

Making Eco-Friendly Tea Packaging from Arecanut Leaf Sheath

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Abstract: Areca leaf sheath is a kind of agricultural waste, which has a certain thickness, stiffness, and mechanical strength. It is strong and plastic, and has development potential in the field of environmental protection packaging. The existing leaf sheath processing products are all primary processing products, which generally have defects such as rough surfaces and insufficient mechanical strength, which limit their large-scale application. In this study, tea packaging containers were prepared from areca leaf sheath by a pure physical process of pretreatment, water soaking, cooking, hot pressing, cooling, and finishing. The process parameters were evaluated, and the optimum process conditions were determined as follows: molding pressure 2.0 MPa, molding temperature 150°C, holding time 6 min. The container has a smooth surface, dense microstructure, stable size, no crack stratification, and good waterproof and bearing capacity. The process has no chemical addition and low cost, which provides a high-value utilization way for agricultural waste, helps to alleviate plastic pollution, and promotes green manufacturing and the circular economy.

Keywords: Areca Leaf Sheath; Green packaging; Tea container; Agricultural waste

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1. Introduction

Driven by the concept of global environmental protection, resource conservation, and sustainable development, the packaging industry is accelerating its transformation to bio-based alternative materials^[1–3]. An ideal environmentally friendly packaging material should be biodegradable, renewable, and have little impact on the environment during processing, in line with the principles of circular economy and green manufacturing^[4–7]. Due to its wide range of sources, low cost, and biodegradability, lignocellulosic agricultural by-products are regarded as environmentally friendly packaging materials with both waste recycling and plastic reduction potential, and have become the focus of development^[8–9]. The material naturally has the advantages of mechanical strength and flexibility, which just meet the needs of packaging applications^[10]. Areca leaf sheath fiber contains about 57.3% cellulose and 13.3% hemicellulose, which is an ideal substrate for the preparation of biocomposites^[11]. About 10–12 tons of organic waste are produced per hectare per year on its plantations, and most of the leaf sheaths are currently abandoned or burned, resulting in waste of resources and additional carbon emissions^[12]. However, at present, the packaging products of areca leaf sheath generally have defects such as poor mechanical durability and poor surface quality, which restrict their industrialization promotion and market

competitiveness^[13]. Therefore, it is necessary to develop innovative processing technologies that can be scaled up to fully improve the comprehensive performance of areca leaf sheath-based packaging and release its application potential in the field of green packaging^[14].

Steam explosion is a common heat treatment process, which is often used in the dehydration of lignocellulose. The rapid evaporation of intracellular water by high-pressure steam and instantaneous decompression leads to the expansion and separation of fiber bundles, which can significantly improve the aspect ratio of lignocellulosic fibers, enhance the bonding force between fibers and the mechanical properties of products^[15–16]. This process has been successfully applied to agricultural wastes such as bagasse and corn straw, but has not yet been applied to the study of areca leaf sheath. Tea has strict requirements on the barrier and fragrance retention of packaging materials^[17]. The use of areca leaf sheaths to prepare durable and reusable tea containers can realize the high-value utilization of local agricultural waste. At the same time, the beautiful shape of the container also conforms to the commodity attributes of tea.

Therefore, in this study, a pure physical method based on steam explosion was used to prepare tea packaging containers. The feasibility of the process under different parameter settings was analyzed, and the appearance quality and basic properties of the prepared containers were determined, which provided a basis for judging its applicability as a tea packaging material.

2. Materials and methods

2.1. Materials

The areca leaf sheath was obtained from Xinping County, Yunnan Province, China, and the thick and flat leaf sheath was selected as the raw material to ensure that the thickness and structure of the sample were consistent (**Figure 1**).



Figure 1. Areca leaf sheath

2.2. Preparation of arecanut tea containers

The container fabrication process consists of six sequential steps, as illustrated in **Figure 2**. Three representative process parameter combinations, designated S1, S2, and S3, were investigated (**Table 1**).

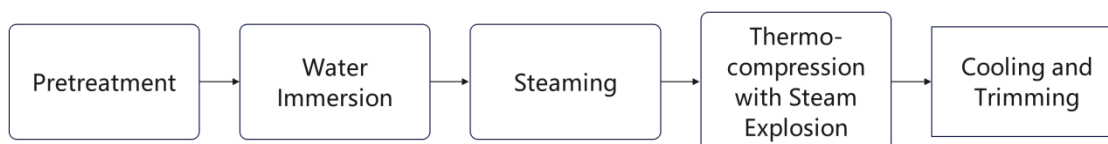


Figure 2. Process flow diagram

Table 1. Processing parameters

Sample ID	Pretreatment MC (%)	Immersion Time (min)	Steaming Time (min)	Cooling Time (min)	Molding Pressure (MPa)	Molding Temp (°C)	Dwell Time (min)
S1	20	150	15	15	2.0	150	6
S2	25	120	10	10	1.0	200	8
S3	15	60	20	20	3.0	120	4

2.2.1. Pretreatment

The leaf sheath was placed in an environment with a temperature of 25°C and a relative humidity of 45% for 3 days, so that the water content was between 15% and 25%, and then stored in a sealed container.

2.2.2. Cleaning and soaking

The pretreated leaves were washed with deionized water and soaked in deionized water. The soaking time was adjusted according to the water content after pretreatment. The soaking time of the sample S2 with higher water content was 150 minutes, while the soaking time of the sample S3 with lower water content was 60 minutes. In this process, water molecules gradually infiltrated into the fiber gap, softening the leaf sheath tissue and increasing the plasticity. After soaking, the surface of the leaves was gently wiped with non-woven fabric to absorb the free water attached to the surface.

2.2.3. Steaming

The soaked leaves were cooked at 100°C for 10–20 minutes. The pretreatment moisture content of S1 is suitable, and the cooking time is 15 minutes. The water content of S2 is high, and the cooking time is 10 minutes to avoid excessive softening and affect the structural stability. Due to the low initial water content of S3, the cooking time was 20 minutes to fully activate the cellulose chain and improve the thermoplasticity.

2.2.4. Thermo-compression with steam explosion

After cooking, the leaf sheath was cooled at room temperature for 10–20 minutes, so that the water content reached 50%–60%. The mold was placed in a preheated mold for hot pressing. The mold temperature was 120–200°C, and a pressure of 1.0–3.0MPa was applied for 4–8 minutes (see **Table 1** for specific parameters), and then the pressure was immediately released. The rapid pressure relief process causes the superheated water inside the fiber to vaporize instantaneously, and the fiber rebounds rapidly and finalizes. After cooling, the molded product is taken out.

2.2.5. Cooling and trimming

The author placed the freshly formed container at room temperature, which was around 25°C. For about 30 to 60 seconds, the author just let it sit there. The shape became fixed. The author trimmed off the extra edges. The author used fine sandpaper to lightly sand the surface. The edges became smooth.

2.3. Performance evaluation

The appearance quality was visually tested to observe the surface smoothness, color uniformity, edge regularity, cracks, delamination, and other defects of the container. Each group of parameters (S1, S2, S3) was subjected to 10 repeated tests, and the yield of the process was calculated by the proportion of defect-free containers. A water resistance test was carried out by injecting 2 cm deep water into the container at room temperature, and the leakage and surface softening after standing for 1 hour and 2 hours were checked and evaluated.

3. Results and analysis

3.1. Macroscopic quality and process feasibility

Three sets of process parameters (S1, S2, S3) obtained containers with significantly different macroscopic characteristics, as shown in **Figure 3**.

Among the three samples, S1 has the highest surface smoothness and uniform brown color. The edge is clear, the outline is clear, and no cracks or delaminations are observed (**Figure 3A**). The surface texture of S2 is slightly rough, and there are slight burrs on the edge. This is mainly due to the low molding pressure and insufficient fiber compression, resulting in slightly insufficient thermoplastic deformation, but the overall structure is complete (**Figure 3B**). The surface of S3 is relatively smooth, but the color is darker, showing a certain degree of excessive compression. Slight cracks appeared in the folding line position of some samples (**Figure 3C**). Too high a processing temperature is the main cause of these defects. Too high a temperature can also cause local carbonization, microcracks, and uneven color.



(A) Sample S1 (2 MPa, 150°C)



(B) Sample S2 (1 MPa, 200°C)

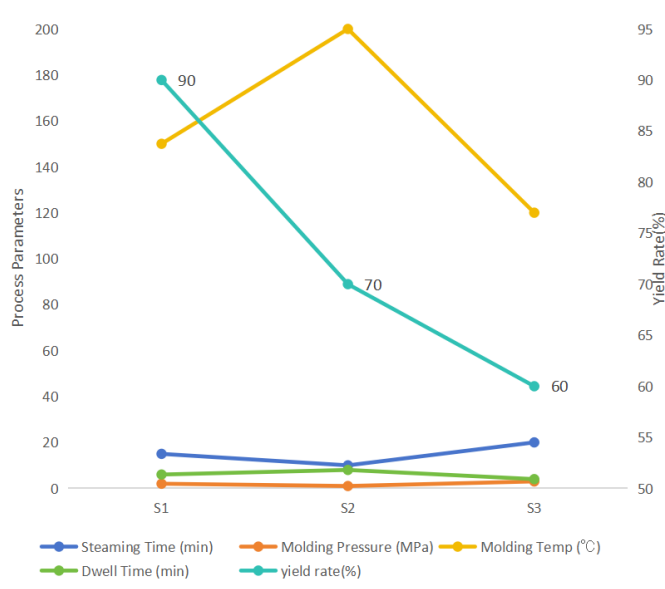


(C) Sample S3 (3 MPa, 120°C)

Figure 3. Tea containers made under different parameters

3.2. Process yield and stability

Each group of parameters was subjected to 10 repeated tests, and the yield was calculated. The curve of process parameters and yield is shown in **Figure 4**. The yield of S1 was 90% (9 out of 10 containers had no defects), and the defective product was caused by slight tearing at the edge of the sheath material, indicating that the defect was mainly affected by the quality of the material itself, rather than the process problems in the manufacturing process. The yield of S2 is 70 %. The main reasons for the failure include insufficient filling of the mold corner, rough surface, and insufficient compaction, which leads to uneven local thickness and increased edge burrs. The yield of S3 is only 60%, and the failure is mainly reflected in the occasional fine cracks in the cooling stage, which may be caused by the increase in internal stress caused by higher molding pressure.

**Figure 4.** Process parameters-yield rate curve

Under the conditions corresponding to sample S1, the fibers are uniformly heated and fully softened during the hot pressing process. The surface of the product is smooth, the microstructure is dense, and there is no phenomenon of excessive drying or stress concentration. Due to the high hot pressing temperature of sample S2, the fiber was dried too fast before complete curing. Sample S3 is over-compressed due to excessive pressure, resulting in increased internal stress and increased cracking risk. The reasonable matching of pressure and temperature is the key factor to realize the surface

finish and structural integrity of the container.

3.3. Water resistance

The tested container had no leakage after 1 hour of water injection, and only the inner surface began to be slightly wet, without softening or deformation. After 2 hours, there was still no leakage, and the humidity of the inner surface increased further (**Figure 4**). This indicates that the dense structure formed by hot-pressed areca leaf sheath fibers has the ability to prevent water penetration and provides sufficient rigid support.



Figure 5. Water leakage of three container groups after 2 h

3.4. Discussion

In the process of soaking, cooking, and hot pressing, the sheath fibers underwent a series of changes of water absorption, expansion, and structural reorganization, which realized the improvement of mechanical strength and waterproofness, and retained the degradation of natural fibers ^[18]. The container prepared under the optimal experimental parameters has a smooth surface, stable size, and high yield. It shows that the areca leaf sheath can be used to manufacture a packaging container with both durability and aesthetics, and this method is feasible in practical application.

The whole manufacturing process does not add any chemical composition, which can ensure the safety of food contact. The microporous structure formed after hot pressing can not only effectively block the entry of moisture from the outside of the container, but also allow the internal moisture to disperse outward in an orderly manner. This ‘two-way regulation’ feature can maintain the water content of tea. The surface of the container has the natural texture and vein pattern of areca leaf sheath. These natural features are in line with the aesthetic style of the oriental tea ceremony, which can show unique regional cultural connotation and manual texture, enhance the recognition of brand narrative, and help to realize product differentiation in the high-end tea market. Using locally procured agricultural wastes as raw materials can significantly reduce carbon emissions in transportation. After the container is discarded, it can be completely degraded within 60 days under natural conditions without any microplastic residues.

4. Conclusion

Tea packaging containers with excellent surface quality, high processing yield, and good waterproof performance can be prepared by a steam explosion pure physical process of areca leaf sheath. The process has no chemical addition, simple operation, and low cost. The excellent comprehensive performance of the container provides reliable protection for tea packaging, indicating that this path uses agricultural waste as raw material to achieve high-value conversion through physical processing, which plays a positive role in reducing plastic pollution and promoting the green economy, and provides a practical solution for sustainable packaging.

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Disclosure statement

The author declares no conflict of interest.

References

- [1] Zhang Z, Cao L, Feng M, et al., 2025, Recent Developments and Prospective Packaging-related Applications of Lignocellulose. *Packaging Engineering*, 46(15): 62–71.
- [2] Regmi S, Pradhan S, Thakur A, 2025, Packaging through the Ages: A Heuristic Journey from Leaves to Plastics to Cellulosic Fibers and Smart Technologies. *International Journal of Biological Macromolecules*, 330(1): 147885.
- [3] Angela T, Rusmanto T, 2025, Global Economic and Sustainability Trends in Green Packaging: A Systematic Literature Review. *Edelweiss Applied Science and Technology*, 9(9): 715–730.
- [4] Kumar V, Sonika, Ram DK, et al., 2025, Sustainable Modifications in Food Packaging: A Comprehensive Review of Biodegradable Material Revolutions. *Applied Food Research*, 5(2): 101385.
- [5] Dewangan B, Mittal M, Eelager MP, 2025, Tailored Biopolymer and its Nanocomposites along with EPR Frameworks under Circular Economy: A Dual Strategy for Sustainable Packaging Solutions. *Sustainable Chemistry and Pharmacy*, 2025(46): 102092.
- [6] Mujtaba M, Lipponen J, Ojanen M, et al., 2022, Trends and Challenges in the Development of Bio-based Barrier Coating Materials for Paper/cardboard Food Packaging: A Review. *Science of the Total Environment*, 2022(851): 158328.
- [7] Hasoon KTN, Panicker UG, 2026, Beyond Fossil Plastics: Next-generation PLA-based Bio-packaging for Industrial Applications—Advances, Challenges, and Data-driven Insights. *RSC Advances*, 2026(16): 15095–15118.
- [8] Carvalho ACF, Ghosh S, Hoffmann TG, et al., 2025, Valuing Agro-industrial Waste in the Development of Sustainable Food Packaging based on the System of a Circular Bioeconomy: A Review. *Cleaner Waste Systems*, 2025(11): 100275. <https://doi.org/10.1016/j.clwas.2025.100275>
- [9] Monisha S, Selvakesavan RK, Navaroja R, et al., 2025, Utilization of Arecanut Leaf Sheath and Orange Peel as Environmentally Friendly Alternative Substrates for Cultivating *Pleurotus ostreatus*. *Biomass Conversion and Biorefinery*, 15(6): 9035–9046.
- [10] Vishun KS, Anuroop PA, Anto LP, et al., 2020, Areca Fiber Reinforced LLDPE Biocomposite. *Materials Today: Proceedings*, 24(Part 3): 1924–1931.
- [11] Madyaratri EW, Ilyas RA, Fatriasari W, et al., 2025, Recent Developments in Lignocellulosic Areca catechu-based Biocomposites and their Potential Industrial Applications: A Review. *International Journal of Biological Macromolecules*, 328(Pt 1): 146867.
- [12] Prasannakumaran KM, Shivani VM, Chariar SJK, 2024, Areca Sheath Waste: An Underutilised Entrepreneurial Resource. Springer, Berlin, 63–73.
- [13] Xu XY, 2023, Innovative Application of Natural Packaging Materials in Yunnan Agricultural Product Packaging: A Case Study of Betel Palm Leaf Sheaths. *Papermaking Equipment and Materials*, 52(214): 69–70.
- [14] Dissanayake DGK, Weerasinghe D, Perera TDR, et al., 2021, A Sustainable Transparent Packaging Material from the Arecanut Leaf Sheath. *Waste and Biomass Valorization*, 12(10): 1–18.
- [15] Zhao W, Zhang J, Zhang W, et al., 2023, Effect of Bamboo Unit Morphology on the Preparation of Bamboo Fibers by

- Steam Explosion. *Industrial Crops and Products*, 2023(202): 117066.
- [16] Vishal K, Arun A, Rajkumar K, 2024, Extraction and Characterization of Steam-exploded Silane-treated Cellulosic Natural *Vernonia elaeagnifolia* Long Fibre. *Industrial Crops and Products*, 2024(214): 118576.
- [17] Bai FQ, Chen GJ, Liu YX, et al., 2025, Flavor Stripping in Green Tea Induced by Plastic Packaging Materials during Storage. *Food Packaging and Shelf Life*, 2025(48): 101451.
- [18] Chen H, Liu L, 2019, Unlocking the Potential of Lignocellulosic Biomass: Steam Explosion as a Pretreatment. *Bioresource Technology*, 2019(293): 122039.

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