OXFORD JOURNAL
OF STUDENT
SCHOLARSHIP

Replacing Polystyrene Bread Tags with Polyhydroxyalkanoate

Ashvath Katakam and Aryan Katakam
katakamashvath@gmail.com, katakamaryan@gmail.com

ABSTRACT

Most bread tags are made from a material called polystyrene, a petroleum-based plastic that does not biodegrade and can persist in the environment for a long period of time (Hopewell et al., 2009). Also the design of these bread tags remain unchanged for several decades despite improvements in material science. Because bread tags are so small, they frequently escape waste systems and contribute to long-term plastic accumulation. This study examines whether polyhydroxyalkanoate can be an appropriate substitute for polystyrene in the production of bread tags, while remaining compatible with existing packaging infrastructure. A comparative literature-based materials analysis evaluated mechanical characteristics, environmental life span, fitting with existing manufacturing processes, and price. A hinged-closure design was introduced to improve functionality and durability to accommodate the differences in the material performance. Literature analysis indicates that replacing persistent plastic bread tags with biodegradable alternatives appears potentially feasible based on published literature, and that existing manufacturing systems may support this transition, suggesting that redesigning a small, high-volume plastic product could reduce long-term environmental persistence.

INTRODUCTION

Plastic packaging has had an important influence on the way we distribute food today primarily due to its flexibility, adaptability, and ability to integrate into automated manufacturing lines. Plastic bread tags are one of the most common methods used to close bread bags in grocery retail. Bread tags are generally produced using polystyrene, a petroleum-based thermoplastic noted for being rigid, inexpensive and suitable for large-scale mass production applications (Mark, 2007). Although polystyrene is efficient functionally, it is not biodegradable and can remain in the environment for many years after disposal (Hopewell et al., 2009). Due to their small size and light weight, bread tags are also very rarely recycled, and may also be overlooked by waste management systems. As a result, they contribute to the overall accumulation of plastic in the environment. This study contributes to the sustainable packaging literature by evaluating the feasibility of combining biodegradable material substitution with product redesign in a common packaging component that has received limited attention in previous research.

Although there have been advancements in materials science and sustainable packaging technologies, the design of the bread tags has remained unchanged for decades. This overlooked piece presents an opportunity to rethink the materials used to create bread tags and the way that these bread tags are constructed. Although biodegradable polymers such as polyhydroxyalkanoate (PHA) have been developed for various packaging applications, limited research has evaluated their feasibility as replacements for persistent plastics in small, high-speed packaging components like bread tags. Therefore, the purpose of this research is to determine whether polyhydroxyalkanoate could serve as a suitable replacement for the conventional polystyrene bread tag, without compromising mechanical performance or manufacturing compatibility. This study proposes that with appropriate engineering modifications, a polyhydroxyalkanoate-based bread tag may achieve functional performance comparable to conventional bread tags while reducing long-term environmental persistence.

MATERIALS AND METHODS

Materials

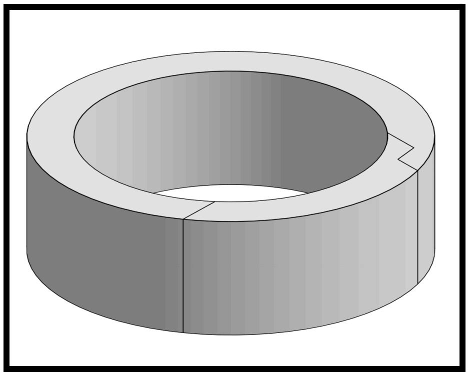
This research evaluated whether it is feasible to replace polystyrene with polyhydroxyalkanoates using a comparison of materials. Data regarding the physical properties of each polymer were collected from scientific studies on polymer chemistry and also from data sheet information provided by manufacturers. Literature was identified by searching Google Scholar using the keywords 'polyhydroxyalkanoate mechanical properties,' 'polystyrene thermoplastic properties,' 'PHA injection molding,' and 'biodegradable packaging materials.' Literature studies were chosen as long as they provided quantitative mechanical, processing, or environmental data on one of these two polymers. Manufacturer datasheets were consulted to corroborate published values for processing temperatures and commercial availability. Physical properties examined during this study included tensile strength, flexural modulus, impact resistance, temperature processing ranges, biodegradation characteristics, and cost or economic feasibility.

Polystyrene was selected as the control material due to its widespread use in bread tag manufacturing. Polyhydroxyalkanoate was selected as the experimental biodegradable alternative due to its known compostability and compatibility with injection molding processes.

Design Engineering Modifications

Because polyhydroxyalkanoate exhibits different mechanical properties than polystyrene, a conceptual redesign of the bread tag was proposed to improve durability and functionality. The proposed design hypothesizes that by allowing for repeated opening and closing of the tag with a hinge closure, it will distribute the mechanical load more evenly throughout the hinge geometry, thereby reducing localized stress concentration and reducing the possibility of cracking. As these hypotheses are as yet untested, validation will require development of a working model and subsequent mechanical testing. The design parameters such as hinge thickness, curvature radius, and overall geometry were adjusted based on known polymer flexibility characteristics.

It is important to note that this redesign remains conceptual. No physical prototypes were experimentally tested as part of this study. Future research should include: CAD modeling of the redesigned tag, finite element analysis (FEA) to evaluate stress distribution, and prototype fabrication and mechanical fatigue testing. Despite the absence of physical validation, the conceptual redesign illustrates how structural optimization could complement material substitution in improving product performance.



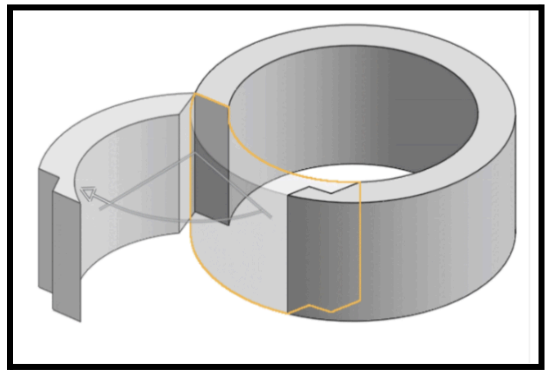


Figure 1. Conceptual design: closed configuration of the proposed PHA bread tag. The continuous ring body is designed to provide an even distribution of mechanical stresses across its full circumference to eliminate local mechanical stresses.

Figure 2. Conceptual design: open configuration of the proposed PHA bread tag. The hinge mechanism (visible at the gap in the ring) is proposed as the primary functional component that would allow for repeated opening and closing motion without breaking.

Evaluation Criteria

The feasibility of material substitution was evaluated using the following criteria:

1. **Mechanical Performance** - Ability to resist cracking and repeated bending.
2. **Environmental Persistence** - How long the material remains in the environment after disposal.
3. **Manufacturing Compatibility** - Whether the material can be used with existing injection molding equipment.
4. **Cost Considerations** - General comparison of production costs and commercial feasibility based on published research.

RESULTS

Table 1. Compares the mechanical properties of two types of polymers: General-Purpose Polystyrene (GPPS) and Polyhydroxyalkanoates (PHA) biopolymers. (Philip et al., 2007; Mark, 2007; Di Lorenzo et al., 2019).

Property	**Polystyrene (PS)**	**Polyhydroxyalkanoate (PHA)**
Tensile Strength (MPa)	30-50	20-32
Elongation at Break (%)	1-4	1-8
Elastic Modulus (GPa)	3.2-3.5	0.8-3.2
Impact Resistance (J/m)	Low (brittle fracture)	PHB similarly brittle; PHBV grades improved
Biodegradability	Non-biodegradable	Fully biodegradable

Mechanical Feasibility: According to material property information, polystyrene has been identified as being brittle and unable to withstand repeating bending (Mark, 2007). The tensile strength of polystyrene is 30-50 MPa, and its low elongation at break limits its capacity for repeated flexure. In comparison, polyhydroxyalkanoates are biodegradable polyesters with reported tensile strengths generally ranging from approximately 20-40 MPa. Although there is little difference in terms of tensile strength when comparing some PHAs to polystyrene, many PHA copolymers display greater flexibility and toughness than more brittle plastic materials (Philip et al., 2007). Therefore, these mechanical properties indicate that PHA could be suitable for bread-tag applications, though actual prototype testing will be required to verify long-term durability.

Environmental Persistence: The material polystyrene is resistant to degradation by microorganisms and it can last for many years within an ecosystem (Hopewell et al., 2009). However, polyhydroxyalkanoates are considered to be biodegradable and will break down in a timely manner, when exposed to the right environmental conditions, which include: polymer type, temperature, amount of moisture present, and the availability of microorganisms that have the ability to actively participate in breaking it down. Transitioning from polystyrene to polyhydroxyalkanoates would greatly diminish plastic waste in ecosystems.

Manufacturing Compatibility: Polyhydroxyalkanoate is a thermoplastic that is capable of being molded by melting it like most common plastics, and in this manner, it can also be processed through an injection molding machine (Chen, 2010). While the processing temperatures for polyhydroxyalkanoates are different than those used for polystyrene, the same machines could potentially be utilized provided the process parameters were to be altered and appropriate validation testing was performed.

Cost Analysis: Although polyhydroxyalkanoates generally remain more expensive to produce than conventional petroleum-based plastics, recent research indicates that advances in feedstock selection, microbial production methods, and process optimization may reduce production costs and improve commercial viability (Zytner et al., 2023; Yao et al., 2025). Despite increased costs for materials, bread tags are extremely small which in turn use a minimum amount of polymer per unit. With an assumed average cost for bulk polystyrene resin as high as $1.00-2.00/kg and an average cost for bulk PHA resin being $4.00-6.00/kg (Yao et al., 2025), and a typical weight of each bread tag being approximately 0.3-0.5 grams; it is projected that the total material cost per tag will increase from around $0.0005-0.0010 for polystyrene to around \$0.0015-0.0030 for PHA, a difference of just under a single cent. The overall economics of using an alternative material to plastic for a small tag can have lower costs per unit compared with larger packaging applications; however, the use of an alternative material at the scale of billions produced annually is likely to result in cost differences that are significant enough to influence manufacturers. However, because industrial resin prices vary considerably across suppliers, geographic regions, and production scales, a detailed economic assessment is beyond the scope of this study. A full cost analysis and evaluation of potential life cycle savings would need to occur at a future time if PHA were to be widely adopted.

DISCUSSION

This literature study has shown that PHA may be an environmentally friendly option for using as an alternative to polystyrene in manufacturing bread tags. The comparative assessment of the physical properties of the materials show that although polystyrene provides good mechanical strength and is used in many industries, it lacks flexibility due to its brittle nature. Polystyrene is also resistant to biological degradation, which can contribute to significant environmental problems. Conversely, PHA's mechanical properties provide acceptable stiffness which is potentially suitable for bread tag applications.

The key difference for an environmental perspective lies in the behavior of each type of material when discarded into the soil. Microbes do not readily degrade polystyrene so it will remain in the environment for extended periods relative to other types of plastic post-disposal (Hopewell et al., 2009). Conversely, PHA degrades through natural microbial activity in either soil or composted material. Studies have shown that many PHA materials can biodegrade within months to a few years under suitable composting or soil conditions (Narancic et al., 2018). Since the majority of bread tag applications utilize polystyrene, substituting conventional polystyrene with biodegradable alternatives could help reduce long term plastic accumulation and micro-plastic formation.

Economic considerations remain an important factor in determining the practicality of material substitution. Published literature suggests that although PHAs currently remain more expensive than conventional plastics, ongoing advances in feedstock utilization, microbial production systems, and manufacturing technologies may improve economic feasibility over time (Zytner et al., 2023; Yao et al., 2025). Because bread tags require only very small quantities of material, the financial impact of material substitution may be less significant than in larger packaging applications. However, further commercial-scale economic analyses are needed to evaluate long-term financial viability. Although PHA offers environmental advantages, its higher production costs and limited commercial adoption remain important barriers to widespread implementation.

This study also highlights the importance of integrating material substitution with product redesign. The proposed hinged-closure design was developed to address potential differences in material performance while improving stress distribution and reusability. Although the redesign remains conceptual, it illustrates how engineering modifications may complement sustainable material choices and improve product functionality.

Several limitations should be acknowledged. First, this study was based entirely on published literature and did not include prototype fabrication or experimental testing. Second, the proposed hinged-closure redesign has not been validated through finite element analysis or mechanical fatigue testing. Third, economic feasibility was assessed qualitatively because industrial pricing varies substantially across suppliers, geographic regions, and production scales. Future research should include CAD modeling, finite element analysis, prototype fabrication, mechanical testing, lifecycle assessment, and commercial-scale economic evaluation.

Overall, the findings suggest that replacing conventional polystyrene bread tags with PHA appears potentially feasible based on published literature and environmentally advantageous. While additional experimental validation is required, this analysis shows how combining biodegradable materials with thoughtful product redesign may offer a practical approach to reducing the environmental impact of small, high-volume plastic products.

CONCLUSION

The results of this research demonstrate the significant relevance of materials selected for product design and structural design in all aspects of consumer goods. Although bread tags are relatively small and many times go unnoticed, when used in mass quantities they could potentially have a greater long-term impact on the environment than one might initially assume. This study provides evidence that using polyhydroxyalkanoate (PHA) rather than polystyrene (PS), suggests that biodegradable plastics such as polyhydroxyalkanoate can be applied to high-volume packaging components.

In addition to replacing existing materials, this study also highlighted the importance of redesign. Designing an improved closure structure by incorporating a hinge is a direct reflection of the potential for effective modification of designs as they relate to improving both durability and usability while allowing the designer flexibility when it comes to choosing appropriate material properties. The redesign process shows how optimizing the structural design can improve functionality and extend product performance.

These results show that significant long term sustainability can occur by making a few changes on an already working production system rather than completely overhauling the entire production process. By creating new products with sustainable materials and changing how products are designed, it is possible for companies to significantly reduce plastic waste. This way of thinking about sustainability could help companies move more toward a more circular economy.

REFERENCES

Chen, G.-Q. (2010). Plastics completely synthesized by bacteria: Polyhydroxyalkanoates. In G.-Q. Chen (Ed.), Plastics from bacteria (pp. 17–37). Springer. https://link.springer.com/book/10.1007/978-3-642-03287-5

Di Lorenzo, M. L., Androsch, R., & Righetti, M. C. (2019). Constrained amorphous interphase and mechanical properties of poly(3-hydroxybutyrate-co-3-hydroxyvalerate). Frontiers in Chemistry, 7, 790. https://doi.org/10.3389/fchem.2019.00790

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: Challenges and opportunities. Philosophical Transactions of the Royal Society B: Biological Sciences, 364 (1526), 2115 - 2126. https://royalsocietypublishing.org/rstb/article-abstract/364/1526/2115/20977/Plastics-recycling-challenges-and-opportunities?redirectedFrom=fulltext

Mark, J. E. (Ed.). (2007). Physical properties of polymers handbook (2nd ed.). Springer. https://link.springer.com/book/10.1007/978-0-387-69002-5

Narancic, T., Verstichel, S., Reddy Chaganti, S., Morales-Gamez, L., Kenny, S. T., De Wilde, B., Babu Padamati, R., & O'Connor, K. E. (2018). Biodegradable plastic blends create new possibilities for end-of-life management. Environmental Science & Technology, 52 (18), 10441-10452. https://pubs.acs.org/doi/10.1021/acs.est.8b02963

Philip, S., Keshavarz, T., & Roy, I. (2007). Polyhydroxyalkanoates: Biodegradable polymers with a range of applications. Journal of Chemical Technology & Biotechnology, 82(3), 233 - 247. https://scijournals.onlinelibrary.wiley.com/doi/10.1002/jctb.1667

Yao, J., Xiao, X.-Y., Wang, M., Zhang, Q., Chen, Y., Gou, M., Xia, Z.-Y., & Tang, Y.-Q. (2025). A review of low-cost production of polyhydroxyalkanoates: Strategies, challenges, and perspectives. Bioresource Technology, 433, 132745. https://doi.org/10.1016/j.biortech.2025.132745

Zytner, P., Kumar, D., Elsayed, A., Mohanty, A. K., Ramarao, B. V., & Misra, M. (2023). A review on polyhydroxyalkanoate (PHA) production through the use of lignocellulosic biomass. RSC Sustainability, 1, 2120-2134. https://doi.org/10.1039/D3SU00126A