Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Issue 3, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/JOPC/

Review JoPC

Need of Biocomposite Polymers In 3D Printing: Addressing Environmental and Public Health

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Abstract

Concerns over the effects of conventional polymer materials on the environment and human health have been highlighted by the growing use of additive manufacturing or 3D printing. Traditional synthetic composites are usually made of petroleum-based plastics that include a range of chemical agents, such as additives and plasticizers. The increasing use of 3D printing has sparked concerns about the environmental and health risks linked to traditional polymer materials. With an emphasis on the advantages for public health and environmental sustainability, this review study evaluates the potential of biocomposite polymers as sustainable substitutes for 3D printing applications. The study looks at the waste production, exposure concerns, and harmful emissions that are currently connected to traditional 3D printing materials from an environmental and public health perspective. The properties, uses, and benefits of several biocomposite polymers, such as PLA, starch-based, and cellulose-based polymers, are then covered. Bio composite polymers offer a potential solution to the sustainability issues associated with conventional 3D printing materials. The review emphasizes how biodegradability, lower emissions, and biocompatibility of biocomposites might mitigate pollution, resource depletion, and health hazards. It looks at the environmental and public health problems linked to traditional 3D printing materials, including waste creation, exposure risks, and the release of harmful substance

Keywords: Biocomposite polymer, Environmental sustainability, public health, carbon footprint, 3D printing

INTRODUCTION

The growing use of 3D printing has raised concerns regarding the environmental and human health impacts associated with conventional polymer materials. Because polymers cannot degrade, they cause a huge amount of waste accumulation in the environment, resulting in significant environmental pressure [1]. Bio composite polymers give an excellent eco-friendly substitute that tackles issues like pollution and the scarcity of affordable resources such as plastic. The major benefit of bio composites is their ability to biodegrade, which helps to sustain the environment [2]. This plays a key role in reducing the buildup of microplastics in our surroundings [3]. Now a days people avoiding the use of fossil fuel, which has led to a need for high-quality products made from biological and renewable sources [4]. This review paper aims to evaluate how bio composite polymers could replace standard polymers in 3D printing to improve Environmental and Public Health. It looks at the environmental and public health problems linked to traditional 3D printing materials, including waste creation, exposure risks, and the release of harmful substances [5].

The characteristics, uses, and advantages of several bio composite polymers, including PLA,

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Received Date: March 12, 2025
Accepted Date: April 15, 2025
Published Date: May 01, 2025

Citation: Prajakta P. Desai, Vivek V. Kulkarni. Need of Biocomposite Polymers in 3D Printing: Addressing Environmental and Public Health. Journal of Polymer & Composites. 2025; 13 (3): 135–142p.

starch-based, and cellulose-based polymers, while considering the significance of both matrix and reinforcement in bio composite design. This paper also discusses how recycling initiatives and waste reduction technology might help reduce the negative environmental effects of 3D printing [6] [7][8].

The Figure no.1 shows Biocomposite material process flow affects positively on public and environment health. Recycling polymers used in 3D printing is a promising alternative to tackle the increasing sustainability concerns regarding waste generation, energy consumption, and overreliance on virgin materials [9]. The establishment of closed- loop recycling systems for 3D printing polymers is critical in reducing negative environmental impacts while promoting circular economy [10].

CURRENT ENVIRONMENT AND PUBLIC HEALTH ISSUES

Environmental Health

It is important to note that addressing plastic waste requires a holistic approach that, consider the entire life cycle of plastics and integrate this perspective into research and policy [11]. Traditional synthetic composites are usually made of petroleum-based plastics that include a range of chemical agents, such as additives and plasticizers. With time, these chemical agents can easily incorporate into the environment and thereby contaminate the air, the water and also the soil, all of which cause potential health risks. Biological composites, on the contrary, utilize natural fibers of renewable origin and biopolymers, which promised to be less toxic and more biodegradable and thus fewer hazardous substances will be allowed to migrate from the environment. The fibers present in bio composites, such as natural plant fibers, form, relative to synthetic composites, a structure much more stable, with their resolving into substances that might poison water and soil. The materials, while degrading, might tend to do so in a much safer manner, leaving fewer toxic by-products behind which might cause damage to aquatic life, plants, and animals [12].

Public Health Issues

The emission of volatile organic compounds and the release of ultrafine particles during the 3D printing process, may have implications for respiratory health and potential risks of chronic exposure, especially in the non-industrial sector [13]. Bio composite polymers offer a potential solution to the sustainability issues associated with conventional 3D printing materials. Additive manufacturing technologies that produce less or negligible waste play an important role in reducing environmental issues. However, Exposure to air borne emissions during 3D printing, can lead to respiratory problems regardless of the material [14]. A study of workers using 3D printers found that a significant percentage reported respiratory symptoms [15]. The non-polymeric components of plastic polymers can migrate to air, water, or contact media, potentially posing health hazards [16]. Volatile organic compounds are those ones with high vapor pressure at room temperature, which makes them easy to evaporate in the air. One of the indirectly related difficulties of VOCs is that they are not acutely toxic. Therefore, possible health effects will become apparent only later on in time. It becomes to be more difficult because normally, the concentrations of VOCs are low, and the symptoms shortly following the exposure to VOCs arise slowly. An exposure assessment measured the emissions from both PLA and ABS. The particles released during printing were identified by microscopy and chemical analysis. When 3D printing with ABS, emissions include cyclohexane, n-decane, ethylene propylene-diene terpolymer, 1-decanol, and isocyanic acid. Whereas with PLA, titanium particles were released during printing.

As is shown in Fig.no.2 [17], EDS- SEM was used to obtain morphology and compositional data which provides an overview of the sample surface properties. The X-ray signal's strength in relation to each element's concentration is represented in the case picture by the equation X-axis (Horizontal) Energy (keV); Y-axis (Vertical); cps/e^-: counts per second per electron. EDS reveals the elemental composition of a given area by detecting characteristic X-ray energies that are emitted from the surface of a sample when electrons bombard the surface. The analysis reveals airborne particulate contamination of complex composition, including carbonaceous material and toxic heavy metals. These doses of low-level radiation pose severe threats to the environment, human health, the degradation of air quality, and even the climate.

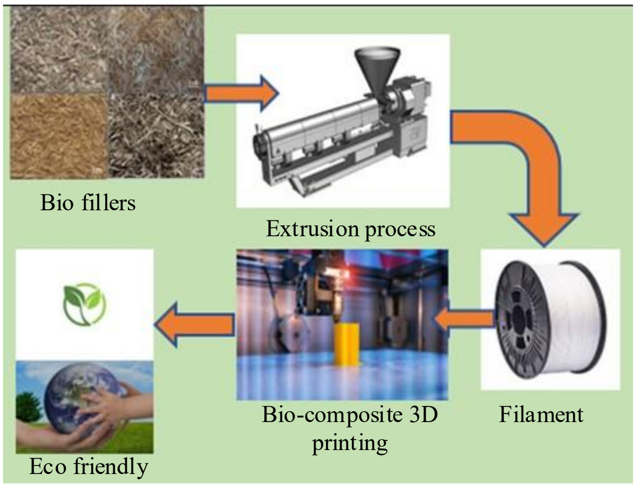

Figure 1. Biocomposite polymer process flow for sustainable environment.

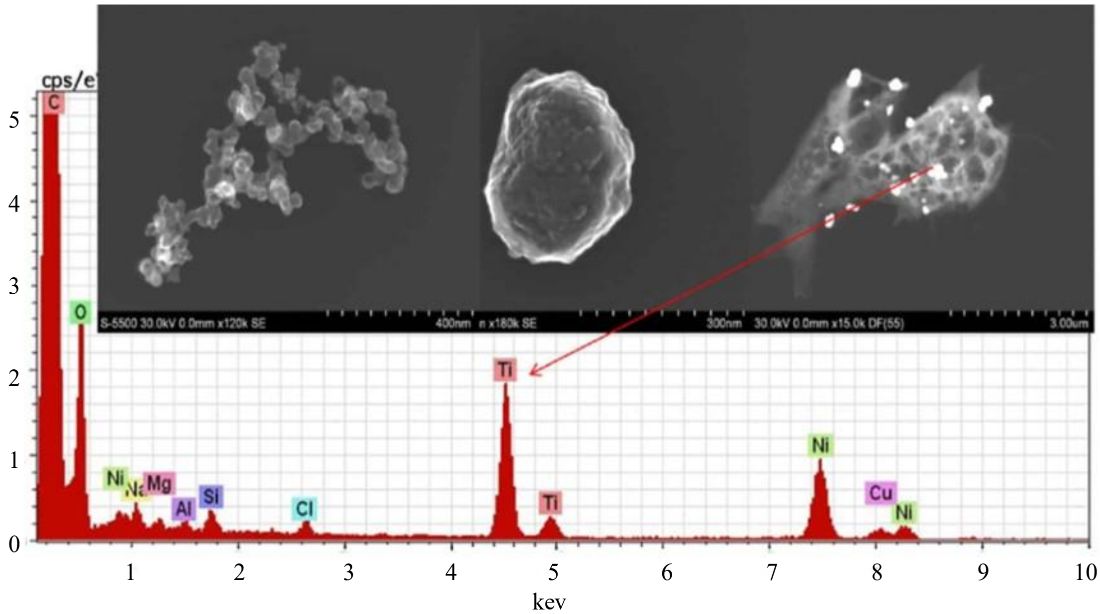

Figure 2. Volatile organic compounds in PLA [17].

Typically made from renewable resources, bio composites and many biopolymers have non-toxic and eco-friendly properties. Moreover, the fact that there are less dangerous chemical components involved in their manufacture gives them a leeway to emit fewer pollutants while manufacturing, bringing in reducing possible health hazards to workers and consumers.

POTENTIAL SOLUTIONS AND INNOVATIONS

Traditional polymers are derived from fossil fuels, which are a finite resource. In contrast, biocomposites utilize renewable resources such as corn starch, sugarcane, cellulose, and chitin [18]. This transition reduces dependence on fossil fuels and promotes a more sustainable material cycle.

One significant environmental advantage of bio composites is their potential to biodegrade [19]. Nowadays many conventional plastics still exist in the environment for several hundred years, while specific bio composites, such as PLA, are able to decay in the right place and in the right time such as an industrial composting facility. This property is helpful in preventing the build-up of the second plastic waste in landfills and in warding off microplastic contamination Additive manufacturing technologies that minimize or eliminate waste are very important for sustainable development. Bio composites support this by having the potential to recycle compost in a closed loop. Natural Fiber Reinforcement: Biocomposites created with the reinforcement of sustainable materials and the reinforcement biopolymer matrix are presently a large research and development area owing to the excellent mechanical properties, recyclability following service, biocompatibility, and biodegradability [20]. The manufacture of bio composites tends to produce lower greenhouse gas emissions than conventional polymers. This is because of carbon sequestration by plant feedstocks and the possibly reduced energy needed for processing. Biocomposites tend to reduce the migration of non-polymeric constituents into air, water, or contact media, which lowers possible health risks.

As a sustainable alternative, Biocomposites, which are made from renewable resources, have several significant advantages [21]. Biocomposites, especially those composed of PLA, starch, or cellulose, can be composted and biodegraded under specific circumstances, which helps to reduce the amount of plastic waste that ends up in landfills [21]. The 3D printing's prospective application 2of post-consumer recycled polymers can further lessen environmental issues. Using biocomposites, industrial processes such as 3D printing can produce fewer volatile organic compounds (VOCs), which will improve air quality and lessen respiratory issues [23]. Biocomposites are appropriate for biomedical applications and reduce potential health dangers due to their diverse properties, including biocompatibility, biodegradability, and low immunogenicity. The printing operations can be performed with adequate ventilation to reduce exposure to UFPs and VOCs. Placing the printer in a well-ventilated area away from occupied spaces can minimize exposure.

These goals are to offer useful information on how to choose bio composite polymers for a given 3D printing application, with specific emphasis on matrix and reinforcement properties, biodegradability, and target properties [4]. Materials research has resulted in the creation of polymers with beneficial properties for mechanics and biocompatibility [24]. With the design of mechanical properties being attained by modifying printing process parameters [25]. For the optimization of the existing range of 3D printing technologies and the avoidance of growing environmental issues, 3D printing of bioactive polylactic acid is widely utilized due to its biodegradable and renewable nature [26].

Traditional polymers such as ABS and PETG are usually less costly to manufacture than biocomposites. The price of certain biocomposites will vary depending on their source and processing method used. These biocomposites, particularly those made from waste materials, may be cost-effective [13]. The costs incurred by 3D printing depend on various factors, including: printer type, type of materials used, and complexity of the printed object [27]. Some biocomposites may need differentiated equipment or techniques to print, which could thereby raise the processing cost. Biocomposites may not necessarily yield the same mechanical properties as traditional polymers [28]. This reinforces or modifies in the bio composite to meet the performance specifications and increase costs. Biocomposites tend generally to have a smaller carbon footprint and can be biodegradable, thus offering environmental perks and savings in terms of disposal and resource management. The overall economy should regard specifically consider the applications, performance of interest, and long-term environmental benefits. With the development and expansion of the market, the price of biocomposites will decline, bringing them closer to an alternative for decreasing traditional polymers.

ENVIRONMENTAL BENEFITS OF 3D PRINTING BIOCOMPOSITES

Biocomposites are found to have a reduced carbon footprint compared to traditional plastics and therefore help to limit greenhouse gas emissions. 3D printing biocomposites have considerable environmental benefits by lessening pollution, reducing exposure to hazardous chemicals, and minimizing volatile organic compound emissions, all of which align them for ecological and sustainability purposes. These materials from natural resources are gaining momentum for their contribution to waste reduction through near-net shape processes and closed-loop recycling, alongside other biodegradable or compostable alternatives. Even though there are still challenges ahead, researchers are working on boosting mechanical properties, thermal stability and all for the purpose of making them a preferably viable and green alternative to traditional polymers [29].

BENEFIT TO PUBLIC HEALTH

Biocomposites in 3D printing have a range of public health benefits, such as reduction of exposure to toxic chemicals, better air quality, and promotion of sustainability through efficient waste reduction. Acting as clean and safe alternative materials to conventional ones, biocomposites enhance not only the environmental quality but also human health due to the upkeep of sustainability under low pollution and low toxicity [30].

APPLICATIONS OF BIOCOMPOSITES POLYMERS IN 3D PRINTING

3D printing provides safety, innovation, and convenience in healthcare, and has great potential for pharmaceutical, drug delivery, and bio-medical industries improvement [31]. Applications are 1. Biomedical implant: 3D-printed biocomposites are transforming drug delivery, tissue engineering, and medical implants because they are biocompatible, patient-specific models, and have the potential for increased therapeutic benefits [22][32]. 2. 4D bioprinting has been studied for possible clinical applications, such as drug delivery systems [33][34]. 3. Tissue Engineering: 3D bioprinting is constantly evolving to overcome the existing shortage for biological tissue repair and replacement. It provides a platform for fabricating functional products from imaging data that goes beyond complex molding procedures [35]. 4.Cell-loaded scaffolds: These can be customized through 3D bioprinting, and tissues and organs such as skin and blood vessels have been printed on a large scale [36]. 5. Automotive sector: Biocomposites are gaining popularity in the automotive sector, as producers aim to minimize the weight of vehicles, enhance fuel efficiency, and minimize their environmental footprints [37][38]. The application of 3D printing technologies with biocomposites allows to produce complex geometries and tailored components, thereby unlocking new design potential [39]. The interior components include door panels, rear package trays, load floors, instrument panels, center consoles, pillars, seat backs, spare tire covers, and door bolsters [40]. External components help to reduce the total weight of the vehicle. 5.Weight Reduction: Biocomposites tend to be lighter than conventional materials which enhances fuel efficiency and lowers emissions. The use of renewable resources reduces the dependence on fossil fuels.

FUTURE SCOPE

There are several opportunities for future research to develop novel biocomposite formulations with enhanced properties for 3D printing applications. These includes lignocellulosic materials, exploring the use of cellulose, hemicellulose, lignin, and their derivatives as 3D printing feedstocks [41]. Investigating bioactive reinforced polymers such as nano hydroxyapatite to improve the mechanical properties of biocomposites [42] Improving the tunability of composite materials to tailor specific properties for multifunctional applications. Research and development of polymers with advantageous characteristics for mechanics and biocompatibility. Exploring novel materials such as ceramics, glass, and shape-memory polymers for 3D printing. Sustainable composites: Exploration of sustainable composite material development as FDM feedstocks in rapid prototyping

CONCLUSION

One important step in addressing serious environmental and public health risks is shifting from traditional polymers made from petroleum to biocomposite polymers in 3D printing. The several advantages associated with employing biocomposites in additive manufacturing methods have been emphasized in this research. First of all, biocomposites provide a sustainable substitute that can greatly lower pollution levels and promote environmental cleanliness. The most urgent environmental concerns of our day are the accumulation of plastic garbage, which is lowered by their capability for biodegradation. The biocomposites offer significant benefits from the perspective of public health. They lessen the possible health concerns connected to conventional polymers by limiting the migration of non-polymeric components into the air, water, or contact media. Using biocomposites can reduce emissions of volatile organic compounds (VOCs) during production.

Conflict of Interest Declaration

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

REFERENCES

1. Mikula, K., Skrzypczak, D., Izydorczyk, G.et al., “3D printing filament as a second life of waste plastics—a review”, Environ Sci Pollut Res28, 12321–12333 (2021). https://doi.org/10.1007/s11356-020-10657-8
2. Rudnik, E., Milanov, N., Matuschek, G., & Kettrup, A., “Ecotoxicity of biocomposites based on renewable feedstock – Preliminary studies”, Chemosphere, Elsevier, Volume 70, Issue 2, December 2007, Pages 337-340, https://doi.org/10.1016/j.chemosphere.2007.06.026
3. Allemann, M.N., Tessman, M., Reindel, J. et al, “Rapid biodegradation of microplastics generated from bio-based thermoplastic polyurethane”, Sci Rep 14, 6036 (2024). https://doi.org/10.1038/s41598-024-56492-6
4. Swain, S. K., Pattanayak, A. J., & Sahoo, A. P., “Functional Biopolymer Composites”, Springer series on polymer and composite materials, 2017, p. 159. https://doi.org/10.1007/978-3-319-66417-0_6
5. Borner, T., & Zinn, M. (2024). Key challenges in the advancement and industrialization of biobased and biodegradable plastics: a value chain overarching perspective. In Frontiers in Bioengineering and Biotechnology (Vol. 12). Frontiers Media. https://doi.org/10.3389/fbioe.2024.1406278
6. Liu, J., Sun, L., Xu, W., Wang, Q., Yu, S., & Sun, J. (2018). Current advances and future perspectives of 3D printing natural-derived biopolymers [Review of Current advances and future perspectives of 3D printing natural-derived biopolymers]. Carbohydrate Polymers, 207, 297. Elsevier BV. https://doi.org/10.1016/j.carbpol.2018.11.077
7. Mazzanti, V., Malagutti, L., & Mollica, F. (2019). FDM 3D Printing of Polymers Containing Natural Fillers: A Review of their Mechanical Properties. Polymers, 11(7), 1094. https://doi.org/10.3390/polym11071094
8. Mattew A. Olawumi, Bankole I. Oladapo, Temitope Olumide Olugbade, “Evaluating the impact of recycling on polymer of 3D printing for energy and material sustainability”, Resources, Conservation and Recycling, Volume 209, 2024, 107769, ISSN 0921-3449. https://doi.org/10.1016/j.resconrec.2024.107769.
9. Peng Zhao, Chengchen Rao, Fu Gu, Nusrat Sharmin, Jianzhong Fu, Close- looped recycling of polylactic acid used in 3D printing: An experimental investigation and life cycle assessment, Journal of Cleaner Production, Volume 197, Part 1, 2018,pages 1046-1055, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2018.06.275.
10. Kubowicz, S., & Booth, A. M. (2017). Biodegradability of Plastics: Challenges and Misconceptions. In Environmental Science & Technology (Vol. 51, Issue 21, p. 12058). American Chemical Society. https://doi.org/10.1021/acs.est.7b04051
11. Seong Je Park, Ji Eun Lee, Han Bit Lee, Jeanho Park, Nak-Kyu Lee, Yong Son, Suk-Hee Park, “3D printing of bio-based polycarbonate and its potential applications in ecofriendly indoor manufacturing”, Additive manufacturing, Volume 31, January 2020, 100974
12. R House, N Rajaram, S M Tarlo, “Case report of asthma associated with 3D printing”, Occupational Medicine, Volume 67, Issue 8, November 2017, Pages 652–654, https://doi.org/10.1093/occmed/kqx129
13. Chan, F., Hon, C., Tarlo, S. M., Rajaram, N., & House, R., “Emissions and health risks from the use of 3D printers in an occupational setting. In Journal of Toxicology and Environmental Health”, Taylor & Francis., Vol. 83, Issue 7, (2020), pg. 279.https://doi.org/10.1080/15287394.2020.1751758
14. Lithner, D., Larsson, Å., & Dave, G., “Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition”, The Science of The Total Environment, Elsevier, Vol. 409, Issue 18, p. 3309. https://doi.org/10.1016/j.scitotenv.2011.04.038
15. Zontek, T. L., Ogle, B. R., Jankovic, J. T., & Hollenbeck, S. M. (2017). An exposure assessment of desktop 3D printing. Journal of Chemical Health and Safety, 24(2), 15-25.
16. Saha, A., Maraz, K. M., & Khan, R. A., “Physio-mechanical properties and applications of natural fiber reinforced bio-composites”, GSC Advanced Engineering and Technology, Vol. 3, .2022, Issue 1, p.1. https://doi.org/10.30574/gscaet.2022.3.1.0021

17. Chinga-Carrasco, G., Rosendahl, J., Catalán, J, "Nanocelluloses – Nanotoxicology, Safety Aspects and 3D Bioprinting", Advances in Experimental Medicine and Biology, Springer, vol 1357, 2022. https://doi.org/10.1007/978-3-030-88071-2_7
18. Shrivastava, A. K., & Dondapati, S, "Biodegradable composites based on biopolymers and natural bast fibres: A review", Materials Today Proceedings, Elsevier BV 46, 1420.,2021. https://doi.org/10.1016/j.matpr.2021.02.652
19. Hodson, L. ; Dunn, K. L. ; Glassford E, Hammond D, Roth G. Cincinnati, OH, National Institute for Occupational Safety and Health, "Approaches to safe 3D printing: a guide for makerspace users, schools, libraries, and small businesses, NIOSH Numbered Publications,2024-103, https://doi.org/10.26616/NIOSHPUB2024103.
20. Arefin, A. M. E., Khatri, N. R., Kulkarni, N. N., & Egan, P., "Polymer 3D Printing Review: Materials, Process, and Design Strategies for Medical Applications", Polymers, 13(9), (2021). pp.1499. https://doi.org/10.3390/polym13091499
21. Nikit Deoray, Balasubramanian Kandasubramanian "Review on Three-Dimensionally Emulated Fiber-Embedded Lactic Acid Polymer composites: Opportunities in Engineering Sector", Polymer-Plastics Technology and Engineering, Pages 860-874,2017. https://doi.org/10.1080/03602559.2017.1354226
22. Partanen, A., & Carus, M., "Biocomposites, find the real alternative to plastic – An examination of biocomposites in the market. In Reinforced Plastics", Elsevier, Vol. 63, Issue 6, 2019, p. 317. https://doi.org/10.1016/j.repl.2019.04.065
23. Derval dos Santos Rosa, Denise Maria, "Biocomposites: Influence of Matrix Nature and Additives on the Properties and Biodegradation Behavior", Tech eBooks, 2013.
24. Formela, K., Kurańska, M., & Barczewski, M., "Recent Advances in Development of Waste-Based Polymer Materials: A Review", Polymers, Multidisciplinary Digital Publishing Institute, 14(5), 1050, (2022). https://doi.org/10.3390/polym14051050
25. Rodríguez, L. J., Peças, P., Carvalho, H., & Orrego, C. E., "A literature review on life cycle tools fostering holistic sustainability assessment: An application in biocomposites materials", Journal of Environmental Management, Elsevier, 262, 110308. https://doi.org/10.1016/j.jenvman.2020.110308
26. Wang, S., Chen, X., Han, X., Hong, X., Li, X., Zhang, H., Li, M., Wang, Z., & Zheng, A. (2023). "A Review of 3D Printing Technology in Pharmaceutics: Technology and Applications, Now and Future", Pharmaceutics, Multidisciplinary Digital Publishing Institute, 15(2), 416. https://doi.org/10.3390/pharmaceutics15020416
27. Gaurav Kale a, Rafael Auras a, Sher Paul Singh a, Ramani Narayan, " Biodegradability of polylactide bottles in real and simulated composting conditions", Polymer Testing, Volume 26, Issue 8, December 2007, Pages 1049-1061, https://doi.org/10.1016/j.polymertesting.2007.07.006
28. Appuhamillage, G. A., Ambagaspitiya, S. S., Dassanayake, R. S., & Wijenayake, A, "3D and 4D printing of biomedical materials: current trends, challenges, and future outlook", Exploration of Medicine, Vol. 5, Issue 1, 2024, p. 17. https://doi.org/10.37349/emed.2024.00203
29. Assad, H., Assad, A., & Kumar, "A. Recent Developments in 3D Bio-Printing and Its Biomedical Applications [Review of Recent Developments in 3D Bio-Printing and Its Biomedical Applications", Pharmaceutics, Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/pharmaceutics15010255
30. Dey, M., & Ozbolat, I. T, "3D bioprinting of cells, tissues and organs. In Scientific Reports", Nature Portfolio, Vol. 10, Issue 1, 2020. https://doi.org/10.1038/s41598-020-70086-y
31. Ma, Y., Deng, B., He, R., & Huang, P, "Advancements of 3D bioprinting in regenerative medicine: Exploring cell sources for organ fabrication", Heliyon, Elsevier, Volume 10, Issue 3,e24593, 2024 https://doi.org/10.1016/j.heliyon.2024.e24593
32. Fantuzzi, N., Bacciocchi, M., Benedetti, D., & Agnelli, J, "The use of sustainable composites for the manufacturing of electric cars", Composites Part C, Elsevier, Vol. 4,2020, p. 100096). https://doi.org/10.1016/j.jcomc.2020.100096

33. Purabi Bhagabati, "Chapter 9 - Biopolymers and biocomposites-mediated sustainable high-performance materials for automobile applications", Sustainable Nanocellulose and anohydrogels from Natural Sources, Elsevier,2020, Pages 197-216, https://doi.org/10.1016/B978-0-12-816789-2.00009-2.
34. Khan, F., Hossain, N., Mim, J. J., Rahman, S., Iqbal, Md. J., Billah, M., & Chowdhury, M. A, "Advances of composite materials in automobile applications – A review", Journal of Engineering Research, 2024 https://doi.org/10.1016/j.jer.2024.02.017
35. Paatsch, W, "Recent trends in surface finishing for automobile industry in Germany", Surface and Coatings Technology, Elsevier, 2003, p. 753. https://doi.org/10.1016/s0257-8972(03)00157-9
36. Ramaux, J., Ziegler-Devin, I., Besserer, A., & Nouvel, C, "3D Printing of Wood Composites: State of the Art and Opportunities", Polymers, 16(19), 2024, 2827. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/polym16192827
37. L. Sandanamsamy, J. P. Mogan, Norhana Abdul Halim, Wan Sharuzi Wan Harun, K. Kadirgama, D. Ramasamy, "A review on 3D printing bio-based polymer composite", IOP Conference Series Materials Science and Engineering, 2020. 10.1088/1757-899X/1078/1/012031
38. Abu Sadat Muhammad Sayem, Hasan Shahariar, Julfikar Haider, "An Overview on the Opportunities for 3D Printing with Biobased Materials", Elsevier, 2019, UK. ISBN 978-0-12-803581-8 https://doi.org/10.1016/B978-0-12-803581-8.10942-7
39. Chia, H.N., Wu, B.M. Recent advances in 3D printing of biomaterials. J Biol Eng 9, 4 (2015). https://doi.org/10.1186/s13036-015-0001-4
40. Deoray, N., & Kandasubramanian, B, "Review on Three-Dimensionally Emulated Fiber-Embedded Lactic Acid Polymer Composites: Opportunities in Engineering Sector", Polymer-Plastics Technology and Engineering, 57(9), 2017, pp 860–874. https://doi.org/10.1080/03602559.2017.1354226

