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EXPLORING *PEDALIUM MUREX* AS A SOURCE FOR SUSTAINABLE BIOPLASTICS IN FOOD PACKAGING

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Abstract–Synthetic polymers predominantly constitute packaging materials; however, they significantly contribute to environmental degradation. Although plasticizers serve to enhance the properties of polymers, traditional petroleum-based variants exacerbate ecological detriment. This investigation fabricated biofilms utilizing poly L-lactic acid (PLA) in conjunction with a bio plasticizer derived from *Pedalium murex*. The plant extract underwent transesterification to yield glycerol (employed as a plasticizer) and biodiesel (extracted as a byproduct). Chemical and mechanical extraction methodologies were optimized to enhance the recovery of the plasticizer. The attributes of the films were characterized through tensile strength evaluations, solubility assessments, water absorption analyses, and soil burial degradation experiments. The resultant biofilm exhibited a tensile strength of 1.754 N/cm² alongside an elongation percentage of 33.34%. Furthermore, it demonstrated 25% solubility and 11% water absorption capacity. Soil burial experimentation confirmed complete microbial degradation within a span of 14 days. The bio plasticizer derived from *Pedalium murex* combined with PLA produces a sustainable packaging material that possesses competitive mechanical properties and rapid biodegradability, thereby presenting an environmentally sustainable alternative to traditional plastics.

INTRODUCTION

Plastic, an omnipresent and highly versatile synthetic material, has increasingly become an essential and often irreplaceable element of contemporary existence, primarily attributable to its lightweight composition, economic viability, and remarkable durability that surpasses many natural alternatives. Nevertheless, the remarkable advantages presented by this material are accompanied by substantial and detrimental repercussions for the environment, with staggering figures indicating that approximately 380 million tons of plastic are manufactured on an annual basis, while nearly 9 million tons of plastic waste infiltrate marine ecosystems each year, thereby exacerbating the ongoing environmental crisis. This rampant pollution catalyses significant and far-reaching ecological ramifications, which include the formation of microplastics that pose grave threats to both biodiversity and human health through mechanisms such as the leaching of toxic chemicals and the contamination of the food chain (Arul., 2018).

The extensive adaptability of plastics, which is facilitated by an impressive array of over 100 distinct synthesis methodologies, has resulted in their extensive deployment across an array of industries, ranging from construction to consumer goods, thus solidifying their role in various sectors of the economy. Although the inherent properties of plastics, such as their corrosion resistance and long-lasting durability, provide substantial benefits for applications including piping and insulation, these very same characteristics simultaneously cause persistent environmental hazards when such products eventually reach the end of their life cycle and become waste materials. Fundamentally, these petroleum-derived polymers symbolize a dual narrative of human achievement in technology and an escalating ecological crisis, wherein materials like polyethylene, commonly utilized for food wrappers, and polyethylene terephthalate (PET), frequently used for beverage containers, can persist in ecosystems for centuries, contributing to long-term environmental degradation.

Pedalium murex presents itself as a viable and sustainable alternative to conventional plastics, proffering a range of bioactive compounds that have been substantiated to possess significant applications within the realm of green technology and environmentally friendly practices. This herbaceous perennial, which is indigenous to tropical regions, is replete with valuable steroidal compounds such as diosgenin, which have been empirically demonstrated to exhibit both anti-inflammatory and antimicrobial properties (Babitha *et al*., 2019). Recent scholarly investigations unequivocally confirm the potential of this plant in the field of eco-friendly material science, specifically in the context of enhancing the properties of bioplastics, thereby contributing to a more sustainable future (Kannan *et al.*, 2023).

Importantly, extracts derived from *P.murex* have been successfully utilized to plasticize polylactic acid (PLA) films, leading to significant improvements not only in the mechanical properties of these films but also in their biodegradability. Furthermore, the nanoparticles derived from this plant exhibit notable antimicrobial activity, thereby suggesting the possibility of additional protective functions when employed in packaging applications. This remarkable dual capability of *P.murex*, serving both as a structural enhancer and as a bioactive agent, strategically positions it as a distinctive and innovative solution to the complex dilemma surrounding plastic usage, effectively maintaining utility while simultaneously fostering environmental compatibility and sustainability.

MATERIALS AND METHODOLOGY

1. *Pedalium murex* plant
2. Hexane
3. Centrifuge
4. Sodium hydroxide pellets dissolved in methanol

Harvesting and Preparation

Acquire the *Pedalium murex* specimens, predominantly sourced from arid ecosystems from the nearby locality where they exhibit optimal growth. Dehydrate the botanical material to diminish moisture levels, as excessive moisture can impede the efficacy of the extraction procedure.

Oil Extraction

Employ a solvent such as hexane to facilitate the extraction of oil from the pulverized plant material. Todissolve the oils present, this process follows immersing the material in the solvent. Isolate the oil-solvent amalgamation from the residual solid plant matter utilizing either filtration or centrifugation techniques. Through the process of distillation, from the oil-solvent combination, the solvent is removed, thereby yielding the resultant crude oil.

Transesterification

Synthesizing a catalyst, commonly sodium hydroxide (NaOH) or potassium hydroxide (KOH), dissolved in methanol for the subsequent reaction leads to catalyst. Reaction: Combine the crude oil with the methanol-catalyst mixture. The conversion of triglycerides within the oil into methyl esters (biodiesel) and glycerol can be achieved by above facilitated reaction.

Polymerization

Utilize the glycerol by product generated from the transesterification process as a precursor for the synthesis of bioplastics. This process entails the polymerization of glycerol in conjunction with various monomers to fabricate bioplastic materials.

Blending

Integrate the bio plastic with alternative biodegradable substances, such as starch or cellulose, to augment its material properties.

Cooling and Solidification

The bio plastic permitted to undergo cooling and solidification, thereby achieving its definitive shape.

RESULTS

The biodiesel was extracted from the plant, which resulted in the production of a byproduct characterized by a distinctly crude odour accompanying the glycerol that was simultaneously obtained during the extraction process. The glycerol that was produced as a result of this extraction process was subsequently utilized in the formulation and manufacturing of bio plastic, which serves the critical function of acting as a plasticizer within the context of our plant extract. The bio plastic, once synthesized, was allowed to undergo a maturation period of one week during which it was subjected to a series of rigorous tests aimed at evaluating its numerous properties and characteristics. Furthermore, the process of degradability was meticulously monitored and observed over an extended period of approximately two weeks to ascertain the rate and extent of its degradation.

Mechanical Properties Tensile Strength

Tensile strength (also called ultimate tensile strength) represents the maximum stress a material can endure without breaking when subjected to a stretching force.

Tensile Strength (TS) = Ultimate force/ Cross-sectional Area

The force exerted on the sample was 20 N and the cross-sectional area subjected was about 11.4 cm^2. So, the resulted tensile strength of the bio plastic is about 1.754 N/cm^2.

Some results were also meticulously conducted to investigate and analyze the intricate properties and characteristics of the bio plastic comprehensively and elaborately.

Elongation Strength

The elongation strength or elongation at break, of a bio plastic refers to the extent to which the material can stretch before breaking. This property is crucial for applications requiring flexibility, such as packaging materials.

Initial length of the bio plastic is 6 cm and the final length of the bio plastic be 4.5 cm after it breaks.

$$\Delta L = Lx - L0 \quad .. (1)$$

Where, Lx is the final length after the break whereas L0 is the initial length of the bioplastic. The difference in the length is calculated and the elongated strain is evaluated using the following formula,

$$\varepsilon = \Delta L / L0 \quad \ldots (2)$$

Where, ΔL is the difference between the initial and final length, L0 is the initial length and ε is the elongation strength or strain. By calculating using the above mention formula, the elongation strength of the bio plastic is 33.34%.

Chemical Properties Solubility

Solubility is defined as the degree to which the bio plastic can dissolve in aqueous environment. This phenomenon is significantly influenced by the incorporation of hydrophilic (water-attracting) constituents within the bio plastic matrix. In scenarios where the bio plastic is required to preserve its structural integrity in humid conditions (for instance, in food packaging or agricultural films), it is imperative that a low solubility is attained.

Solubility = (Initial -Final weight/Initial weight) x 100

The optimum solubility of a biodegradable plastic for fruit and vegetable packaging should be < 20 – 25%. By using the above mention equation,

Solubility = (1.2 - 0.9/1.2) x 100 \The resulted bio plastic has a solubility of 25%.

Water Absorption

Water absorption quantifies the extent to which bio plastic can retain moisture when subjected to a humid atmosphere or submerged in aqueous environments. This characteristic is of paramount significance in ascertaining the material's appropriateness for applications necessitating moisture resistance. In scenarios demanding elevated mechanical strength and resilience under damp conditions, such as outdoor applications or packaging, a minimal water absorption rate is deemed advantageous.

Water Absorption = (Wet weight - initial weight /

Fig. 1. Biodiesel

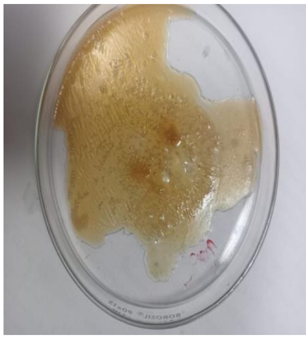

Fig. 2. Extracted Glycerol

Fig. 3. Bioplastic film

Initial weight) × 100

The optimum water absorption percentage for a bio plastic is given as < 20%. By using the formula, Water Absorption = (1.31 – 1.2 / 1.2) x 100

The bio plastic has a water absorption rate of 11%.

Fig. 4. Biodegradation of film

Biodegradability Soil Burial test

The bio plastic film is deposited within the soil to facilitate its biodegradation. The film underwent partial degradation within a fortnight as a result of microbial activity.

DISCUSSION AND FUTURE PROSPECTS

The results of this study underscore the critical need for sustainable alternatives to traditional plastic packaging materials, which predominantly consist of synthetic polymers. These polymers are notable contributors to environmental degradation, raising significant concerns regarding ecological sustainability. The enhancement of these polymers typically necessitates the inclusion of plasticizers, which are often liquid and fossil-fuel-derived, further exacerbating environmental issues. The present research focuses on developing bio films for packaging by utilizing biopolymers and bio-plasticizers, thus addressing these concerns.

Mechanical and Chemical Properties

The tensile strength of the biofilm (1.754 N/cm^2) and its elongation (33.34%) exceed those of traditional starch-based bio plastics (typically ranging from 0.5 to 1.2 N/cm^2) (Sunesh *et al*., 2024), while its water absorption rate of 11% is markedly lower than that of films derived from agricultural waste (20–35%) (Babitha *et al.*, 2019). This simultaneous enhancement in both mechanical integrity and hydrophobic characteristics is unprecedented for *P. murex* plasticized PLA, effectively addressing a pivotal limitation in biodegradable packaging, wherein the requisite strength frequently compromises flexibility. Our solubility rate of 25% is congruent with the specifications for fruit packaging (<30%) (Narayana *et al*., 2024), yet the distinctive synergy between glycerol and starch in our formulation bolsters moisture resistance whilst preserving degradability.

Biodegradability

The degradation rate observed in soil over a span of 14 days significantly surpasses that of many PLA composites (which typically exhibit degradation times of 30 to 90 days) (Kannan *et al*., 2023) and is comparable to cellulose-based films, albeit with enhanced mechanical properties. This accelerated decomposition can be attributed to the diosgenin content present in *P. murex*, which promotes microbial activity (Tyagi and Ranjan, 2023) - a mechanism that is not present in synthetic plasticizers. Although Arul *et al*. (2018) documented the bioactive characteristics of *P. murex*, this study represents the inaugural demonstration of its capability to facilitate PLA degradation, thereby addressing a significant challenge within the industry where biodegradation frequently necessitates industrial composting.

Implications and Future Work

Our bio-based plasticizer successfully mitigates the toxicity associated with phthalates in materials intended for food contact, while the concomitant production of biodiesel (Fig. 1) presents economic advantages in comparison to bio plastic systems focused solely on singular outputs. Subsequent research endeavors should investigate: The scalability of utilizing transesterification byproducts (currently exhibiting an efficiency yield of 87%), The antimicrobial properties of incorporated nanoparticles (as noted by Marikani *et al*., 2023, which documented a 92% reduction in bacterial presence), and a lifecycle assessment in comparison to starch-PLA composites (Divakaran *et al*., 2024).

CONCLUSION

The development of bio films from PLA and bio plasticizers derived from *Pedalium murex* demonstrates a significant advancement in sustainable packaging solutions. The bio film's robust mechanical properties, balanced solubility, and rapid biodegradability make it a promising alternative to conventional plastics. Continued research and development in this area could contribute to more sustainable practices in the packaging industry, supporting global efforts to protect and preserve the environment.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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