Transforming Agricultural Waste into the Circular Economy: Biopackaging with Cocoa Mucilage

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Abstract

This study addresses the development of biopackaging for cocoa beans using agricultural residues, specifically cocoa waste, as raw material. An exploratory and descriptive scientific methodology was used, divided into three stages: literature review, laboratory experimentation, and life cycle analysis. The biopackaging was prepared from cocoa mucilage, a sugar-rich material, by extracting polyhydroxyalkanoate and biocellulose. These biomaterials are subjected to biotechnological techniques to improve their physical and barrier properties. Quantitative results showed that the biopackaging exhibits an oxygen barrier index of 9206.6 cm^3/m^2day, comparable to conventional plastics of 8500 cm^3/m^2day. In addition, the water barrier index of the biopackaging was 25.2 cm^3/m^2day, while petroleum-derived plastics show a value of 23 cm^3/m^2day. Furthermore, the life cycle analysis revealed that cocoa mucilage biopackaging can reduce greenhouse gas emissions, dependence on non-renewable resources, and energy consumption, thereby reducing negative environmental impacts in the cocoa value chain. In addition, they promote sustainable practices in the cocoa value chain, promote the circular economy of the product, reduce dependence on non-renewable polluting plastics derived from petroleum, and promote a culture of responsible consumption. Consequently, biopackaging derived from cocoa waste is a promising and environmentally friendly alternative that can be of great use to the food and packaging industry, although further research is required to improve the scalability of its production while promoting environmentally conscious management.

Keywords: biopackaging, cocoa waste, cocoa mucilage, cocoa beans, biotechnology.

1. Introduction

Cocoa is an agricultural product of great relevance worldwide because of its richness in bioactive compounds, particularly flavonoids and polyphenols, which confer antioxidant properties and potential benefits for cardiovascular health (Indiarto et al., 2021). As a result, cocoa is of multifaceted importance in the food and confectionery industry; being versatile in the production of various products, from fine chocolates to derivatives such as cocoa butter and liquor, positions it as a strategic resource in the global economy (Quek et al., 2020).

Cocoa production has increased over the years; by 2023, approximately 5 million tons of cocoa were produced, mainly in Africa, which produces about 74.5%, while in America 20% is produced and the remaining 5.5% is obtained from Asian countries (Melo, 2024). However, only 10% of cocoa pods are used in the industry, leading to the significant generation of agricultural waste, including shells, pulp, and other biomasses that can be a potential source of soil and water contamination (Mendoza-Meneses et al., 2021). Therefore, it is necessary to develop solutions for the management of this waste, addressing both its environmental impacts and opportunities for the creation of added value through the valorization of these by-products (Oussou et al., 2023).

In contrast, in the contemporary context of the food industry, a notable increase in the demand for eco-friendly packaging alternatives has been observed, driven mainly by growing environmental awareness and government regulations (Gholap et al., 2023). Similarly, this trend has increased interest in biopackaging, which is characterized by its biodegradable or compostable origin, thus contributing to the reduction of the environmental footprint (Acosta-Medina et al., 2023).

To address both needs, the main objective of this research is to explore the development of biopackaging for cocoa bean packaging using cocoa waste as a key raw material. Within this framework, the following three specific objectives are proposed for the research: (1) identify advances and trends in biopackaging from agricultural waste; (2) develop a biopackaging from cocoa waste that optimizes the conservation properties of the beans, improving the barrier characteristics against oxygen and humidity compared to conventional plastics; and (3) evaluate the environmental impact of the use of biopackaging in the cocoa value chain through a life cycle analysis, identifying reductions in the carbon footprint and the consumption of non-renewable resources. The following research questions are therefore sought to be answered: How can cocoa waste be transformed into biopackaging with improved properties for the conservation of cocoa beans? What is the impact of the implementation of these biopackaging products on the cocoa value chain within the framework of the circular economy?

2. Methods

To conduct this study, an experimental and exploratory methodology divided into three stages was used. First, to establish a solid basis for the design and formulation of biopackaging, a review of the scientific and technical literature related to the development of biopackaging and the use of agricultural residues as feedstock in the packaging industry was conducted.

Subsequently, the technical team of the project, led by the Macromolecules research groups of the National University of Colombia, the Research Group in Theoretical and Experimental Physical Chemistry and the Center for Environmental Studies and Research of the Industrial University of Santander in Colombia, used a biotechnological approach based on the work of Asgher et al. (2020) to produce the biopackaging. This approach included the extraction of bioactive compounds from cocoa residues through assisted fermentation, a process that facilitates the release of enzymes and the controlled decomposition of organic materials to increase the availability of useful biopolymers (Pawar & Rathod, 2020). Next, techniques such as ultrasonication were applied, which employs ultrasonic waves to break up cellular structures and improve the homogeneity of the mixtures, resulting in greater mechanical strength and better barrier properties in the packaging (Afzal et al., 2018).

Additionally, amidation and oxidation processes were carried out, which modify the chemical properties of the biopolymers by incorporating functional groups, improving their ability to form stable bonds and their resistance to moisture. Controlled drying allowed reducing the residual water content, which is essential to enhance the durability and structural stability of the biopackaging (Ghosh et al., 2012). Also, enzymatic fermentation techniques were applied to optimize biodegradability and moisture absorption capacity, using specific enzymes to break down cocoa residues and generate polymers with better physical and chemical characteristics (Cruz-Casas et al., 2021). These modifications significantly improved the functional properties of the material, such as its mechanical strength, water vapor permeability and antioxidant capacity, key attributes for its performance in the sustainable packaging market (Gamboa, 2024).

Finally, a life cycle analysis was implemented to assess the impact of biopackaging on the cocoa value chain. This analysis considered all stages of the product life cycle, from raw material extraction to final disposal, and included factors such as natural resource consumption, greenhouse gas emissions, and waste generation (Kakadellis & Harris, 2020).

3. Results and Discussion

3.1. Biopackaging from agricultural waste

In the last decade, there has been a growing interest in finding sustainable alternatives to conventional packaging materials, which are mostly petroleum-based. Biopackaging has emerged as a promising solution that harnesses agricultural waste as a renewable and abundant source of feedstock (Jahangiri et al., 2024). These materials offer advantages in terms of biodegradability and mitigation of adverse environmental impacts (Khandeparkar et al., 2024).

The scientific and technical literature has addressed various aspects of the development of biopackaging using agricultural residues. Studies have been conducted to evaluate the physical, mechanical, and barrier properties of materials obtained from different types of waste, such as fruit peels, plant stems, sugarcane bagasse, and fibers (Felicia et al., 2024). Fernández et al. (2024) found the feasibility of using these wastes as raw materials for the manufacture of biopackaging with characteristics suitable for specific applications.

One of the most used wastes in the manufacture of biodegradable and compostable packaging is sugarcane bagasse. This bagasse is a by-product of the sugar industry and contains a high proportion of cellulose, making it suitable to produce packaging materials (Marasinghe et al., 2024). Studies have shown that packaging made from sugarcane bagasse can exhibit barrier properties and mechanical strength comparable to conventional packaging while being biodegradable and compostable.

Another prominent example is banana peel. Hoque and Janaswamy (2024) found that the cellulose present in banana peels can be extracted and processed to produce biodegradable films with barrier properties suitable for food packaging applications. In addition, banana peel offers the advantage of being an abundant and low-cost waste, making it an attractive option from an economic and environmental point of view (Yin & Woo, 2024).

Similarly, coconut shell, a by-product of the coconut industry, contains a high proportion of lignocellulose, making it an ideal raw material for the manufacture of packaging materials (Udomphoch & Pormsila, 2023). Noor et al. (2020) found that coco coir can be processed to produce biodegradable films with adequate barrier properties to protect food from moisture, oxygen, and light, thereby prolonging its shelf life and maintaining its quality.

Similarly, a patent was found in the technical literature that describes the use of pineapple waste for the manufacture of biodegradable packaging. This technology takes advantage of the fiber of pineapple peel, which is rich in cellulose, to produce films that exhibit barrier and strength properties suitable for food packaging applications (Hughes, 2015). Another example comes from a patent describing a process for using corn waste in the production of packaging that can serve as an eco-friendly solution to reduce plastic waste in the food industry (Bao et al., 2023).

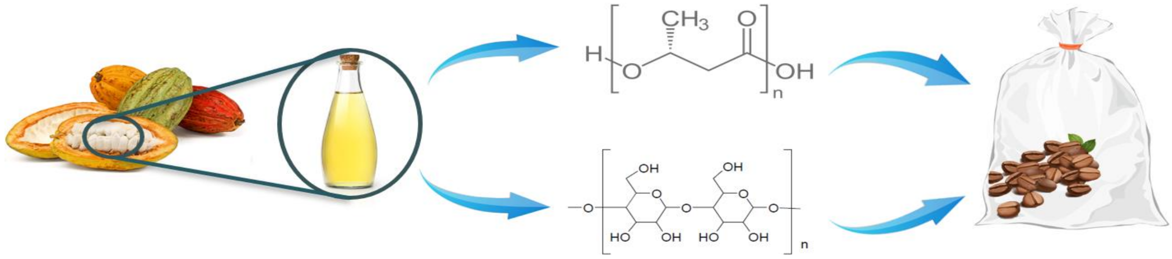
3.2. Development of biopackaging

In this case, the development of biopackaging for cocoa beans is based on cocoa mucilage, which is currently considered a waste. It is worth mentioning that the development of this biopackaging was carried out by the project's technical team led by the Macromoléculas research group of the Universidad Nacional de Colombia, the “Investigación en Fisicoquímica Teórica y Experimental GIFTEX” and the “Centro de Estudios e Investigaciones Ambientales CEIAM” of the Universidad Industrial de Santander in Colombia. This mucilage is a viscous, gel-like substance that is white or yellowish in color and coats the cacao nibs inside the fruit pods (Mian et al., 2022). For this study, mucilage was chosen as the main raw material because of its high concentration of simple sugars, such as glucose and sucrose, which can be used as a source of carbon in biotechnological processes (Villarreal-Bastidas et al., 2022).

Subsequently, this cocoa mucilage was extracted and purified using native Colombian bacteria to obtain polyhydroxyalkanoate (PHAs) and biocellulose (BC). These biodegradable polymers were then subjected to different material improvement techniques to optimize their mechanical and barrier properties. These techniques included assisted fermentation for the release of enzymes and controlled decomposition of organic materials, which increased the availability of useful biopolymers. Subsequently, ultrasonication was used to break down cellular structures and improve the homogeneity of the mixtures, which increased the mechanical strength of the material. Additionally, amidation and oxidation processes were applied, which modified the chemical properties of the biopolymers by incorporating functional groups, improving their resistance to moisture and the ability to form stable bonds. Controlled drying of the material allowed the residual water content to be reduced, enhancing its durability and structural stability.

Likewise, enzymatic fermentation techniques were implemented to optimize the biodegradability and moisture absorption capacity of the packaging, obtaining polymers with better physical and chemical characteristics. Once the basic components were obtained, the manufacturing process of the packaging itself began, which included steps such as mixing the different components to obtain a homogeneous composition, extrusion to shape the packaging and cutting to obtain the desired dimensions (See Figure 1). These steps were carried out under controlled conditions to ensure the quality of the final product.

Figure 1. Production of biopackaging with cocoa waste



Source: Own elaboration

The effectiveness of biopackaging was evaluated using various parameters and regarding barrier properties, water vapor transmission (WVTR) reached 25.2 cm^3/m^2day and oxygen vapor transmission (OTR) 9206.6 cm^3/m^2day (Gamboa, 2024). Values similar to those of low-density polyethylene barriers whose WVTR is 23 cm^3/m^2 day and its OTR is 8500 cm^3/m^2 day (Shebani et al., 2018).

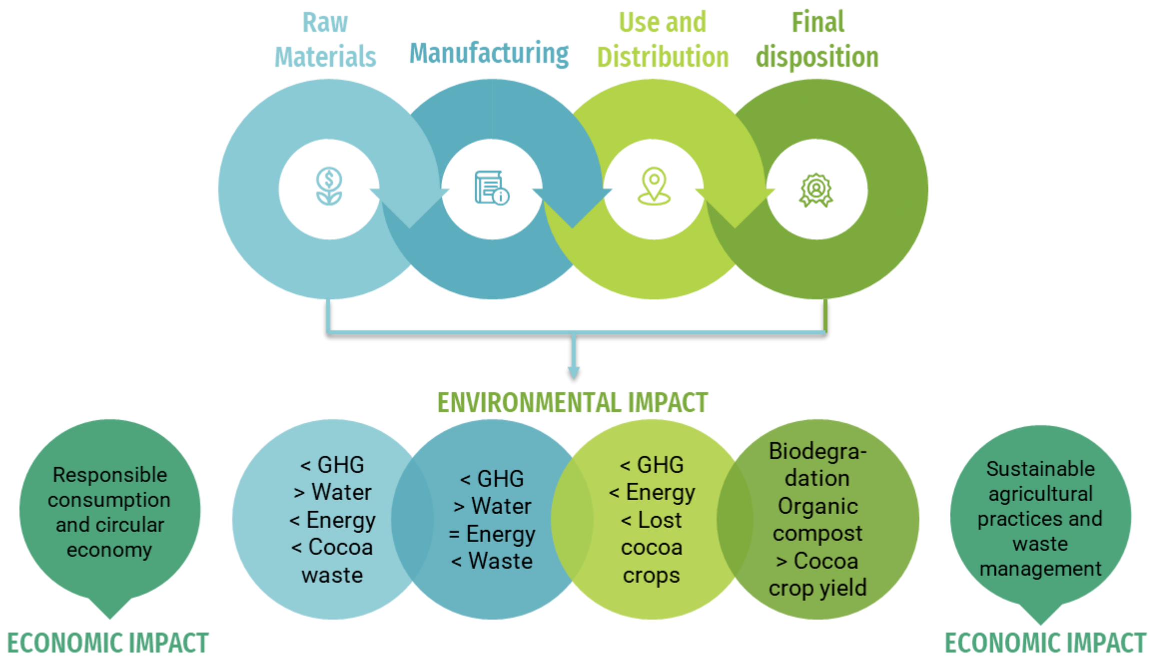
Regarding the permeability of biopackaging, oxygen permeability PO2 is 50.5 gm^2/m^2atmd, a property comparable to that of propylene whose PO2 index ranges between 50 and 100 gm^2/m^2atmd. Furthermore, the water permeability PH2O is 913.6 gm^2/m^2atmd, similar to that of polyethylene whose PH2O is 1083 gm^2/m^2atmd (Gamboa, 2024).

Regarding mechanical properties, cocoa waste biopackaging had a tensile strength ranging from 5.7 to 11 MPa, a Young's modulus of 346 MPa and a maximum deformation of 8.3 % (Gamboa, 2024). Properties similar to those possessed by low-density polyethylene (tensile strength of 9.93 MPa) and polypropylene (Young's modulus of 380 MPa and a maximum deformation of 14%), which are petroleum-derived materials widely used for packaging manufacturing (Shebani et al., 2018).

3.3. Life Cycle Analysis of Cocoa Waste Biopackaging

This analysis focuses on evaluating the life cycle of biopackaging made from cocoa waste, with the primary objective of determining its impact on the cocoa value chain, as shown in Figure 2. Therefore, all stages of the product life cycle will be considered:

Figure 2. Life Cycle Analysis of Cocoa Waste Biopackaging



Source: Own elaboration

1. Raw Material Extraction: The first stage involves the extraction of mucilage from cocoa. This mucilage is a by-product of cocoa production and is currently considered a residue (Mian et al., 2022). For this stage, specific harvesting and processing methods are employed, which can involve significant water consumption, but also allow for a reduction in greenhouse gas (GHG) emissions and positively impact the sustainability of cocoa plantations by offering a new source of income for farmers. In addition, this extraction process is directly connected to the management of waste in cocoa plantations, waste that decreases, as waste is transformed into a valuable resource.
2. Processing and Manufacturing: During this phase, cocoa mucilage is transformed into packaging material through industrial processes. At this stage, the carbon footprint is lower than that of conventional plastic packaging because the process of transforming cocoa waste into material emits less GHG. However, from the shredding of the waste to the formation and shaping of the material, large amounts of water and significant consumption of electrical and thermal energy are also required. In addition, the generation of solid waste is reduced compared to conventional manufacturing

processes, thanks to the comprehensive utilization of mucilage and the implementation of efficient waste management practices.

3. Distribution and use: Transporting and distributing biopackaging to end consumers also requires energy consumption. However, biopackaging can contribute to a further reduction in GHG emissions for two main reasons, First, by being designed to be lighter and more compact than conventional packaging, transport is optimized and emissions from distribution vehicles are reduced. The second reason is related to the potential of these biopackages to protect the quality of cocoa during storage and marketing, thus contributing to the reduction of post-harvest losses, which improves profitability for producers and contributes to the economic stability of the value chain.
4. End-of-life and final disposal: Upon reaching the end of its useful life, biopackaging can be composted and biodegraded at home to reduce waste accumulation in landfills and mitigate soil and water pollution. This is an environmental advantage over conventional plastic packaging, which can persist in the environment for centuries (Khandeparkar et al., 2024). In addition, this composting process generates organic compost that can be used as fertilizer in cocoa plantations, thus improving soil fertility and increasing crop yields.

Likewise, the implementation of these biopackages can have a series of benefits, not only environmental but also economic. First, dependence on nonrenewable plastic materials such as polyethylene and polypropylene are reduced. The latter materials are derived from petroleum, and their extraction and processing generate greenhouse gas emissions. Therefore, the use of biopackaging also reduces soil and water pollution and negative impacts on wildlife and aquatic ecosystems. Fostering a culture of responsible consumption and environmentally conscious management.

Similarly, the production of biopackaging from cocoa waste can encourage sustainable agricultural practices in cocoa plantations. Proper management of this waste not only provides an additional source of income for farmers but also promotes the circular economy by turning waste into useful resources. In addition, this incentivizes farmers to adopt cultivation practices that minimize waste generation, such as composting agricultural by-products and implementing agroforestry techniques.

However, as the production of these biopackages is sought to be scaled up and implemented at an industrial level, several important challenges arise. First, consistency in the supply of raw material is a critical factor, given that mucilage is a seasonal byproduct that depends on the cocoa harvest, which generates fluctuations in its availability. This can affect the continuity of production, so the implementation of efficient waste collection, storage, and processing systems is necessary to ensure a constant supply throughout the year. In addition, the infrastructure required for large-scale production of these packages involves significant investments in specialized technology, such as fermentation, ultrasound, and polymer processing equipment, as well as the training of qualified personnel to operate and maintain these systems. This infrastructure can increase initial costs and prolong implementation times.

Additionally, changes in packaging and logistics processes within the cocoa industry supply chain represent a relevant barrier, as companies must adapt their current systems to the requirements of biopackaging, which generates transition costs, adjustments in distribution processes, and potential delays in the adoption of these new technologies. These barriers can be even more challenging without public policies that encourage the transition to sustainable packaging or economic incentives that reduce the risks associated with investment in innovation. For large-scale adoption to be viable, the support of key actors in the value chain, both from the private and government sectors, is essential to facilitate the integration of this solution within the industry.

4. Conclusions

First, this study reveals a growing interest in biopackaging as a sustainable alternative to conventional packaging materials, highlighting its ability to harness agricultural waste as a renewable and abundant source of raw material. The findings highlight that sugarcane bagasse, banana peel, coconut shell, pineapple, and corn waste are promising feedstocks for the manufacture of biodegradable and compostable biopackaging with adequate barrier properties. These results suggest a path toward a more sustainable packaging industry that not only reduces dependence on petroleum-based materials but also contributes to mitigating adverse environmental impacts.

Similarly, biopackaging made from cocoa mucilage, explored in this study, represents a sustainable solution for the food industry. The use of this waste as the main raw material, due to its high concentration of simple sugars, allows the production of polyhydroxyalkanoate (PHAs) and biocellulose (BC), biodegradable polymers that, after being subjected to improvements and after manufacturing the packaging, achieve characteristics similar to traditional low-density polyethylene packaging. However, additional studies are needed to address the improvement of some properties such as mechanical resistance. In addition, large-scale economic viability remains a challenge, as the techniques used in this study are in pilot phases and require optimization for industrial application.

These biopackages made from cocoa waste promote a circular economy and mitigate the environmental impact on the cocoa value chain. The life cycle analysis of these biopackages not only reduces greenhouse gas emissions, energy consumption, and dependence on non-renewable resources but also promotes sustainable practices in the cocoa industry. In addition, the adoption of these biopackages could not only promote a culture of responsible consumption but also improve the brand image of the companies that use them, which are committed to environmental sustainability. Therefore, this study demonstrates the potential of cocoa mucilage biopackaging to mitigate environmental impact within a circular economy.

However, one of the main limitations of the current study is the lack of a comprehensive life cycle analysis of cocoa mucilage biopackaging compared to other biopackaging alternatives available on the market. Although the study provides a preliminary assessment of the environmental benefits, comprehensive data covering all life cycle phases from production to final disposal are not available. Second, the scalability of the processes used remains a significant challenge. The methods employed to transform cocoa mucilage into biopackaging are still in the pilot phase, raising questions about their economic and technical feasibility on a large scale. Third, there are limitations regarding the mechanical properties of the biopackaging produced. Although they show promising characteristics, such as biodegradability and barrier properties, their mechanical strength is not yet comparable with conventional petroleum-derived polymer packaging, which could limit their commercial adoption in high-performance applications. Additionally, a fourth limitation concerns the geographical and industrial diversity of the scenarios evaluated. This study has focused on a limited context, and variations in climatic, production, and market conditions that could affect both the performance of biopackaging and its environmental impacts in other regions or industrial sectors have not been adequately assessed.

To overcome these limitations and advance research, several concrete directions are suggested. First, it is essential to conduct broader life cycle studies that include a variety of geographic and industrial settings, in order to obtain a more complete picture of the environmental impact of these biopackaging in different contexts. Second, it is necessary to investigate the long-term stability of biopackaging under various storage and transportation conditions, especially in the food industry, where compliance with safety standards and product integrity are crucial. Also, the development of more efficient and scalable processing technologies that reduce energy and water consumption could be prioritized, improving the economic viability of large-scale biopackaging production. Finally, it would also be beneficial to further explore opportunities for integrating these biopackages into a circular value chain, which would include analyzing potential applications in the reuse or recycling of biopackages and their compatibility with other bioproducts generated from agricultural waste.

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References

Acosta-Medina, J. K., Pacheco, O. E. C., & Avella, A. C. P. (2023). Empaques vs Bioempaques para alimentos: Una comparación a nivel técnica, comercial y normativa. *Ingeniería y Competitividad Revista Científica y Tecnológica*, 25(3), e-21213066. https://doi.org/10.25100/iyc.v25i3.13066

Afzal, A., Nawfal, I., Mahbubul, I. M., & Kumbar, S. S. (2018). An overview on the effect of ultrasonication duration on different properties of nanofluids. *Journal Of Thermal Analysis And Calorimetry*, 135(1), 393-418. https://doi.org/10.1007/s10973-018-7144-8

Asgher, M., Qamar, S. A., Bilal, M., & Iqbal, H. M. (2020). Bio-based active food packaging materials: Sustainable alternative to conventional petrochemical-based packaging materials. *Food Research International*, 137, 109625. https://doi.org/10.1016/j.foodres.2020.109625

Cruz-Casas, D. E., Aguilar, C. N., Ascacio-Valdés, J. A., Rodríguez-Herrera, R., Chávez-González, M. L., & Flores-Gallegos, A. C. (2021). Enzymatic hydrolysis and microbial fermentation: The most favorable biotechnological methods for the release of bioactive peptides. *Food Chemistry Molecular Sciences*, 3, 100047. https://doi.org/10.1016/j.fochms.2021.100047

Felicia, W. X. L., Rovina, K., ‘Aqilah, N. M. N., Mantihal, S., & Huda, N. (2024). Chitosan/aloe vera gel coatings infused with orange peel essential oils for fruits preservation. *Current Research In Food Science*, 8, 100680. https://doi.org/10.1016/j.crfs.2024.100680

Fernández, M., Levy, I. K., Salustro, D., Negri, R. M., & Medina, L. M. S. (2024). Use of Lemon Peel Extract as Antimicrobial Supported on Eco-friendly Polyvinyl Alcohol/Polydimethylsiloxane Sponges. *Journal Of Polymers And The Environment*. 32, 3179–3194 https://doi.org/10.1007/s10924-023-03148-7

Gamboa S. M. (2024, 1 febrero). Producción de biopelículas de polihidroxialcanoatos/nanofibras de celulosa modificada y estudio de sus propiedades fisicoquímicas, mecánicas y de barrera. https://noesis.uis.edu.co/items/9290238b-a624-45e1-8b2b-e893f6764742

Gholap, A. D., Sawant, S. D., Sayyad, S. F., Hatvate, N. T., Chavan, M. J., Rojekar, S., & Faiyazuddin, M. (2023). Food Biopackaging for Human Benefits: Status and Perspectives. *En Biobased Packaging Materials: Sustainable Alternative to Conventional Packaging Materials*. Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-6050-7_1

Ghosh, S. C., Ngiam, J. S. Y., Seayad, A. M., Tuan, D. T., Chai, C. L. L., & Chen, A. (2012). Copper-Catalyzed Oxidative Amidation of Aldehydes with Amine Salts: Synthesis of Primary, Secondary, and Tertiary Amides. *The Journal Of Organic Chemistry*, 77(18), 8007-8015. https://doi.org/10.1021/jo301252c

Hoque, M., & Janaswamy, S. (2024). Biodegradable packaging films from banana peel fiber. *Sustainable Chemistry And Pharmacy*, 37, 101400. https://doi.org/10.1016/j.scp.2023.101400

Hughes, D. H. (2015, 17 septiembre). US2053238A - Pineapple packing - Google Patents. https://patents.google.com/patent/US2053238A/en

Indiarto, R., Subroto, E., Sukri, N., & Djali, M. (2021). Cocoa (Theobroma cacao L.) Beans Processing Technology: A Review of Flavonoid Changes. *Asian Journal of Plant Sciences*, 20(4), 684-693. https://doi.org/10.3923/ajps.2021.684.693

Jahangiri, F., Mohanty, A. K., & Misra, M. (2024). Sustainable biodegradable coatings for food packaging: challenges and opportunities. *Green Chemistry*. 26, 4934-4974. https://doi.org/10.1039/d3gc02647g

Kakadellis, S., & Harris, Z. (2020). Don't scrap the waste: The need for broader system boundaries in bioplastic food packaging life-cycle assessment – A critical review. *Journal Of Cleaner Production*, 274, 122831. https://doi.org/10.1016/j.jclepro.2020.122831

Khandeparkar, A. S., Paul, R., Sridhar, A., Lakshmaiah, V. V., & Nagella, P. (2024). Eco-friendly innovations in food packaging: A sustainable revolution. *Sustainable Chemistry And Pharmacy*, 39, 101579. https://doi.org/10.1016/j.scp.2024.101579

Marasinghe, W. N., Jayathunge, K. G. L. R., Dassanayake, R. S., Liyanage, R., Bandara, P. C., Rajapaksha, S. M., & Gunathilake, C. (2024). Structure, Properties, and Recent

Developments in Polysaccharide- and Aliphatic Polyester-Based Packaging—A Review. *Journal Of Composites Science*, 8(3), 114. https://doi.org/10.3390/jcs8030114

Melo, M. F. (2024, 28 marzo). África: principal productor mundial de cacao. *Statista Daily Data*. https://es.statista.com/grafico/31996/volumen-de-la-produccion-mundial-de-cacao-en-grano/

Mendoza-Meneses, C. J., Feregrino-Pérez, A. A., & Gutiérrez-Antonio, C. (2021). Potential Use of Industrial Cocoa Waste in Biofuel Production. *Journal Of Chemistry*, 2021, 1-11. https://doi.org/10.1155/2021/3388067

Mian, T. M. S., Camara, F., Coulibaly, W. H., & Beugré, G. A. M. (2022). Assessment of physicochemical, biochemical and functional properties of mucilage cocoa juice during storage at room temperature. *Trends Journal Of Sciences Research*, 1(1), 10-26. https://doi.org/10.31586/ojfn.2022.186

Noor, A. M., Afriani, F., Puriza, M. Y., & Tiandho, Y. (2020). Bio-packaging based on a composite of paper waste and coconut fiber. *IOP Conference Series. Earth And Environmental Science*, 599(1), 012051. https://doi.org/10.1088/1755-1315/599/1/012051

Oussou, K. F., Guclu, G., Kelebek, H., & Selli, S. (2023). Valorization of cocoa, tea and coffee processing by-products-wastes. *Advances In Food And Nutrition Research*, 91-130. https://doi.org/10.1016/bs.afnr.2023.03.003

Pawar, S. V., & Rathod, V. K. (2020). Role of ultrasound in assisted fermentation technologies for process enhancements. *Preparative Biochemistry & Biotechnology*, 50(6), 627-634. https://doi.org/10.1080/10826068.2020.1725773

Shebani, A., Klash, A., Elhabishi, R., Abdsalam, S., Elbreki, H., & Elhrari, W. (2018). The influence of LDPE content on the mechanical properties of HDPE/LDPE blends. *Res. Dev. Mater. Sci*, *7*(5), 791-797.

Udomphoch, P., & Pormsila, W. (2023). Readiness of the Community and Customer Attitudes towards Making Packaging from Coconut Residue: A Case Study of The Kala Ake-Ban Krachom Thong Group. *Journal of Community Development Research (Humanities and Social Sciences)*, 16(2), 50-61.

Quek, R. y. C., Peh, E., & Henry, C. J. (2020). Effects of Cocoa Butter and Cocoa Butter Equivalent in a Chocolate Confectionery on Human Blood Triglycerides, Glucose and Insulin. *Foods*, 9(4), 455. https://doi.org/10.3390/foods9040455

Villarroel-Bastidas, J. V., Del Carmen Angulo-Ortega, G., & Briones-Bitar, J. (2022). Degradación de azúcares reductores del mucílago de cacao para la producción de bioetanol. *Revista Facultad de Ingeniería Universidad de Antioquia*. (108), 98–106. https://doi.org/10.17533/udea.redin.20220992

Yin, Y., & Woo, M. W. (2024a). Transitioning of petroleum-based plastic food packaging to sustainable bio-based alternatives. *Sustainable Food Technology*, 2(3), 548-566. https://doi.org/10.1039/d4fb00028e