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Exploring sustainable alternatives: Utilizing natural precursor for eco-friendly polybenzoxazine

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ABSTRACT

Rising concerns about petrochemical-based materials' sustainability and health risks drive the search for alternatives to natural resources. Polybenzoxazines, known for their exceptional thermal stability, low water absorption, and high glass transition temperature, are promising candidates. However, conventional synthesis relies on petroleum-derived monomers like phenol, raising concerns. This review highlights the vast potential of bio-based polybenzoxazines. Biorefinery advancements and new biosynthetic pathways are paving the way for versatile natural monomers like resveratrol and furfurylamine. These alternatives address sustainability and health concerns while offering comparable, and sometimes even superior, material properties. The review delves into the chemistry and structure of polybenzoxazines, tracing their evolution since 1944. It explores the sources and extraction methods of potential bio-based monomers, showcases their application in resin production, and analyzes technical and economic challenges and opportunities. By promoting sustainable materials development and addressing safety considerations, this review paves the way for bio-based polybenzoxazine resins, contributing to a greener and more sustainable future for materials production.

1. Introduction

In recent years, the increasing global reliance on fossil fuels has raised significant concerns due to its implications for various environmental factors, including fossil fuel dependency, greenhouse gas emissions, waste, and pollution. It is estimated that a substantial 7 % of the world's fossil fuel resources are currently devoted to the production of polymeric materials [1,2]. This heavy dependence on fossil fuels not only depletes finite resources but also contributes to the alarming rise in greenhouse gas emissions. Moreover, producing and disposing of petroleum-based products often result in substantial waste and pollution, aggravating environmental challenges. One critical issue is the non-biodegradable nature of many of these products, which further compounds waste management problems. In response to these pressing challenges, biobased products have emerged as a promising alternative. It offers the potential to reduce fossil fuel dependency, mitigate greenhouse gas emissions, alleviate waste and pollution issues, and provide biodegradable options, marking a significant step toward a more sustainable industrial landscape [3].

Polybenzoxazine is an emergent polymeric material that was introduced as phenolic resin replacement due to its various advantages, such as minimal volumetric change during polymerization, low water absorption, excellent thermal stability, high char yield, and high glass transition temperature [4–7]. Polybenzoxazine, like phenolic resins, is synthesized through the reaction of petro-based phenol and aldehyde precursors alongside primary amines. However, what sets it apart from the current phenolic resins is the formation of a mannich-base bridge during the synthesis process [8–11]. Despite the advantages of using polybenzoxazine as a substitution for phenolic resin, some critical concerns need careful consideration. These concerns are primarily driven by the need for sustainable bio-based raw materials and improvements in health and safety during production and application processes. Currently, the utilization of petro-based materials remains unavoidable in producing polybenzoxazine. Phenol, a crucial raw material for polybenzoxazine, is primarily produced through the chemical oxidation of toluene or by heating chlorobenzene and sodium hydroxide. It can also be found naturally in coal tar and creosote [12,13]. Similarly, formaldehyde, another essential raw material for polybenzoxazine, is derived

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