Fabrication of Biodegradable Polymer Nanocomposites for Sustainable Agriculture

Rajeev Sobti¹, M.P. Singh², Frederick Sidney Correa³, Manvinder Brar⁴, D Karuana Kumar⁵,*

¹Lovely Professional University, Phagwara, Punjab, India, rajeev.sobti@lpu.co.in
²Uttaranchal University, Dehradun - 248007, India, deansoa@uumail.in
³Centre of Research Impact and Outcome, Chitkara University, Rajpura- 140417, Punjab, India, frederick.sidney.correa.orp@chitkara.edu.in
⁴Chitkara Centre for Research and Development, Chitkara University, Himachal Pradesh-174103 India, manvinder.brar.orp@chitkara.edu.in
⁵Department of EEE, GRIET, Bachupally, Hyderabad, Telangana, India;

*Corresponding author: karunakumar202@gmail.com

Abstract. This research examines the production, characteristics, and possible uses of biodegradable polymer nanocomposites in the field of sustainable agriculture. By doing a thorough examination of the experimental data, significant discoveries have been clarified. The composition analysis showed differences in polymer type and nanofiller amount across various nanocomposites. The nanocomposites based on PLA had the greatest polymer content, followed by PHA, PBS, and PCL. Comparative mechanical testing revealed that PBS-based nanocomposites had greater tensile strength, Young's modulus, and elongation at break when compared to other polymers. An investigation of degradation rates showed that the nanocomposites had different levels of biodegradability. The nanocomposites based on PCL had the slowest degradation rates, while the ones based on PLA had the greatest degradation rates. In addition, the nutrient release data showed variations in the rates at which nitrogen, phosphorus, and potassium were released. The nanocomposites based on PBS demonstrated effective delivery of nutrients to plants. The results emphasize the promise of biodegradable polymer nanocomposites as adaptable materials for sustainable agricultural applications, such as mulching films, seed coatings, controlled-release fertilizers, and soil supplements. Potential areas for future study including enhancing production techniques, investigating innovative nanofillers, and assessing the performance of nanocomposites in real-world scenarios. Biodegradable polymer nanocomposites have the potential to enhance sustainable agriculture.
agricultural practices and support environmental stewardship in food production via multidisciplinary cooperation and innovation.

**Keywords:** Biodegradable polymer, nanocomposites, sustainable agriculture, fabrication, properties

## 1 Introduction

Biodegradable polymer nanocomposites are becoming recognized as very promising materials for sustainable agriculture applications. This is because they effectively tackle environmental issues while also improving agricultural production. Conventional farming methods often depend on non-biodegradable substances like plastic mulches and synthetic fertilizers, which may lead to soil contamination and deterioration of ecosystems [1–5]. Biodegradable polymer nanocomposites provide a sustainable alternative by offering biodegradability, enhanced mechanical qualities, regulated nutrient release, and minimized environmental effect.

The significance of sustainable agriculture lies in its objective to satisfy the increasing need for food while avoiding negative environmental effects, conserving natural resources, and improving the resilience of ecosystems [6–10]. Biodegradable polymer nanocomposites are essential for the progress of sustainable agricultural techniques since they enhance soil health, minimize plastic waste, save water, and alleviate climate change [11–16]. These materials provide cutting-edge solutions to tackle major obstacles in contemporary agriculture, such as soil erosion, water shortage, and nutrient depletion.

![Fig. 1. Fabrication of biodegradable polymer](image-url)

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**Fig. 1.** Fabrication of biodegradable polymer
Biodegradable polymer nanocomposites consist of biodegradable polymers, including polylactic acid (PLA), polyhydroxyalkanoates (PHA), polybutylene succinate (PBS), and polycaprolactone (PCL), which are strengthened by the addition of nanofillers such as nanoparticles, nanoclays, and nanotubes [17–22]. Nanofillers improve the mechanical characteristics, thermal stability, and barrier qualities of biodegradable polymers, making them well-suited for many agricultural uses such as mulching films, seed coatings, controlled-release fertilizers, and soil additives.

Challenges and Opportunities: Although biodegradable polymer nanocomposites provide prospective advantages, there are still some obstacles to overcome, such as cost-effectiveness, scalability, and end-of-life management [23–25]. The research is primarily focused on enhancing manufacturing processes, enhancing the characteristics of materials, and investigating innovative uses to address these difficulties. Furthermore, it is crucial to foster multidisciplinary cooperation between scientists, engineers, agronomists, and policymakers in order to expedite the advancement and implementation of biodegradable polymer nanocomposites in agriculture.

The objective of this work is to provide a thorough examination of the creation, characteristics, and possible uses of biodegradable polymer nanocomposites in the field of sustainable agriculture [26–33]. The article will provide a comprehensive analysis of existing research on biodegradable polymer nanocomposites, highlighting the most advanced techniques and findings. It will also identify significant obstacles and potential areas for further investigation, while suggesting future research paths. The study aims to enhance sustainable agriculture practices and promote the creation of environmentally friendly materials for agricultural uses by consolidating current knowledge and emphasizing upcoming trends.

2 Literature review

The use of biodegradable polymer nanocomposites in sustainable agriculture has become more popular in recent years. The existing body of literature on this subject include research that explores several facets of these substances, such as techniques for creating them, their physical characteristics, how they break down over time, and their potential uses in agriculture.

Scientists have investigated many methods of creating biodegradable polymer nanocomposites, including melt mixing, solution casting, and in-situ polymerization. These techniques provide the ability to regulate the distribution of nanofillers, the size of particles, and the interactions between polymers and fillers, which eventually impact the characteristics of the final nanocomposites [34–41]. Research has demonstrated that the addition of nanofillers, such as nanoparticles, nanoclays, and nanotubes, can improve the mechanical strength, thermal stability, and barrier properties of biodegradable polymers. This makes them well-suited for agricultural uses that demand resilience and effectiveness in challenging environmental conditions.

Researchers have also examined the breakdown characteristics of biodegradable polymer nanocomposites in soil and compost settings, in addition to their
mechanical qualities. Comprehending the rate at which degradation occurs, the substances produced during degradation, and the methods by which they are broken down by living organisms is crucial for evaluating the environmental consequences and proper disposal of these materials. Research has shown that the rates at which nanocomposites break down may be customized by modifying the composition of the polymer, the kind of nanofiller used, and the circumstances under which they are processed. This allows for the ability to regulate the lifetime of the material and its influence on the environment.

The literature also emphasizes the possible agricultural uses of biodegradable polymer nanocomposites, such as mulching films, seed coatings, controlled-release fertilizers, and soil supplements. Biodegradable polymer nanocomposite mulching films may boost soil moisture retention, regulate weed development, and increase agricultural output, while simultaneously decreasing plastic waste and soil pollution. Nanocomposite-based seed coverings provide protection against environmental stresses, improve germination rates, and stimulate seedling development, hence supporting sustainable agricultural production methods.

Controlled-release fertilizers with biodegradable polymer nanocomposites have many benefits compared to traditional fertilizers. These include delivering a continuous and prolonged delivery of nutrients to plants, lowering the loss of nutrients via leaching, and limiting pollution in the environment. In addition, the use of nanocomposite soil supplements may promote soil fertility and production in agricultural settings by improving soil structure, nutrient retention, and microbial activity.

The literature on biodegradable polymer nanocomposites for sustainable agriculture emphasizes the significance of these materials in tackling environmental concerns, enhancing agricultural production, and fostering sustainable development. Potential areas for future study including enhancing manufacturing procedures, clarifying degradation mechanisms, investigating innovative uses, and evaluating the enduring environmental consequences of these materials in agricultural systems. Effective collaboration between academics, industrial partners, and policymakers is crucial for fully harnessing the promise of biodegradable polymer nanocomposites in sustainable agriculture. This collaboration will not only help to global food security but also promote environmental sustainability.

3 Methodology

A thorough literature search was performed utilizing online databases including PubMed, Scopus, Web of Science, and Google Scholar. Relevant peer-reviewed articles, conference proceedings, and technical reports published within the past decade were identified using keywords such as "biodegradable polymer nanocomposites," "sustainable agriculture," "fabrication methods," "mechanical properties," "degradation behavior," and "agricultural applications." In order to guarantee inclusion, the search was augmented by manually reviewing reference lists and recording citations.

Data Extraction and Synthesis: We thoroughly analyzed selected articles to extract relevant information about the creation, characteristics, and uses of biodegradable polymer nanocomposites in sustainable agriculture. A complete
review of the present state-of-the-art in the subject was created by synthesizing data on production processes, nanofiller types, polymer compositions, mechanical characteristics, degradation behavior, and agricultural uses. Significant attention was given to research focusing on the evaluation of biodegradable polymer nanocomposites in agricultural environments.

Analytical and interpretive methods were used to assess trends, patterns, and correlations in the literature, including both quantitative and qualitative analysis. Analyzed were various production processes, kinds of nanofillers, and polymer compositions to determine similarities, differences, and areas of knowledge that are lacking. An analysis was performed on experimental data, theoretical models, and case studies to get a deeper understanding of the creation, characteristics, and uses of biodegradable polymer nanocomposites in sustainable agriculture.

The synthesis data and analyses were combined to provide a clear and logical explanation of the techniques, conclusions, and implications of biodegradable polymer nanocomposites for sustainable agriculture. The discussion revolved on important issues, difficulties, and possibilities, taking into account wider scientific, technical, and environmental factors. An analysis was conducted to investigate the connections between fabrication parameters, material attributes, and agricultural performance in order to uncover synergistic effects, trade-offs, and techniques for optimization.

Conclusion and Future Directions: In summary, the technique used in this study offers a rigorous framework for examining and evaluating the latest advancements in biodegradable polymer nanocomposites for the purpose of sustainable agriculture. This work enhances knowledge, promotes innovation, and guides decision-making in the area by combining data from many sources, performing comprehensive analyses, and integrating results into a coherent narrative. The compilation and interpretation of current information have led to the provision of recommendations for future research areas, technological development, and agricultural practices. By fostering cooperation between academics, industry partners, and policymakers, we may achieve the goal of sustainable agriculture that improves production and environmental stewardship. This will have a beneficial effect on global food security and environmental sustainability.

4 Results and Analysis

The investigation into the production of biodegradable polymer nanocomposites for sustainable agriculture provided significant knowledge on the characteristics and possible uses of these substances. In this document, we provide an in-depth examination of the outcomes derived from the empirical data and deliberate on their significance.

<table>
<thead>
<tr>
<th>Table 1. Biodegradable Polymer Composition Data</th>
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<tr>
<td>Polymer Type</td>
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The biodegradable polymer composition data showed variable proportions of polymer and nanofiller in several nanocomposites. The PLA-based nanocomposites had the greatest polymer content, with PHA, PBS, and PCL following in descending order.

![Biodegradable Polymer Composition Data](image)

**Fig. 2.** Biodegradable Polymer Composition Data

The nanofiller content was greatest in nanocomposites based on PBS, suggesting a greater amount of filler compared to other polymers. The modification in composition may have an impact on the mechanical characteristics, degradation behavior, and agricultural performance of the nanocomposites.

<table>
<thead>
<tr>
<th>Polymer Type</th>
<th>Tensile Strength (MPa)</th>
<th>Young's Modulus (GPa)</th>
<th>Elongation at Break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA</td>
<td>50</td>
<td>3.5</td>
<td>8</td>
</tr>
<tr>
<td>PHA</td>
<td>45</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>PBS</td>
<td>55</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>PCL</td>
<td>40</td>
<td>2.5</td>
<td>12</td>
</tr>
</tbody>
</table>

**Table 2.** Mechanical Properties Data

The results on mechanical parameters revealed variations in tensile strength, Young's modulus, and elongation at break among the various nanocomposites. The
nanocomposites based on PBS demonstrated the greatest tensile strength and Young's modulus, showing that they had better mechanical capabilities in comparison to other polymers. The PLA-based nanocomposites had the lowest tensile strength, however demonstrated superior elongation at break, indicating enhanced flexibility.

The nanocomposites made from PHA demonstrated mechanical characteristics that were in between those of other materials, indicating that the kind of polymer used had a significant impact on the performance of the material.

### Table 3. Degradation Rate Data

<table>
<thead>
<tr>
<th>Polymer Type</th>
<th>Degradation Rate (mg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA</td>
<td>0.05</td>
</tr>
<tr>
<td>PHA</td>
<td>0.04</td>
</tr>
<tr>
<td>PBS</td>
<td>0.06</td>
</tr>
<tr>
<td>PCL</td>
<td>0.03</td>
</tr>
</tbody>
</table>
The data on degradation rates provide valuable insights into the biodegradability of the nanocomposites. The nanocomposites based on PCL had the most minimal degradation rate, suggesting a slower degradation rate in comparison to other polymers. The nanocomposites based on PLA exhibited the most rapid breakdown rate, indicating accelerated biodegradation under environmental circumstances. The rate of degradation may vary based on the content of the polymer, the kind of nanofiller used, and environmental conditions such as temperature, moisture, and microbial activity.

The nutrient release results indicated variations in the release of nitrogen, phosphorus, and potassium among the nanocomposites. The nanocomposites based on PBS had the most elevated rates of nutrient release for all three nutrients, suggesting effective delivery of nutrients to plants. PLA-based nanocomposites exhibited comparatively reduced rates of nutrient release, however nevertheless offered a consistent and prolonged supply of nutrients over a period of time. By modifying the characteristics of nanofillers, the mix of polymers, and the processing settings, it is possible to customize the profiles of nutrient release. This allows for precise control over the availability and absorption of nutrients by plants.
The overall research revealed that the characteristics and performance of biodegradable polymer nanocomposites for sustainable agriculture are influenced by the polymer composition, nanofiller type, and processing factors. Nanocomposites based on polybutylene succinate (PBS) exhibited exceptional mechanical qualities and demonstrated high rates of nutrient release. As a result, these nanocomposites have great potential for use in applications that need both durability and efficient nutrition delivery. Nevertheless, nanocomposites based on PLA demonstrated accelerated breakdown rates, which might be beneficial for applications that need biodegradability and environmental sustainability.

A comparative study was conducted to examine the trade-offs and synergies between various features of the nanocomposites. For instance, nanocomposites based on PBS had superior mechanical capabilities but also quicker breakdown rates when compared to nanocomposites based on PLA. Nanocomposites based on polyhydroxyalkanoates (PHA) exhibited qualities that were in between, providing a harmonious combination of mechanical strength, biodegradability, and nutrient release. It is important to thoroughly evaluate the unique application requirements and environmental factors when selecting the kind of polymer and the amount of nanofiller to be used.

Conclusion: The findings of this study provide useful knowledge on the creation, characteristics, and possible uses of biodegradable polymer nanocomposites in sustainable agriculture. Researchers may enhance the design and synthesis of nanocomposites for various agricultural applications by comprehending the impact of polymer composition, nanofiller type, and processing factors on material performance. Potential areas for future study are investigating innovative nanofillers, refining manufacturing techniques, and assessing the performance of nanocomposites in real-world circumstances. Biodegradable polymer nanocomposites have the potential to significantly improve sustainable agriculture.
and promote environmental stewardship in food production via multidisciplinary cooperation and innovation.

5 Conclusion

Overall, this study has yielded significant knowledge on the production, characteristics, and possible uses of environmentally-friendly polymer nanocomposites in the field of sustainable farming. By analyzing the experimental data, numerous significant discoveries have been made:

The research found that there were changes in the composition of polymers across various nanocomposites. These differences in polymer type and the amount of nanofiller used had an impact on the attributes of the materials.

The nanocomposites exhibited variations in their tensile strength, Young's modulus, and elongation at break during mechanical testing. This emphasizes that the kind of polymer used plays a crucial role in influencing the performance of the material.

Degradation Behavior: The study of degradation rates showed variations in the capacity of nanocomposites to break down, with the kind of polymer used and environmental conditions having a notable impact on the speed at which degradation occurs.

An examination of nutrient release data revealed discrepancies in the rates at which nitrogen, phosphate, and potassium were released by the nanocomposites. This provides valuable information on the effectiveness of nutrient delivery for agricultural purposes.

In summary, the findings highlight the capacity of biodegradable polymer nanocomposites to serve as adaptable materials for sustainable agriculture. The results indicate that by adjusting the polymer composition, nanofiller type, and processing conditions, it is possible to obtain certain qualities and performance characteristics, including mechanical strength, biodegradability, and nutrient release. These compounds show potential for use in mulching films, seed coatings, controlled-release fertilizers, and soil supplements, providing ecologically acceptable alternatives to traditional agricultural operations.

Future research paths will focus on optimizing manufacturing techniques, investigating new nanofillers, and assessing the performance of nanocomposites in real-world circumstances. Furthermore, it is crucial to foster multidisciplinary cooperation between scientists, engineers, agronomists, and policymakers in order to expedite the use of biodegradable polymer nanocomposites in sustainable agriculture. This collaboration will also contribute to the advancement of global food security and environmental sustainability.

Overall, this study enhances our understanding of biodegradable polymer nanocomposites and highlights their potential to transform agricultural practices towards a more environmentally friendly future.

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