by China, Thailand, and Japan. Europe is the other major market, largely justified by regulatory and funding processes aimed at encouraging sustainable materials and circular economy practices in the European Union. North America is also emerging as an important industry for bioplastic development, with increased production capacity for PLA and PHA, specifically at the industrial scale [7].

Much progress has been made on bioplastic development; however, key barriers to large-scale adoption remain, mainly of an economic and technological nature. Production costs continue to exceed those of petrochemical plastics, due to the lack of economies of scale in production and the cost of feedstock processing [8]. The end-of-life management of biodegradable plastics also continue to prove problematic; there is a lack of industrial composting facilities, as well as variation in the degradation rate of some bioplastics being dependent on the environment in which degradation occurs [7]. Recent studies also emphasized the need for sustainability of feedstock as a means of bioplastic development, when bioplastics are derived from starch or sugar which competes with food crops [9]. This can potentially steer the bioplastic industry towards different raw materials, for example using waste and lignocellulosic feedstock.

Future innovations in the bioplastic sector are projected to concentrate on third-generation feedstocks (i.e., algae, waste biomass), enzyme-assisted polymer synthesis, and closed-loop recycling to improve economic viability and reduce lifecycle emissions [10]. As sustainability emerges as an industrial priority, the use of biotechnological processes with circular economy models will be integral to scaling up the industrial production of environmentally benign plastics.

From Agri-Food Waste to Biopolymers

The global rise in agri-food waste (fruit and vegetable pomace, lignocellulosic residues such as straw and husks, spent grains, and waste oils) represents a major environmental burden while also being a significant source of renewable feedstock for the production of value-added biopolymers. Many recent reviews and experimental studies show there's potential to transform this waste using physical, chemical and biological processing steps to produce different classes of biopolymers such as lactic-acid/PLA precursors, cellulosic nanomaterials, pectins, chitosan-like polysaccharides and polyhydroxyalkanoates (PHAs) [11].

Feedstock and pretreatment characteristics: The chemical composition of agri-food residues can vary quite a bit. Crop bran and straw are lignocellulosic (cellulose ~30–45%, hemicellulose ~20–35%, lignin ~5–25%); fruit and vegetable pomace predominantly contains soluble sugars, pectins, and simple polysaccharides; and that of waste oils and greases are primarily a mix of triglycerides that can ferment to volatile fatty acids (VFAs) or hydrolyze to fatty acids. Also, it is pertinent to perform targeted pretreatment for efficient valorization: solvent/acid extraction both extract pectin from apple/citrus pomace; alkaline or oxidative delignification + hydrolysis to disrupt fiber architecture to release cellulose to produce nanocellulose; and mild enzymatic hydrolysis or diluted-acid hydrolysis to release fermentable sugars for lactic acid or VFA production. The selection of pretreatment improves environmental impact, downstream processing costs, and yields [12].

Polyhydroxyalkanoates (PHAs) are becoming more common as microbial products, with some microbes utilizing food waste as a low-cost carbon source for PHA production. Typically, there are two approaches: 1) PHA accumulating microbes ferment hydrolyzed food waste (sugar, glycerol, and oils) directly, or 2) two-stage processes where food waste is fermented to volatile fatty acids before it is subsequently fed to specialized PHA producers. Overall, recent reviews and experimental work have shown promising improvements in production and carbon conversion efficiencies. For example, multi-scale studies have indicated that greater productivities and carbon conversion efficiencies are achieved when using waste oils and/or volatile fatty acids, assuming optimum reactor and feeding designs. However, scale-up and maintaining a consistent feedstock supply continue to be a challenge [13]. A representative data point to note is a recent process implementation that reports that, through the use of waste lipids / optimized conditions, >190 $g \cdot L^{-1}$ PHA titer was obtained in a scale fermentation within 48 h and a carbon utilization efficiency of ~86% was achieved, thus demonstrating technical feasibility at piloting scale [14].

Lactic acid is the precursor to PLA. Lignocellulosic residues and discards from the production of fruits and vegetables are rich in free sugars in the composition of hydrolysates, which can also be used as feedstocks for fermentation to produce lactic acid. Sugars can be fermented by microbial strains (such as designed Lactobacillus and Bacillus processes, or fungi) to generate lactic acid, which can be converted to polylactic acid (PLA) via either ring-opening polymerization of lactide, or chemical polymerization. The economics will be influenced by the sugar yield from pretreatment, as well as the expense of separating lactic acid in a high-purity form. Reviews typically discuss integrated biorefineries in which the economics can be improved through co-product valorization (e.g., using residual lignin as energy or materials, etc.) [15].

Nanomaterials derived from cellulose (CNCs/CNFs). Lignocellulosic agricultural residues are a potentially abundant source of cellulose for the development of cellulose nanocrystals (CNCs) and nanofibrils (CNFs). Nanocellulose can be used as reinforcing phases in biobased composites, as barrier coatings, and other functional films due in part to the ratio of its length and width (aspect ratio), stiffness and the tuneable surface chemistry of these materials. Typical yields and crystallinity are dependent on the type of biomass used and how it is hydrolyzed (using sulfuric acid, enzymatic or ionic liquid approaches) and greener routes are a particular research direction as well as solvent recycling [16].

Other polysaccharides, including pectin. Pectin is a valuable gelling polysaccharide with direct biopolymer applications and film and edible coating ingredient applications. It is well known and present in fruit pomace (apple and citrus). The characteristics of films are dependent on the pectins formed by previously used extraction techniques (enzymatic, microwave-assisted, and acid extraction) and their degrees of esterification. Reviews show that, compared to the production of their chemical monomers, the extraction of pectin is much more valued and easier to manufacture [17].

Polymers derived from chitosan and proteins. Chitosan can be produced from processing waste of shellfish (shrimp/crab shells), which can be coupled with deproteinated and demineralized chitosan and many agri-food materials also supply proteins (e.g., whey and/or plant proteins) that are also formulated into films or blended with polysaccharides to produce a desired mechanical and/or barrier property. All are well documented in various valorization reviews [12].

Hybrid bioplastic films with CNCs or blended with pectin or proteins demonstrate greatly increased tensile strength and reduced oxygen permeability compared to non-composite biopolymer films, thus rendering them suitable for controlled-release and food packaging purposes. Biodegradability and compostability are beneficial end-of-life properties, but final fates depend on polymer chemistry and the available waste management system in a region. Waste stream-derived PHAs and PLA are used in packaging and mulch film applications [18].

Hurdles to converting heterogeneous waste streams include the need for robust microbes that can handle inhibitors, feedstock heterogeneity, the costs of downstream separation and purification to a polymer-grade purity, and the logistics of decentralized waste collection. To minimize costs, techno-economic studies promote process intensification and integrated biorefinery designs (co-products, energy integration). Biopolymers that are waste-derived often have a smaller greenhouse gas footprint than plastic made from fossil fuels, according to life-cycle studies; however, results are highly variable depending on the local energy mixes and allocation approaches [19]. The prioritized objectives for accelerating deployment include: robust, modular pretreatment and fractionation technologies capable of handling feedstock variability; microbial/catalytic pathways that enhance carbon conversion efficiencies and minimize the need for purification; scalable downstream techniques for the recovery of biopolymer products; and more integrated food industry logistics that provide consistent feedstock flows. Advancing waste-to-biopolymer concept into transitional, widespread commercial applications will involve continued demonstration at both the pilot and industrial levels, further improving composting and biowaste collection infrastructure, finalized governmental incentives [13].

Table 1: Conversion of Agri-Food Waste into Biopolymers: Feedstocks, Processes, and Yields

Agri-Food Waste Feedstock	**Target Biopolymer**	**Processing / Conversion Method**	**Reported Yield / Productivity**	**Key Findings**	**Reference**
Fruit & Vegetable Waste (apple pomace, citrus peel)	Pectin	Acid or enzymatic extraction (HCl/citric acid); microwave-assisted extraction	15–28% (w/w dry basis) pectin yield	Optimized microwave-assisted extraction increased yield and reduced extraction time by 50%	[17]
Mixed Food Waste Hydrolysate	Polyhydroxyalkanoates (PHA)	Two-stage fermentation: food waste → VFAs → PHA-producing mixed culture	Up to 0.45 g PHA/g COD removed; productivity 0.8 g/L·h	Volatile fatty acids improved substrate utilization and polymer accumulation	[13]
Waste Cooking Oil / Lipid Residue	PHA (PHB/PHBV)	Fed-batch fermentation using Cupriavidus necator	190 g/L PHA within 48 h; 86% carbon conversion	Demonstrated pilot-scale feasibility with low-cost lipid substrates	[14]
Sugarcane Bagasse, Rice Straw	Nanocellulose (CNC/CNF)	Alkaline delignification + sulfuric acid hydrolysis	CNC yield: 28–32%; crystallinity index 78–84%	Produced uniform nanocellulose with improved thermal stability	[16]
Potato Peels / Cassava Waste	Lactic Acid → Polylactic Acid (PLA)	Enzymatic hydrolysis → Lactobacillus delbrueckii fermentation	75–85% sugar conversion; 0.91 g/g lactic acid yield	Demonstrated circular route to PLA from starchy agri-waste	[19]
Shrimp Shell Waste (chitin source)	Chitosan	Deacetylation using NaOH (40–50%)	60–70% conversion to chitosan; DD ~80–85%	Waste seafood shells as biopolymer source for packaging films	[11]

India Funded Projects on Bioplastics from Agri-Food Waste

In recent times, India's research and innovation ecosystem - primarily funded by public sources (DBT, DST, ICAR, CSIR, BIRAC/NRDC and state-level programmes) and university/industry partnerships and start-up supports - has emphasized the conversion of agri-food wastes/crops residues, fruit/vegetable pomace, oil and dairy by-products, shellfish waste - into biopolymers (PHAs, PLA precursors, pectin/chitosan-based films, mycelium/biocomposite boards) targeting value-added benefits and new value (product/service/market). Funded activities range from basic studies (strain/process development) to applied studies enabled pilot demonstrations and supports for incubation or technology transfer/start-ups.

Funding landscape in India:

The Department of Biotechnology (DBT) and associated initiatives have operated calls and translational schemes responsive to biodegradable plastics, standards, and rapid-testing methods — generating impetus for product development and testing platforms (https://dbtindia.gov.in/).

The Indian Council of Agricultural Research (ICAR), at its commodity institutes and national labs, emphasizes "waste → value" R&D; ICAR has outlined guidance and advocated for biodegradable film substitutes for the development of single-use plastics produced from agricultural waste (https://icar.org.in/).
The NIDHI incubators of Department of Science and Technology (DST) and state/academic incubators have supported startups developing agri-waste conversion technologies (bio-composites, substitutes made from fibre, and pelletised bioplastics). Coverage from press reports has highlighted additional projects to examples backed by NIDHI/DST (https://dst.gov.in/).

Table 2 displays significant, documented projects / initiatives across India involving the intentional conversion of agricultural or food processing waste into bioplastic materials or biopolymer products. Each entry contains a link to the funding agency, press release, or project website.

Project / Initiative	Funder / Scheme	Lead Institution / Company	Objective / Output	Direct link
IIT-Madras Zero-Waste Bioplastics Initiative (mycelium-based biocomposites from agri & paper waste)	Institutional + translational support (IIT-M, press coverage suggests institutional and translational funding / support)	IIT-Madras researchers (packaging / materials group)	Develop mycelium-grown biocomposites on agricultural/paper waste for compostable packaging; pilot demonstrations reported.	https://www.iitm.ac.in/
Biodegradable Film for Replacement of Single-Use Plastic (ICAR release)	ICAR (governance / technology transfer)	ICAR institutes (multiple)	Development and release of biodegradable film technologies targeted at replacing single-use plastics in agriculture/packaging.	https://www.icar.org.in/
EcoGran (EcoGran bioplastic from crop residue) — product/scale-up reported	DST-NIDHI / IIT Mandi Catalyst ecosystem (reported)	UKHI (startup incubated via IIT-Mandi ecosystem)	Converts crop residue into a durable, biodegradable bioplastic (reported farmer income benefits & reduced stubble burning)	https://agrospectrumindia.com/
CCRI — VNIT Collaboration: packaging from orange peel waste	ICAR institute collaboration / likely supported by ICAR funding mechanisms	ICAR-Central Citrus Research Institute (Nagpur) + VNIT Nagpur	Develop biodegradable packaging from citrus peel (pectin/chitosan composites); MOU signed for R&D & validation.	The Times of India
Dairy / Ghee-residue bioplastic (patent / prototype)	University research funding / patenting (local institutional support)	GITAM (Visakhapatnam) researcher patent reported	Eco-friendly bioplastic from dairy ghee residue (patented; non-toxic alternative to petroplastics)	The Times of India
Early DBT / SPC Biotech	DBT support	SPC Biotech (industry)	Bio-conversion of agricultural waste	https://www.biospectrumindia.com/

support (historical) — mango kernel → bioplastic validation	reported (technology validation)		(mango kernel) into bio-plastic; technology validation and DBT support / transfer.	

Conclusion

The advancement of functional biopolymers and bioplastics made from agro-industrial wastes, such as crop residues, vegetable/fruit peels, seafood waste, distillery wastewater, and more, has seen notable advancements over the past two-to-three years both in lab/pilot scale and early industrial/commercial efforts, especially in India. Examples of notable technologies in this space are, but are not limited to: mycelium-based materials, composite materials (starch + nanocellulose, chitosan blends), and fermentation/microbial production of polymers such as PLA and PHA from non-food wastes. There are still challenges to be resolved in using bioplastics to be price competitive to petroplastics, scaling up pretreatment, managing the consistency of feedstock quality, attaining suitable mechanical and barrier properties, and gaining regulatory approvals (for food contact applications or compostability). Nevertheless, India seems to be setting a successful course: significant scale through investment (e.g., Balrampur Chini), government investment support programs (e.g., DST, NIDHI, BIRAC), startup innovations (e.g., Natnov, UKHI, NatureWrks), and collaboration between academia/industry. All these changes will require supporting policy (e.g., financial incentives, standards), along with a supply chain for feedstock, and investment in downstream processing to be successful. Looking to the future, as pressure increases from environmental regulation, demand for sustainable packaging, and awareness of circular economy, we anticipate growth in bioplastics made from agro-waste. Integrating them with waste management, rural livelihoods (e.g., farmers sourcing residues), and regional manufacturing (to minimize transportation emissions) will be important.

References

1. Kelaniyagama, S. H., Gannoruwa, A., & Nilmini, A. H. L. (2024). Synthesize and applications of biodegradable plastics as a solution for environmental pollution due to non-biodegradable plastics, a review. Sustainable Polymer & Energy, 2(4), 10011.
2. Mousavi, M., Kowsari, E., Gheibi, M., Cheshmeh, Z. A., Teymoorian, T., & Ramakrishna, S. (2024). Assessing bioplastics' economic, commercial, political, and energy potential with circular economy modeling: a sustainable solution to plastic waste management. Materials Circular Economy, 6(1), 6.
3. Muiruri, J. K., Yeo, J. C. C., Zhu, Q., Ye, E., Loh, X. J., & Li, Z. (2022). Poly (hydroxyalkanoates): production, applications and end-of-life strategies–life cycle assessment nexus. ACS Sustainable Chemistry & Engineering, 10(11), 3387-3406.
4. European Bioplastics. (2024). Bioplastics market development update 2024. https://www.european-bioplastics.org/bioplastics-market-development-update-2024/?utm_source=chatgpt.com.
5. Mattlar, T., & Ekholm, T. (2025). The impact of bioplastics production on climate change mitigation, fossil fuels and land-use. Renewable and Sustainable Energy Reviews, 212, 115234.
6. Gabriel, A. A., Rahmawati, A. Y., Taradipa, Y. S., Enomae, T., Muhammad Nur Fauzan, R. M., Thangunpai, K., ... & Ihsanpuro, S. I. (2024). Canna edulis ker. starch-based biodegradable plastic materials: mechanical and morphological properties. Discover Materials, 4(1), 55.
7. Synani, K., Abeliotis, K., Velonia, K., Maragkaki, A., Manios, T., & Lasaridi, K. (2024). Environmental impact and sustainability of bioplastic production from food waste. Sustainability, 16(13), 5529.
8. Nnolim, N. E., & Nwodo, U. U. (2025). Insight into Global Bio-Based Plastics Development: A Bibliometric Analysis-Aided Assessment of the Past Decades' Research Exploit. Sustainability, 17(13), 5955.
9. Sharma, R., Solanki, P., Chaudhary, M., Gupta, N., & Kaur, P. (2024). Unveiling the potential of microalgae for bioplastic production from wastewater–current trends, innovations, and future prospects. Biotechnology for Sustainable Materials, 1(1), 10.
10. Anli Dino, A., & Kishore, G. (2024). Microalgae: An emerging source of bioplastics production. Discover Environment, 2(1), 10.
11. Selvam, T., Rahman, N. M. M. A., Olivito, F., Ilham, Z., Ahmad, R., & Wan-Mohtar, W. A. A. Q. I. (2025). Agricultural waste-derived biopolymers for sustainable food packaging: Challenges and future prospects. Polymers, 17(14), 1897.
12. Mujtaba, M., Fraceto, L. F., Fazeli, M., Mukherjee, S., Savassa, S. M., de Medeiros, G. A., ... & Vilaplana, F. (2023). Lignocellulosic biomass from agricultural waste to the circular economy: a review with focus on biofuels, biocomposites and bioplastics. Journal of cleaner production, 402, 136815.
13. Kusuma, H. S., Sabita, A., Putri, N. A., Azliza, N., Illiyanasafa, N., Darmokoesoemo, H., ... & Kurniawan, T. A. (2024). Waste to wealth: Polyhydroxyalkanoates (PHA) production from food waste for a sustainable packaging paradigm. Food Chemistry: Molecular Sciences, 9, 100225.

14. Täuber, S., Riedel, S. L., & Junne, S. (2025). Polyhydroxyalkanoate production from food residues. Applied Microbiology and Biotechnology, 109(1), 171.
15. Gautam, K., Vishvakarma, R., Sharma, P., Singh, A., Gaur, V. K., Varjani, S., & Srivastava, J. K. (2022). Production of biopolymers from food waste: Constrains and perspectives. Bioresource Technology, 361, 127650.
16. Ansari, M. M., Heo, Y., Do, K., Ghosh, M., & Son, Y. O. (2024). Nanocellulose derived from agricultural biowaste by-products–Sustainable synthesis, biocompatibility, biomedical applications, and future perspectives: A review. Carbohydrate Polymer Technologies and Applications, 8, 100529.
17. Sarangi, P. K., Mishra, S., Mohanty, P., Singh, P. K., Srivastava, R. K., Pattnaik, R., ... & Sahoo, U. K. (2023). Food and fruit waste valorisation for pectin recovery: Recent process technologies and future prospects. International Journal of Biological Macromolecules, 235, 123929.
18. González-López, M. E., Calva-Estrada, S. D. J., Gradilla-Hernández, M. S., & Barajas-Álvarez, P. (2023). Current trends in biopolymers for food packaging: a review. Frontiers in Sustainable Food Systems, 7, 1225371.
19. Gautam, K., Vishvakarma, R., Sharma, P., Singh, A., Gaur, V. K., Varjani, S., & Srivastava, J. K. (2022). Production of biopolymers from food waste: Constrains and perspectives. Bioresource Technology, 361, 127650.