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Research article

Influence of Molding Condition and Moisture Content of Arecanut Leaf Sheath on Quality of Food Plates

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Abstract: This research focuses on the molding conditions for producing areca nut leaf sheath-based food plates. Food plate samples from the Arecanut leaf sheath were prepared using compression molding. The molding temperature varied at 150, 160, and 170 °C, and the molding time was 1, 2, and 3 min. The quality of the obtained plates was assessed based on their physical appearance. Increasing the molding temperature and molding time obtained smoother and more beautiful surfaces. However, the most suitable molding condition was a temperature of 170 °C for 2 min. The moisture content of areca nuts before molding should be in the range of 20–60 wt.%. The research findings will assist those looking to produce food packaging from the arecanut leaf sheath by providing insights into their components and optimal molding conditions. This will streamline the process, reducing the time spent studying molding conditions and minimizing production waste.

Keywords: Arecanut leaf sheath; Food packaging; Molding condition; Optimal moisture content range and Minimizing production waste

1. Introduction

The packaging industry has often emphasized the importance of production costs and product quality rather than considering the disposal of used packaging. As a result, the amount of waste generated has increased, especially food and beverage packaging that degrades slowly or is non-biodegradable. Also, around 95–99% of plastic materials are synthetic plastics produced by petrochemical industries from non-renewable sources [1]. Synthetic plastic products find extensive applications in medical appliances, packaging, and building materials. In India, the packaging sector alone consumes 43% of the synthetic polymers produced annually. Improper disposal methods, such as burning, produce toxic pollution that impacts human health and the environment. Visible environmental problems arise from discarded packaging littering streets, directly affecting communities and the environment. This is particularly true of food and beverage containers made from plastics and foams, contributing to marine litter. Additionally, this type of packaging can release pollutants into the air. Certain production processes involve harmful substances like chlorofluorocarbons that deplete the ozone layer, contributing to global warming and the consequent heatwaves, droughts, and flooding. When packaging-related waste becomes significant, it leads to various environmental problems that may cause irreversible damage. This, in turn, generates diverse impacts such as the depletion of natural resources, air pollution, water pollution, waste proliferation, rising global temperatures, ozone layer depletion, and shifts in biodiversity.

The food and processed products industry uses more packaging than other businesses. Four types of materials are used to produce food packaging: glass, metal, plastic, and paper-based materials. Each type of packaging material has advantages and disadvantages, and there is a growing trend towards using environmentally friendly packaging materials. This trend has become a global phenomenon due to the increasing awareness of environmental conservation. Consequently, packaging made from readily biodegradable and environmentally friendly paper or paper-based materials has gained popularity. This shift towards eco-friendly practices has prompted interest in recycling processes that enable materials to be reused.

Developed nations have actively advocated adopting recycling technologies and using biodegradable packaging made from natural materials [2]. Concurrently, public authorities in developing nations are increasingly addressing concerns surrounding plastic packaging. Notably, several African countries, including Benin and Rwanda, have recently imposed bans on the use of non-biodegradable packaging [3]. Before plastic food packaging was embraced in these developing countries, people traditionally sourced packaging materials from their immediate environment. Indeed, numerous African, Asian, and Latin American countries traditionally used leaves as a natural wrap for food [4-6]. Given the abundance of large leaves in the surrounding vegetation, they have been extensively tested and proven for long-term use. They are recognized as being non-toxic and free of dyes or irritants [5, 6]. The primary consideration in selecting suitable leaves for food packaging is their availability [6, 7]. Additional criteria encompass their flexibility post-treatment, width, impact on organoleptic properties of food, and ease of treatment, preservation, and transportation [6-8].

This study focuses on the molding conditions suitable for producing food packaging from the arecanut leaf sheath with the compression molding technique. The molding condition was investigated at 150, 160, and 170 °C temperatures for 1, 2, and 3 min, using areca nut leaf sheath with moisture levels ranging from 10% to 80%. This research will unravel the composition of the arecanut leaf sheath and the shaping conditions, offering a more straightforward path forward. Sharpening this understanding trims down the time needed to explore molding techniques and cuts back on waste during production, making the process more efficient and refined.

2. Materials and Methods

2.1 Materials

Areca nut leaf sheath was obtained from the areca palm (Areca catechu), which grows in much of the tropical Pacific (Melanesia and Micronesia), South Asia, Southeast Asia, and parts of East Africa. The areca nut leaf sheath used in this research was obtained from areca palms in Phatthalung Province, Thailand. The arecanut leaf sheath used in the experiment should be thoroughly washed with water, scrubbed on both sides with a sponge until clean, and then baked to reach the desired moisture content. The moisture content of the arecanut leaf sheath is measured using a drying method, where the proportion of moisture is calculated by comparing the weight lost during drying to the initial weight.

2.2 Equipments

The compression molding machine used in this research (model VC200, Hong Yaw Thai Company Limited, Thailand) and metal food plate mold are shown in Figure 1.

Figure 1. Mold for forming food plates.

2.3 Methods

The food plate samples were made by compression molding the arecanut leaf sheath at 150, 160, and 170 °C for 1, 2, and 3 min. The quality of the obtained plates was assessed based on their physical appearance and tensile testing. The perfection of the physical appearance of the sample will mainly be seen from the surface. The surface must be smooth, complex, and free from cracks or tears from the molding process. For the tensile strength, the dumb-bell test specimen (i.e., five samples per formulation) was die cut from the press-cured sheets, and tests were carried out at room temperature with a tensile tester Model UT-2060 (U-Can Dynatex Inc., Taiwan) at a crosshead speed of 50 mm/min according to ASTM D412. A schematic diagram of the molding process is shown in Figure 2

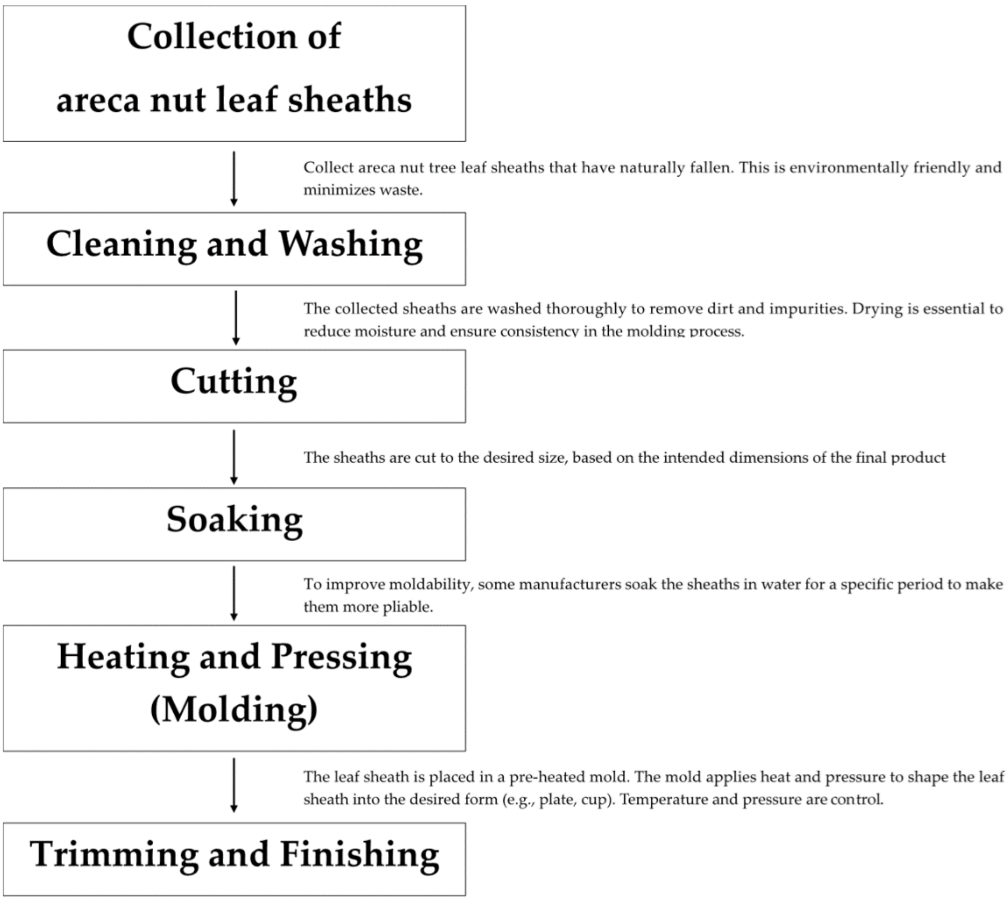

Figure 2. A schematic diagram of the molding process.

3. Results and Discussion

3.1 Results

3.1.1 Influence of temperature and time on plate formation

In this study, we investigated the optimal condition for molding food plates from areca nut leaf sheath. The primary objective was to identify the lowest molding temperature and shortest duration that produced robust, aesthetically pleasing containers that maintained their shape over an extended period of use. The experimental conditions were applied to the arecanut leaf sheath with a moisture content of 20%. The results are illustrated in Figures 3 and 4.

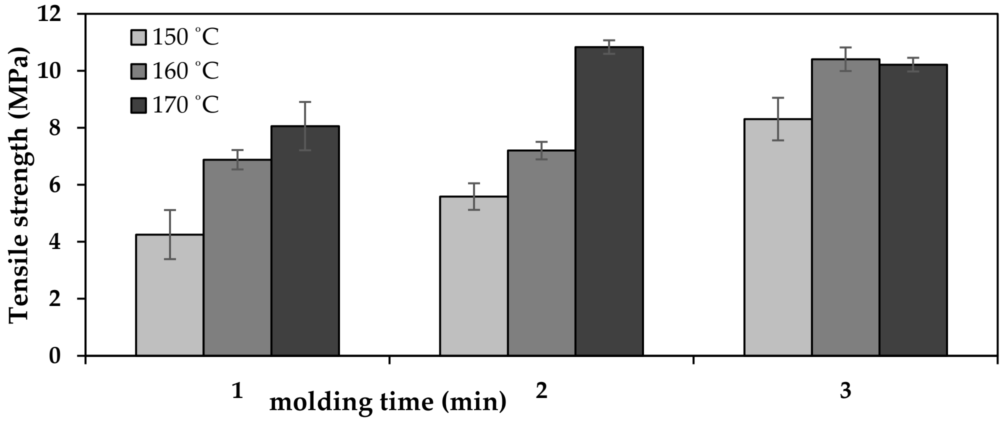

Figure 3. Tensile strength of food plates made from Arecanut leaf sheath molded under different conditions.

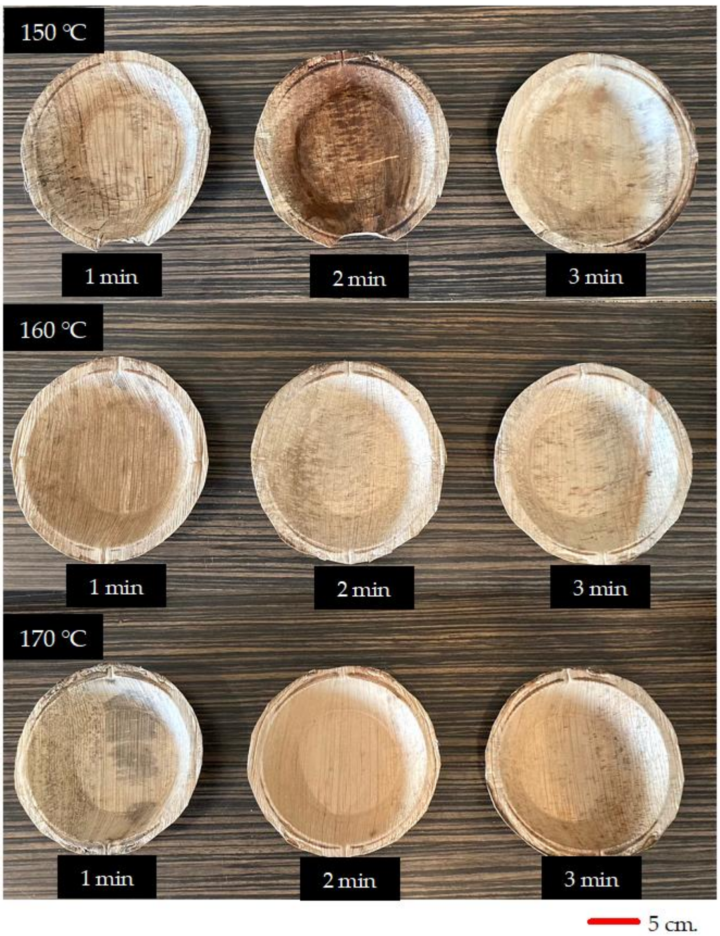

Figure 4. The physical appearance of food plates made from Arecanut leaf sheath molded under different conditions.

Figure 3 illustrates the tensile strength of areca sheaths pressed at temperatures of 150, 160, and 170 °C for 1, 2, and 3 minutes. The experiment revealed that increasing the forming time also increases the strength of the arecanut leaf sheath plates. This is due to the extended time allowing lignin in the areca nut leaf sheath to melt and act as a binder, enhancing fiber adhesion and thus improving plate strength. Additionally, higher forming temperatures were found to enhance plate strength, likely because as the temperature rises, more lignin melts and binds the fibers more effectively, resulting in stronger arecanut leaf sheath plates.

The molding of arecanut leaf sheath plates at a temperature of 150 °C required 3 min to produce a smooth surface (Fig. 5A). When the molding duration was less than 3 min, the surface of the plate was uneven (Fig. 5(B)). Molding at 150 °C for all durations produced plates with cracks in the base of the plate (Fig. 5(C)) that were attributed to the reduced flexibility of the leaf sheath when molded at this temperature. The leaf sheath did not conform to the mold in this condition.

The molding of arecanut leaf sheath plates at a temperature of 160 °C for 2 and 3 min produced plates with relatively smooth surfaces (Fig. 6A) similar to plates molded at 150 °C for 3 min. However, approximately 30% of the plates exhibited cracks in the base (Fig. 6(B)). Therefore, the actual production of molded products at 160 °C would pose the risk of a 30% defect rate, which is considered high in manufacturing processes.

The molding of arecanut leaf sheath plates at 170 °C for 2 and 3 min (Fig. 7(A)) produced relatively smooth surfaces, similar to plates molded at 160 °C. Moreover, no cracks were in the base of any plates molded at 170 °C (Fig. 7(B)). This result indicated that, at 170 °C, the fibers of the areca nut leaf sheath could soften sufficiently to conform to the mold without experiencing the stress that would produce cracks and defects in the material of the final product.

Figure 5. Food plates made from areca nut leaf sheath molded at 150 ˚C.

Figure 6. Food plates made from areca nut leaf sheath molded at 160 ˚C.

Figure 7. Food plates made from areca nut leaf sheath molded at 170 ˚C.

The most suitable molding condition was a temperature of 170 °C for 2 min. This finding is consistent with a previous study investigating the mechanical and thermal properties of arecanut leaf sheath fibers reinforced with polypropylene. The fibers' chemical composition and tensile strength analysis showed that the arecanut leaf sheath comprised cellulose at 66%, hemicellulose at 7%, and lignin at 20%. Notably, lignin is a crucial component in areca nut leaf sheath, significantly influencing its molding characteristics. Therefore, the optimal molding condition identified in this study aligns with the chemical composition and emphasizes the importance of lignin in molding areca nut leaf sheath [9].

Lignin is a complex compound of carbon, hydrogen, and oxygen. It exists in various subunits, making it a high-molecular-weight, complex polymer. Lignin is the second most abundant natural polymer globally, after cellulose. It is characterized by a molecular mass exceeding 10,000 atomic mass units and is known as a hydrophobic aromatic polymer [10]. Lignin is predominantly found in the secondary cell wall and the middle lamella between fiber layers. In addition to bonding the molecules of hemicellulose and cellulose together to enhance strength, lignin also aids in reducing water permeability between the cellulose matrix and cell walls, providing plant tissues protection against microbial degradation [11, 12].

Lignin exhibits a glass transition temperature (Tg) of around 90 °C and a melting temperature (Tm) of approximately 170 °C [13]. These properties are crucial in understanding why arecanut leaf sheath can be effectively molded at 170 °C. At 170 °C, the lignin in the arecanut leaf sheath starts to melt, facilitating the transformation of the material to conform to the mold. Upon removal from the mold, lignin transitions from a molten polymer to a glass-like solid, resulting in a lasting change in shape.

3.1.2 Influence of arecanut leaf sheath moisture content on plate forming

Figure 8. Effect of moisture content on the appearance of food plates made from areca nut leaf sheath.

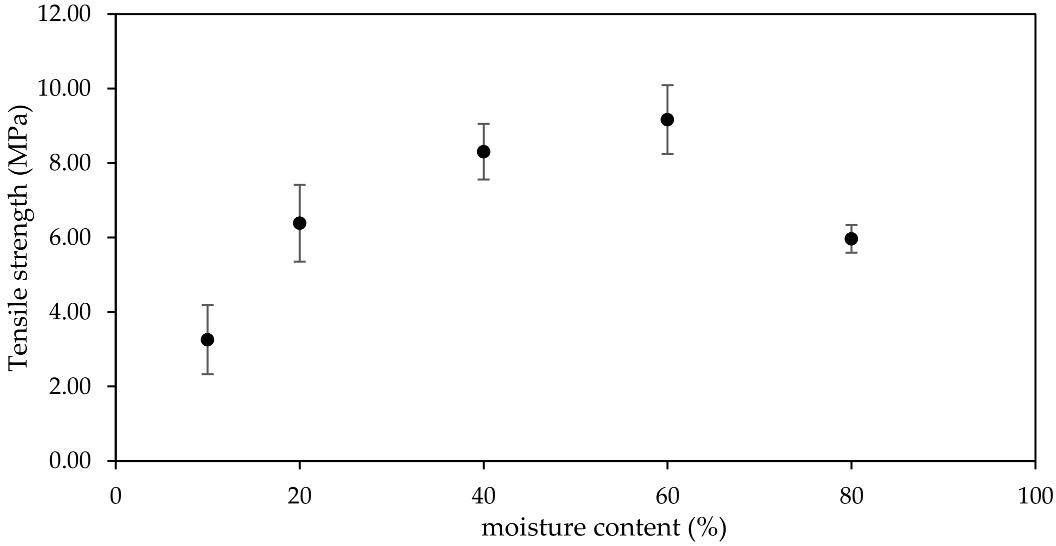

Figure 9. Effect of moisture content on the appearance of food plates made from areca nut leaf sheath.

After determining the optimal temperature and duration for molding food plates from the arecanut leaf sheath, the suitable moisture content of the leaf sheath was investigated. Areca nut leaf sheath, when dried, becomes rigid and brittle. Moisture content is, therefore, a crucial determinant of the flexibility of the leaf sheath fibers during molding. This flexibility is essential for the plate to conform well to the mold without cracking. However, excessive moisture can potentially impact the quality of the molded products. Therefore, the moisture content varied at 10, 20, 40, 60, and 80%, as measured by weight. The molding condition was maintained at 170 °C for 2 min. Areca nut leaf sheath with a moisture content of 10% by weight before molding could not be successfully shaped without cracking due to the excessive rigidity and brittleness of the leaf sheath (Fig. 8). When the moisture content was 80% by weight, the molded pieces exhibited warping. This defect was attributed to a phase change from moisture to gas during molding that caused the workpieces to swell. Areca nut leaf sheath with a moisture content ranging from 20% to 60% by weight was suitable for molding, resulting in well-shaped, smooth pieces that did not crack during processing. The results of the physical characteristics of arecanut leaf sheath plates formed at varying moisture levels align closely with the strength test results shown in Figure 9. It was observed that as the moisture content of the areca nut leaf sheaths increased from 10% to 60%, the strength of the plates also improved. However, when the moisture content exceeded 60%, the strength of the plates decreased. Based on the physical and mechanical properties, soaking the areca nut leaf sheaths to achieve a moisture content of approximately 20-60% by weight produced plates with relatively high strength and minimal waste. Therefore, the optimal moisture content range for forming these workpieces is between 20% and 60% by weight. Based on these findings, areca nut leaf sheath was used to produce the products shown in Figure 10.

3.2 Discussion

Areca nut leaf sheath plates provide a high food safety standard due to their natural, chemical-free composition, heat tolerance, and natural antimicrobial properties. They are generally safe for hot and cold foods and avoid many contaminants associated with conventional disposable food ware. With proper manufacturing and adherence to hygiene standards, these plates offer a food-safe, eco-friendly option that aligns well with health-conscious and environmentally aware consumers.

Areca nut leaf sheaths hold significant promise as an eco-friendly material for sustainable food packaging, mainly due to their biodegradability and suitability for single-use applications. Naturally compostable, areca leaf sheaths break down within months without releasing harmful chemicals, making them a compelling alternative to single-use plastics, contributing heavily to persistent waste issues. Sourced from agricultural by-products, these leaf sheaths offer a low-impact alternative to petrochemical-based plastics, supporting circular economy principles and reducing overall packaging carbon footprints. Beyond their environmental benefits, areca leaf sheaths have a unique, rustic appearance that appeals to eco-conscious consumers and brands focused on sustainability. Their visual appeal can strengthen brand identity, aligning with values of reduced plastic use and environmental responsibility while allowing companies to highlight their commitment to sustainable practices in marketing efforts that resonate with environmentally aware audiences. With abundant by-product availability in areca nut-producing regions like India and Southeast Asia, using areca leaf sheaths could stimulate local economies by providing additional income for farmers and creating rural employment. While initial production costs may be higher than traditional plastics, scaling up manufacturing and reducing waste management expenses could lead to greater cost efficiency. Incentives or subsidies for biodegradable packaging materials could also make these products more economically viable.

However, challenges remain in ensuring a stable supply of high-quality leaf sheaths to meet increasing demand. Factors such as climate, processing methods, and regional differences can impact material quality, and processing requires water, which can be an issue in drought-prone areas. Innovations in water conservation or recycling during production could further enhance the environmental profile of areca nut leaf sheaths, supporting their potential as a sustainable solution in the food packaging industry. Scaling the compression process of arecanut leaf sheath plates for industrial production is feasible but requires investment in automation, quality control, and sustainable practices. Addressing material consistency, labor, and energy usage challenges will be critical for success. With these systems in place, areca leaf plates could reach a level of production that meets global demand, offering an eco-friendly alternative in a scalable, economically viable way. Though production costs for areca nut leaf packaging might initially be higher than plastic, scaling up production and reducing the need for waste management could eventually make it more economical. Additionally, subsidies or incentives for using biodegradable materials could offset some of these costs. However, Increased demand for this material can support local economies, provide additional income streams for farmers, and create jobs in rural areas.

Figure 10. Food containers made from areca nut leaf sheath.

4. Conclusions

A study of the influence of temperature and time on the molding of food containers from areca nut leaf sheath indicated that the best conditions for forming food containers from areca nut leaf sheath were a molding temperature of 170 ˚C for 2 min and an arecanut leaf sheath moisture content before molding in the range of 20-60 wt.%. The current arecanut leaf sheath plate molding process primarily has consistency, efficiency, and scalability limitations. Addressing these with more automated, environmentally controlled, and energy-efficient solutions can support large-scale production. Through these improvements, the process could achieve better quality control, higher throughput, and reduced costs, positioning areca nut leaf plates as a more competitive alternative to conventional disposable tableware. The experiment results indicate that food containers made from areca sheaths can be successfully produced and are viable for practical use. However, calculations of production costs and selling prices reveal that these containers are much more expensive than plastic alternatives, which may reduce their appeal despite their environmental benefits. Future research will focus on reducing production costs to make the prices of areca sheath containers more competitive.

5. Acknowledgements

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