



VALORIZATION OF BANANA PEEL WASTE INTO FUNCTIONAL INGREDIENTS AND SUSTAINABLE PACKAGING MATERIALS: A CIRCULAR ECONOMY FRAMEWORK

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ABSTRACT

Banana peel, which accounts for approximately 30-40% of the total fruit weight and contributes to an estimated 114 million tonnes of agro-industrial waste annually, represents one of the most abundant yet underutilized by-products worldwide. Despite its substantial nutritional and functional profile - including dietary fiber, resistant starch, phenolic compounds, carotenoids, pectin, and phytosterols - banana peel is predominantly discarded, generating significant environmental and economic burdens. This review examines the scientific advances in the valorization of banana peel waste within a circular economy framework, focusing on two principal application pathways: the extraction of functional food ingredients and the development of packaging materials. Regarding functional ingredients, we discuss conventional and emerging extraction methodologies, biosustainable compound characterization, and evidence of antioxidant, antimicrobial, and prebiotic properties, as well as potential applications in food fortification and nutraceutical formulation. Concerning sustainable packaging, we address the use of banana peel-derived pectin, cellulose nanofibers, and bioactive extracts in the formulation of biodegradable films and coatings, highlighting their mechanical, barrier, and antimicrobial performance. Techno-economic and life cycle considerations are also reviewed to assess the feasibility of industrial-scale implementation. Collectively, the evidence supports banana peel as a promising raw material for the development of value-added products aligned with circular economy principles and a sustainable food supply chain.

INTRODUCTION

Banana peel represents one of the most abundant agro-industrial by-products generated by the global banana industry, accounting for approximately 30-40% of the total fruit weight. Although commonly discarded or used as low-value animal feed, banana peel contains valuable compounds such as dietary fiber, resistant starch, pectin, cellulose, phenolics, flavonoids, carotenoids, and tannins, which support its use as a functional and sustainable raw material. Within a circular economy framework, banana peel can be valorized through two main pathways: the recovery of bioactive compounds for functional food and nutraceutical applications, and the development of biodegradable, active, and sustainable packaging materials. Recent studies highlight its potential in food product reformulation, green extraction technologies, and innovative biopolymer-based packaging systems, offering promising alternatives to conventional waste management and petroleum-based plastics.

RESULTS AND DISCUSSIONS

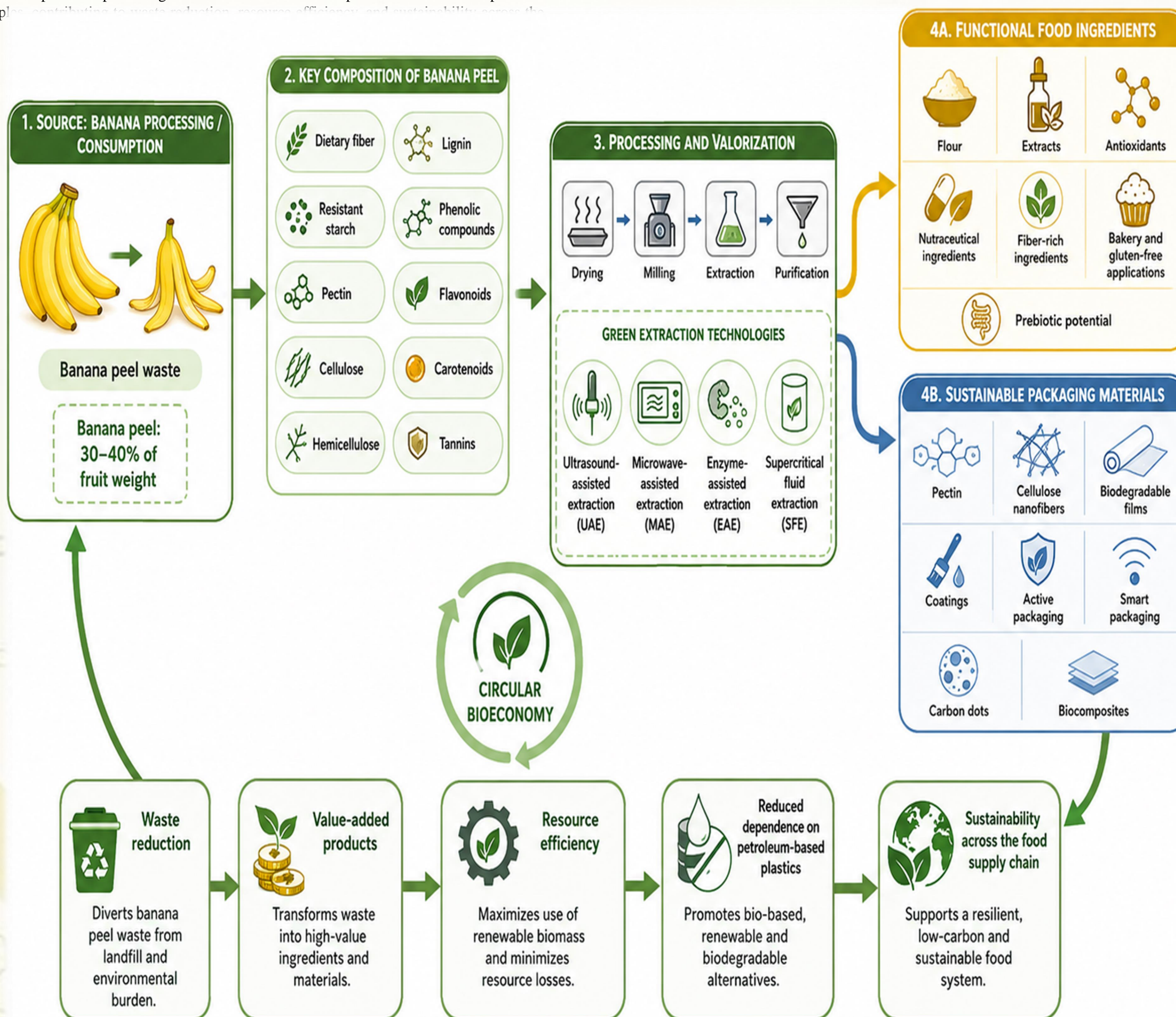
The reviewed studies highlight banana peel as a multifunctional agro-industrial by-product with significant potential for food, packaging, and biomaterial applications. Its valorization is mainly supported by its rich composition in dietary fiber, resistant starch, pectin, cellulose, phenolic compounds, flavonoids, carotenoids, and tannins, which provide antioxidant, antimicrobial, prebiotic, and film-forming properties.

From a processing perspective, green extraction technologies such as ultrasound-assisted extraction, microwave-assisted extraction, supercritical fluid extraction, and enzyme-assisted extraction have been shown to improve the recovery of bioactive compounds while reducing solvent use, processing time, and thermal degradation. However, drying remains a critical step due to the high moisture content of banana peel and its impact on energy consumption and compound stability.

In food applications, banana peel flour and extracts have been successfully incorporated into bakery, gluten-free, fortified, and functional products, contributing to increased dietary fiber, phenolic content, antioxidant activity, and prebiotic potential. These findings support the use of banana peel as a sustainable ingredient for food reformulation and nutritional enhancement.

In packaging applications, banana peel-derived pectin, cellulose, powder, bioactive extracts, and carbon dots have been used to develop biodegradable films, biocomposites, active coatings, smart packaging systems, and UV-protective materials. These systems showed improved mechanical, barrier, antioxidant, antimicrobial, and UV-blocking properties, suggesting their potential as alternatives to petroleum-based plastics.

Overall, banana peel valorization fits strongly within the circular bioeconomy framework, transforming an abundant waste stream into value-added functional ingredients and sustainable biomaterials. Nevertheless, industrial implementation still requires further optimization of extraction, drying, standardization, scale-up, life cycle assessment, and techno-economic feasibility.



CONCLUSION

The reviewed literature confirms that banana peel is not merely an agro-industrial residue, but a valuable raw material with strong potential within the circular bioeconomy. Due to its high content of dietary fiber, pectin, resistant starch, cellulose, and bioactive compounds, banana peel can be valorized through two major pathways: functional food ingredient development and sustainable packaging production.

In food applications, banana peel flour and extracts improve the nutritional and functional profile of bakery, gluten-free, and fortified products by increasing dietary fiber, phenolic content, antioxidant activity, and prebiotic potential. In packaging applications, banana peel-derived pectin, cellulose, biofillers, extracts, and carbon dots contribute to the development of biodegradable films, active coatings, smart packaging systems, wrapping paper, and biocomposites with improved mechanical, barrier, antimicrobial, antioxidant, and UV-blocking properties.

However, industrial-scale implementation still requires further optimization of drying, extraction, standardization, biorefinery integration, life-cycle assessment, and techno-economic feasibility. Overall, banana peel valorization represents a promising strategy for reducing food waste, improving resource efficiency, and supporting the transition toward sustainable and circular food and packaging systems.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the Faculty of Animal Production Engineering and Management, University of Agronomic Sciences and Veterinary Medicine Bucharest.

