The potential of tartarates as a compatibilizers and plasticizers in biodegradable films

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Abstract: Traditional plasticizers, predominantly phthalates, pose significant health and environmental risks due to their endocrine-disrupting properties and tendency to leach from products. In response, green plasticizers, sourced from renewable materials like vegetable oils and plant-based polyols, have emerged as a crucial, sustainable alternative. They offer reduced toxicity and biodegradability, making them ideal for sensitive applications like food packaging. Our research investigated the use of novel tartrate-based plasticizers, synthesized from glycerol and PET waste, in biodegradable active packaging. Studies showed that glycerol tritartrate significantly improved the mechanical and barrier properties of cellulose acetate (CA) and CA/polycaprolactone diol (PCL diol) blends, with a 7 wt% concentration providing an optimal balance. Additionally, a plasticizer from polyethylene terephthalate (PET) waste and tartaric acid demonstrated a dual role as both a plasticizer and a compatibilizer, enhancing film flexibility and barrier performance at concentrations of 30% and 20%, respectively. These findings confirm the viability of using green plasticizers to create high-performance, environmentally friendly packaging materials that address the sustainability challenges posed by the plastics industry.
Keywords: green plasticizers, tartarates, packaging, PET waste.

1. Introduction

Plasticizers are substances, usually consisting of small organic compounds, that lower the glass transition temperature (T_g) of the polymer they are combined with, resulting in flexible or semi-rigid materials with enhanced processing properties [1]. Plasticizers can be divided into two categories: internal and external. Internal plasticizers enhance flexibility by reducing T_g via the incorporation or copolymerization of softer monomer units into the polymer backbone, whereas external plasticizers are merely mixed with the polymer at higher temperatures and do not form permanent bonds [2]. The use of traditional plasticizers, mostly phthalates, brings certain health and environmental risks. Phthalates are recognized as chemicals that disrupt endocrine function, meaning they can affect hormonal systems. Exposure to these substances has been linked to developmental and reproductive complications, along with various chronic health concerns. Environmental impact implies releasing these toxic plasticizers into the soil, water, and air. These substances have the potential to pollute ecosystems, impacting wildlife and potentially accumulating within the food chain.

Green plasticizers play a crucial role in creating a more sustainable plastics industry due to their numerous benefits compared to traditional fossil fuel-based alternatives. Sourced from renewable bio-based materials like vegetable oils, these plasticizers significantly lower the carbon footprint associated with plastic manufacturing. Their significance is further highlighted by their non-toxic and biodegradable characteristics, making them a safer option for sensitive uses such as medical devices and food packaging, thereby reducing health risks and environmental pollution. In addition to their ecological advantages, green plasticizers are also highly effective, providing performance that is either on par with or exceeds that of conventional options, with improved thermal stability and durability, ensuring that product quality is maintained without compromising on sustainability. Several important green plasticizers are gaining popularity in the market, each providing distinct advantages sourced from renewable materials. For instance, Epoxidized Soybean Oil (ESBO) is a commonly utilized, biodegradable plasticizer obtained from soybean oil, valued for its superior thermal stability in PVC. Citrate esters, produced from citric acid, are a favored non-toxic choice for food packaging and children's toys, ensuring safety in sensitive applications. Additionally, polyols such as glycerol and sorbitol, derived from plant sources, are being developed for a variety of applications, highlighting the flexibility and increasing potential of bio-based materials to replace traditional, petroleum-based plasticizers.

Increasing the use of green plasticizers in the food and beverage packaging industry is crucial, given its status as the largest consumer of plastic packaging. This shift is driven by the fact that the industry accounts for over half of the plastic packaging market, making it a primary source of both plastic consumption and waste. By adopting green plasticizers, derived from renewable sources, the industry can significantly reduce its environmental footprint, lower the health risks associated with traditional plasticizers, and meet growing consumer demand for sustainable and safe products. This transition is essential for mitigating the industry's significant contribution to global plastic pollution and promoting a circular economy.

Using novel plasticizers derived from tartrates in biodegradable active packaging is a promising development. Our studies have shown that these plasticizers not only enhance the flexibility of biopolymers but also serve as effective compatibilizing agents within biopolymer blends. This dual functionality is crucial for overcoming the inherent brittleness and poor compatibility often found in biodegradable polymers. By improving these properties, tartrate-based plasticizers contribute to the creation of more durable and functional packaging materials that can meet the rigorous demands of the industry while remaining environmentally friendly.

2. Methodology section

2.1. The influence of tartarate plasticizers on functional properties of biopolymer blends

Plasticizers were synthesized by reaction of esterification using glycerol and tartaric acid described by Erceg et al. [3] and in the reaction of tartaric acid with the product of PET glycolysis, bis(2-hydroxyethyl) terephthalate (BHET), described in the study by Erceg et al. [4].

Our research into the plasticizing abilities of glycerol tritartrate has shown promising results when used with cellulose acetate (CA) and a CA/polycaprolactone diol (PCL diol) blend. The investigation of these films' mechanical and barrier properties—crucial for effective packaging—revealed an optimal concentration. Specifically, films containing 7 wt% of the plasticizer demonstrated the best balance of flexibility, durability, and barrier performance. This finding highlights glycerol tritartrate's potential as a highly effective green plasticizer for developing advanced, biodegradable packaging materials. In a separate study, a plasticizer synthesized from PET waste and tartaric acid was introduced into a cellulose acetate/polycaprolactone diol (CA/PCl diol) blend at varying concentrations. The results showed that the blend with 30% plasticizer had the best elongation at break, indicating improved flexibility. However, the blend with 20% plasticizer demonstrated superior barrier properties. This suggests that at this specific concentration, the plasticizer's dual role as both a plasticizer and a compatibilizer was most effective, creating a more cohesive and less permeable film.

3. Conclusions

According to the research, plasticisers made from recycled and sustainable materials—like glycerol, tartaric acid, and PET waste—work very well to create sophisticated biodegradable packaging materials. Glycerol tritartrate greatly improves the mechanical and barrier qualities of blends of cellulose acetate (CA) and polycaprolactone diol (PCL diol). The best performance balance is achieved at an ideal concentration of 7 weight percent. According to the research, plasticisers made from recycled and sustainable materials—like glycerol, tartaric acid, and PET waste—work very well to create sophisticated biodegradable packaging materials. According to studies, glycerol tritartrate greatly improves the mechanical and barrier qualities of cellulose acetate (CA) and CA/PCL diol blends; the greatest performance balance is achieved at an ideal concentration of 7 weight percent.

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