AGRO-INDUSTRIAL WASTE FOR THE DEVELOPMENT OF BIOMATERIALS FOR SUSTAINABLE PACKAGING: CIRCULAR BIOECONOMY

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ABSTRACT

Preserving food and beverage quality and cost-effectiveness remains a crucial aspect of packaging, although durable synthetic polymers pose significant environmental threats. Biodegradable materials are increasingly favored due to regulatory shifts and growing environmental concerns, prompting investments in bio-based plastics. Rising awareness of environmental issues and volatile crude oil prices drive the demand for renewable, non-petroleum-based polymers, with biopolymers emerging as promising alternatives. Agro-waste utilization for biopolymer production offers sustainable solutions for food packaging, aligning with the goals of the circular economy. However, challenges such as high production costs hinder widespread adoption. Integrating circular bioeconomy principles with agribusiness practices can mitigate environmental strain and promote sustainability. Despite the abundance of agro-waste resources, their exploitation remains limited due to various factors. Efficient waste recovery and transformation into valuable by-products can contribute to a zero-waste approach while meeting the demand for eco-friendly packaging materials. The circular bioeconomy emphasizes resource optimization, waste reduction, and environmental health. Continuous research is crucial for advancing sustainable technological processes and developing natural materials with enhanced properties, driving the food packaging industry toward greater environmental efficiency. Despite existing challenges, ongoing efforts by researchers aim to overcome technological barriers and expand the horizons of the circular bioeconomy.

Keywords: Food packaging. Circular bioeconomy. Biopolymer. Agro-waste. By-products.

1 INTRODUCTION AND MATERIAL & METHODS

Packaging preserves food and beverage quality and safety while cost-effective, and durable synthetic polymers cause significant environmental damage. Regulations now promote biodegradable materials to reduce ecological impact. Companies invest in bio-based plastics to replace harmful synthetic options and support sustainability [1].

Rising environmental awareness and crude oil prices drive demand for renewable, non-petroleum-based polymers. Biopolymers offer excellent barrier properties, flexibility, and transparency, making them viable alternatives to synthetic packaging. Utilizing agro-waste for biopolymer production presents a sustainable, eco-friendly solution for food packaging, with global bioplastic production expected to rise significantly [2].

The circular economy promotes fair, safe, and eco-friendly food systems. Utilizing agro-waste for packaging aligns with these goals. Despite increased research, agro-waste remains underexploited due to high production costs. Converting food waste into packaging supports sustainability by reducing waste and optimizing resources. Also, the circular bioeconomy concept focuses on creating a sustainable economic system by utilizing renewable biological resources, such as agro-waste, to produce food, materials, and energy. It emphasizes recycling, minimizing waste, and optimizing resource use to promote environmental health and economic resilience. While the circular economy focuses on minimizing waste and optimizing resources through reuse, recycling, and regeneration, the bioeconomy replaces fossil carbon with renewable sources from marine environments, agriculture, forestry, and various waste and by-products [3].

In this context, the primary goal of this work is to advocate for the increased use of agro-industrial waste, acknowledging its potential in food and beverage packaging. Furthermore, it seeks to educate and raise awareness about the significance of the circular bioeconomy system.

2 RESULTS & DISCUSSION

A significant amount of environmental pollution stems from human activities, highlighting the importance of studying societal attitudes and behaviors toward the environment. Due to the limited availability of natural resources and rising pollution levels, it is increasingly crucial to research and analyze the causes, impacts, and prevention strategies for these issues. Environmental challenges threaten Earth's life support systems, including air and soil pollution, water contamination, resource depletion, biodiversity loss, and overexploitation [4].

Integrating circular bioeconomy principles with sustainable practices in agribusiness lessens the strain on natural resources and reduces pollution while ensuring food security. Highlighting collaboration between these sectors emphasizes efficient resource use and by-product reuse. Adopting circular bioeconomy strategies to close systems promotes a shift in agriculture from linear to cyclical production models (Figure 1) [5,6].

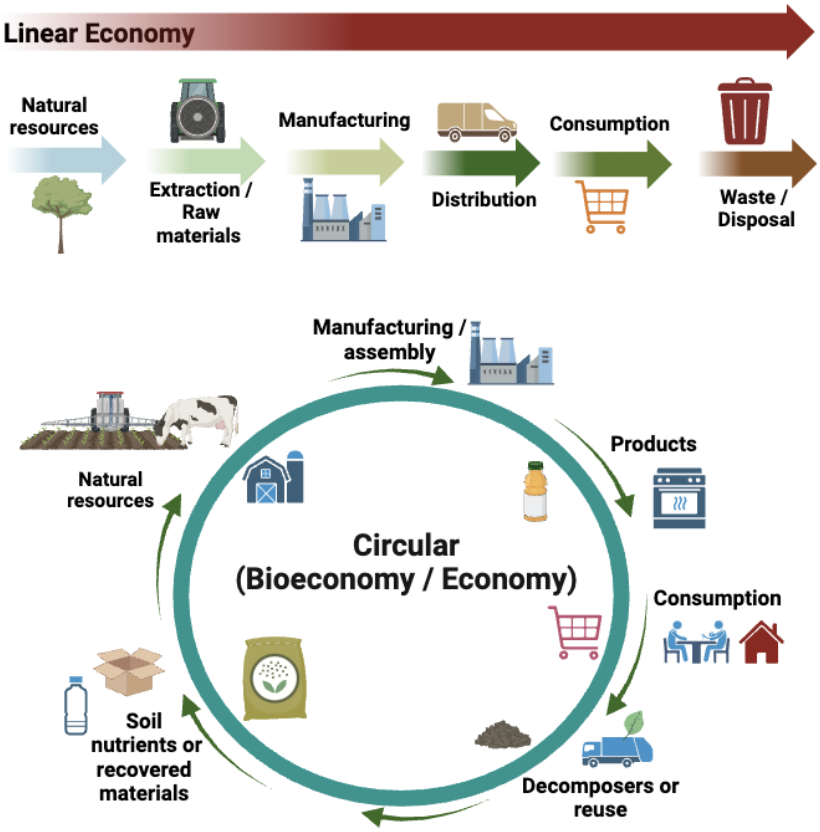

Figure 1. Schematic representation of the linear economy and circular bioeconomy systems.

Numerous underutilized biomass resources, known as agro-waste, could pose ecological and economic challenges. These should be regarded as residual resources discarded on land, contributing to environmental issues. In the capitalist economy, they can be transformed through cascade conversion processes into bioenergy and bio-based products [7]. An alternative waste minimization and utilization approach is converting readily available agricultural waste into valuable nano-reinforcing elements for biopolymers. There is a specific category of environmentally friendly polymers known as biodegradable polymers, which are both biodegradable and biocompatible. The demand for biotechnology-based sustainable packaging is increasing due to growing concerns about the environmental impact of packaging waste [8]. Despite significant advancements in the properties and versatility of synthetic polymers, major issues remain regarding their limited biodegradability and environmental harm. Biopolymers, however, can be produced from various feedstocks, including food waste, algae, and agricultural products like soybeans and corn [9].

Precursor or source materials are crucial in synthesizing biopolymers from agro-based waste. The demand for naturally occurring biobased polymers will continue to rise, and agro-based biopolymers, being abundant and cost-effective, are among the top resources for producing renewable energy. Numerous biopolymers have been produced using plant resources [10]. Plant resources provide essential polymers such as cellulose, lignin, starch, and pectin; it has also been observed that these polymers are easily extracted from agro-waste, including the peels, seeds, and shells of vegetables and fruits. The primary source of resources for polysaccharide-based biopolymers is plant-based food, particularly vegetables. While numerous agro-waste resources exist for biopolymer production, selecting the appropriate source is essential for yielding high-quality, sustainable polymers [11].

Agricultural waste comprises a large amount of material discarded by companies daily. Research suggests that this waste is not without value, as it contains substantial amounts of pectin, cellulose, hemicellulose, starch, and lignin. In the food sector, fruit is commonly used to produce various products, such as juices, jams, and jellies. The primary sources of fruit waste for producing starch, pectin, cellulose, and other products encompass seeds, pomace, pulp, and skin. Reports indicate that rice straw contains over 35% lignin, while maize stalks boast a cellulose content of approximately 60%. Conversely, bagasse, a sugarcane byproduct, comprises a hemicellulose content of about 55% [11,12]. Biodegradability, biocompatibility, sustainability, and non-toxicity are defining traits of polysaccharide-based biopolymers. Unlike lipid and protein-based counterparts, polysaccharide-based polymers exhibit greater thermal stability as they resist irreversible denaturation upon heating. However, they suffer from limited mechanical strength and heightened sensitivity to moisture. Vegetables represent a significant source of polysaccharides from agricultural waste. Starch, an inexpensive and naturally occurring biopolymer, finds wide application as a packaging material. Grains, legumes, and tubers are examples of agricultural waste rich in starch, serving as a valuable carbon source for bio-based polymers [13].

One of the most ubiquitous and extensively studied biopolymers is cellulose. Cellulose, abundant in supply, can be extracted through various methods, including acid hydrolysis. These materials must possess unique qualities to be highly coveted as replacements for conventional plastics. Despite its inedibility, cellulose is readily biodegradable and has diverse food engineering applications. The sensory properties of cellulose, including aroma, appearance, color, flavor, and taste, are widely acknowledged [11,14]Because of their lightweight nature, biomaterials can help reduce the weight of packaged materials. Additionally, cellulose readily integrates or encapsulates various naturally occurring antibacterial and antioxidant compounds, rendering it suitable for active food packaging applications. Moreover, cellulose-based packaging sheets offer excellent mechanical strength and barrier properties [9]. Cellulose, derived from diverse sources, is cost-effective and widely accessible. Wood is a primary source, while cellulose extracted from wood pulp has numerous applications. Other notable sources include cereal husks, corn kernels, sugarcane bagasse, and fruit and vegetable peels. Despite cellulose's suitability for packaging, recent research focuses on enhancing cellulose multilayers' mechanical and barrier properties, significantly improving tensile strength, grease resistance, and water resilience. Cellulose proves to be an excellent candidate for biocomposite film production; however, further advancements and regulations are necessary for its commercial utilization [15].

3 CONCLUSION

Minimizing losses and mitigating environmental harm can only be accomplished by efficient waste recovery, leading to zero waste. Transforming agricultural waste into valuable by-products for active and intelligent manufacturing materials is a sustainable approach that fosters zero waste. This valorization meets the rising demand for eco-friendly packaging materials while ensuring the continued safety of food products. Agro-industries often generate vast amounts of waste during their production processes, a concern with global ramifications. The more waste an industry produces, the greater the squandering of capital, resources, labor, materials, water, and energy invested in production. This waste contributes to adverse environmental effects, underscoring the industry's inefficiency. As concerns over the environmental impact of traditional food packaging grow, there's a surge in interest in biodegradable packaging among industries prioritizing sustainability. Petrochemical-based packaging, derived from non-renewable resources, raises environmental alarms. Sustainability principles guide stakeholders in the circular bioeconomy, aiming to minimize waste and maximize resource utilization, including agro-industrial waste. With the rising demand for sustainable food packaging, ongoing research is essential for advancing sustainable technological processes. Continual innovation aims to develop natural materials with bioactive, biodegradable, and even edible properties, revolutionizing the food packaging industry for improved environmental friendliness and efficiency. Yet, the circular bioeconomy faces challenges and unexplored territories. Technological barriers persist, but researchers' efforts drive the movement forward, continually broadening its horizons.

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