Production of disposable takeaway food container from areca leaf sheath (ALS) as sustainable packaging material

Oi Ka Jong¹, Tze Mi Yong¹,² and Muharam Rafidi Jaafar¹

¹ Innovative Manufacturing Technology Research Group (IMT), Advanced Technology Centre (ATC), Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), Pagoh Edu Hub, KM 1, Jalan Panchor, 84600 Pagoh, Muar, Johor, Malaysia

E-mail: tmyong@uthm.edu.my

Abstract. Areca leaf sheath has been used traditionally to produce disposable plates and bowls in India for decades. This project aims to produce disposable takeaway food containers by using the fallen Areca leaf sheath. In order to achieve the aim, a press mold is self-designed and fabricated, and installed into a disposable paper plate press machine to form the sheath into container shape. The density of the sheath is 0.423 g.cm⁻³ and 0.391 g.cm⁻³ before and after press respectively. The moisture content percentage obtained before heat press is 19.19%, while after press is 5.01%. The sheath at its sheath line direction shows higher stiffness, which is 416.9 g.cm, compared to the perpendicular sheath direction of 65.1 g.cm. The sheath has a water absorption rate of 0.021 g.min⁻¹, which fulfils the purpose of disposable food packaging to contain foods with soup or sauce.

1. Introduction
Disposable tableware or dining ware is the articles used for eating a meal such as crockery, cutlery and others which are meant to be thrown away after use. Today, because of its single-use purpose, disposable tableware is low cost, convenient for takeaway, and easy to be disposed after used. For these reasons, disposable foodservice wares are preferred over the reusable ones by both the food servers and consumers[1-2]. Among the globally most used tableware are disposable cups, which have alone contributed over 37% of all foodservice disposables, with a total of 500 billion pieces to be sent to landfill yearly as reported by The Freedonia Group in 2010 [3]. Such massive quantity of trash alarms the environmentalists to study and even to raise awareness among the public regarding the disastrous impacts that the disposables can cause to our Mother Earth. The most direct solution is to stop the usage of the disposables, and be replaced by reusable dining ware. This solution is even initiatively employed by Starbucks, the leading global beverage brand in collaboration with researcher from Iowa State University [2].

In contrast to the encouragement in usage of reusable dining ware, there are studies suggesting that disposable dining ware might have more eco merit than reusable dining ware in terms of manufacturing energy and wash energy consumption. The reusable plates or cups need to be reused for a certain times to outweigh the impact that disposables bring to the environment, which is known as...
the ‘break-even point’ [4-6]. Although being criticized widely, the initiator of such argument, Martin B. Hocking [4-5] emphasized that reusable dining ware is suitable for regular usage basis; but for one-time events like large parties where the return rate is low, disposable dining ware is still a better option. Since the disposable dining ware unavoidably still plays an important role in people’s life, researches have been conducted in order to replace the conventional plastic disposables by using other materials such as paper, biodegradable plastics, bio-based plastics and even just leaves. In this project, the Areca leaf sheath (ALS) is proposed as a sustainable raw material to produce disposable takeaway food container.

ALS is the agro waste from the areca palm plantation, which the palm is scientifically known as Areca catechu L.. Due to its slow decomposition rate, it is usually gotten rid of by open burning [7-8]. The sheath of an adult is concaved in the center. The structure, composition and appearance of the sheath are heterogeneous. The outer surface of the ALS is greenish or brown, waxy and tough, while the inner surface is creamy in color and has a natural glossy finish [9]. ALS is generally a hard natural material, with tensile strength of 163.36 MPa along the grain direction, and 0.18 MPa along the transverse grain direction [10]. The fiber of ALS also contains higher amount of lignin (38.68%), lower amount of cellulose (26.40%) and hemicellulose (16.50%) compared to other commercialized natural non-wood fibers like jute, hemp, flax and etc [11-12]. The high lignin content gives ALS high stiffness and rigidity [13].

Due to the rigidity and high mechanical strength of ALS, it has been used as a biodegradable raw material to produce disposable plates and bowls for decades in India through compression molding process [7-8,10]. After washed, the ALS is subjected into the hydraulic press machine at which the upper die and lower die temperature is set to 110-115 °C and 35-45 °C respectively, and stamped for 40-60 seconds [8]. It should be noted that the moisture content of the sheaths should be maintained at above 5% to prevent cracking during the stamping process. However, if the moisture content exceeds 30%, the product will be difficult to remain dimensionally stable, and fungi be most likely to grow during the storage time of the products. Besides, the products are also sanitized when they are subjected to high temperature. It is also recommended that the moisture content of the raw sheath should be maintained at 14-17% before production [8,10]. With these production parameters as guidelines, this project attempted to produce a self-designed disposable takeaway food container with burger box size. The design of the container aims to explore a more complicated structure for ALS disposable products compared to the existing ones. Some physical and mechanical properties of ALS will also be investigated in this study.

2. Methods

2.1 Collection of ALS
The fallen ALS were collected from the areas of Batu Pahat and Muar, Johor in Malaysia. These areca palm trees are used as decoration plants. The collected ALS were then washed with running water and dried under the sun, before being stored in an air-conditioned laboratory.

2.2 Density of ALS
Density test was done in accordance to standard of TAPPI T 410 om-08. This standard procedure of paper grammage test was adopted for measurement of ALS density due to its flat, thin and hydrophilic characteristics which are similar to that of a paperboard. The density of the ALS was measured before and after the compression molding production process of food container. 10 replicates of 8 cm ×8 cm were measured.

2.3 Moisture content of ALS
The initial moisture content of 10 ALS samples (8 cm × 8 cm) were measured as well as the moisture content after the compression molding process. The procedure was in accordance to standard of TAPPI T 550 om-08 which uses the oven drying method.
2.4 Taber bending stiffness of ALS
The test was carried out by referring to TAPPI T 489, on the ALS to find out the bending moment required to deflect it. By using a Taber Stiffness Tester (Model 150-E, Taber), 10 specimens for both parallel and perpendicular grain direction of ALS were tested at Range 4 of Taber Stiffness unit. Then, the bending moment and resistance to bending are calculated by using equation (1) and (2):

\[
\text{Bending moment (mN.m)} = \text{Average instrumental readings in stiffness units (g.m)} \times 0.098066 \tag{1}
\]

\[
\text{Resistance of bending (mN)} = \frac{\text{Bending moment (mN.m)}}{\text{Length (m)}} \tag{2}
\]

2.5 Design of ALS food container
The design of the food container was done using the CAD software SolidWorks 2016. The shape of the takeaway container is designed to be having only a single cavity (figure 1) instead of the clamshell shape with 2 joined cavities like the conventional takeaway containers. To make a complete container, two cavities are needed to combine with each other by the tab-and-slot mechanism. A post-process to cut a gap on the slot of the container is needed with this design. This food container design is intended to save the raw material of press mold.

![Figure 1. Design of ALS food container.](image)

2.6 Design and fabrication of press mold
The press mold was designed using SolidWorks 2016, with the ‘Core and Cavity’ feature. Then, the designed mold is fabricated by using a three-axis CNC milling machine (Hwacheon Vesta 660) after the fabrication process was simulated with MasterCAM 2017 software. The material chosen to make the press mold is aluminum due to its more affordable cost, higher ductility, and light weight for a prototype making purpose. End milling processes were performed by the CNC milling machine to produce both punch and die of the press mold. The fabricated mold is as shown in figure 2. The mold was then installed on an existing press machine which was used to produce disposable paper plates.
2.7 Production of ALS food container
A few trial runs with the newly fabricated mold were carried out by referring to the parameters recommended by Kalita et al. [10]. Finally, the temperature of the punch was set to be 100±10°C, whereas the cavity was 40±10°C. The pressing time duration was controlled to be 2 minutes. After the shape of the product is formed, post-processes like trimming the excess part of the containers and cutting the gap on the slot were done. Two containers were combined to form a complete product.

2.8 Water absorption rate of ALS containers
The ALS disposable containers are expected to be able to contain foods with gravy, thus it should be able to withstand water penetration. 4 containers were filled with 50 ml of water, and the water would be removed for every 30 minutes to weigh the wetted containers. This weighing process repeated till 3 hours and 30 minutes. Then, the water absorption rate of the ALS containers was calculated using equation (3) below:

\[
\text{Water absorption rate (g.min}^{-1}) = \frac{\text{Total weight increased (g)}}{\text{Time (min)}}
\]  

3. Results and discussion
3.1 Density
The average thickness of 10 ALS samples before being pressed is 1.08 mm, while the thickness after press is 1.00 mm. Next, the average weight ALS specimens before press is 2.93g, and 2.50g after press. Hence, the density is 0.423 g.cm\(^{-3}\) and 0.391 g.cm\(^{-3}\) before and after press respectively. Although the density of ALS is higher than that of polystyrene (0.045g.cm\(^{-3}\)), which may increase its transportation cost, the obvious advantage of being eco-friendly is able to overcome this shortcoming of ALS.

3.2 Moisture content
The range of the moisture content of the ALS is between 16.46 to 22.02%, with an average value of 19.19%. These values are similar to those that are reported by Kalita et al. [10], that is 14-17%. After the sheath is pressed, the average moisture content is 5.01%.

3.3 Bending stiffness
As shown in table 1 below, ALS required higher moment to be bent at the parallel grain direction (40.88 mN.m) compared to the perpendicular grain direction (6.38 mN.m). In order to bend the parallel grained ALS, 817.60 mN is needed while 127.60 mN is need to bend the perpendicular grained ALS.

Figure 2. The fabricated punch (left) and die cavity (right).
3.4 Production of ALS food container
A complete ALS food container was produced (figure 3) by compression molding process. However, as the press machine was used to produce disposable paper plate, the machine does not have enough pressure to fully compress the sheaths. Thus, as illustrated in figure 4, the ALS that was folding up at the edge of the container was not completely flattened by the compressive force of the press machine. In spite of the imperfect finishing at the edge of the containers, the produced ALS containers are able to fulfill its main function to contain and enclose foods.

### Table 1. Bending Moment and Resistance to Bending of ALS

| Properties                      | Parallel | Perpendicular |
|---------------------------------|----------|---------------|
| Stiffness unit, g.cm            | 416.90   | 65.10         |
| Bending moment, mN.m            | 40.88    | 6.38          |
| Resistance to bending, mN       | 817.60   | 127.60        |

3.5 Water absorption rate
Throughout the test, the average weight gained by the specimens is 3.85g in 3 hours, which gives a water absorption rate of 0.021 g.min⁻¹ (figure 5). It is also observed that when the water remains in the container for the next 3 hours, the water still did not penetrate through any of the specimen. The sheath container is able to fulfill the requirement of a disposable packaging with its low water absorption rate to withstand soup or sauce penetration through the material.

![Figure 3. A complete ALS container.](image)

![Figure 4. The incomplete folds of ALS container.](image)

![Figure 5. Graph of weight of ALS container (g) against time (min).](image)
4. Conclusion
The ALS takeaway disposable food containers are successfully produced from the fabricated mold. These containers are able to fulfill the purposes of disposable food packaging. The pressing temperature of the punch is set to be 100±10˚C, whereas the cavity is 40±10˚C. The pressing time duration is 2 minutes. The density of the raw sheath is 0.424 g.cm\(^{-3}\), after pressed it is 0.391 g.cm\(^{-3}\). The average moisture content of the sheath before press is 19.19%, while after press is 5.01%. Besides, the sheath line direction of the areca leaf sheath has greater stiffness, which is 416.9 g.cm compared to the transverse sheath line direction, that is 65.1 g.cm. The areca leaf sheath container is able to withstand water penetration for more than six hours, having a water absorption rate of 0.021 g.min\(^{-1}\), which makes it a suitable disposable food packaging material to contain foods with soup or sauce. For future research, the moisture content of the ALS can be controlled to reduce cracking and folding of products. Since a simple paper plate press machine was used for this project, a hydraulic press can be used in the future work for a greater compressive force.

5. Acknowledgement
First and foremost, the authors want to thank Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia in providing the fund and necessary facilities needed to complete this project.

6. References
[1] Fang W T, Ng E, Wang C M and Hsu M L 2017 Normative Beliefs, Attitudes, and Social Norms: People Reduce Waste as an Index of Social Relationships When Spending Leisure Time Sustainability 9 1696
[2] Lee J 2015 A study for increasing reusable cup consumption in the coffee industry : focused on behavior change with motivation Graduate Theses and Dissertations (Iowa: Iowa State University Digital Repository)
[3] Woods L and Bakshi B R 2014 Reusable vs. disposable cups revisited: guidance in life cycle comparison addressing scenario, model, and parameter uncertainties for the US consumer Int. J. Life Cycle Assess. 19 931–940
[4] Hocking M B 1994 Disposable cups have eco merit Nature, 369 107
[5] Sheehan B, Gordon M and Sommer S 2017 Greenhouse Gas Impacts of Disposable vs Reusable Foodservice Products: Literature Review and Inventory (Clean Water Fund)
[6] Hocking M B 1994 Reusable and Disposable Cups: An Energy-Based Evaluation Environ. Manage. 18 889–99
[7] Bavappa K V A, Nair M K and Kumar T P 1982 The Arecanut Palm (Kerala, India: Central Plantation Crops Research Institute)
[8] Kalita P, Dixit U S, Mahanta P and Saha U K 2008 A novel energy efficient machine for plate manufacturing from areca palm leaf sheath J. Sci. Ind. Res. (India). 67 807–11
[9] Nair K P P 2010 The Agronomy and Economy of Important Tree Crops of the Developing World, 1st ed (New Delhi, India: Elsevier Inc.)
[10] Kalita P, Dixit U S, Mahanta P and Saha U K 2006 Effect of Moisture and Temperature on Arecanut Leaf Sheath Products Proc of the 3rd BSME-ASME Int. Conf. on Thermal Engineering
[11] Sadrmanesh V and Chen Y 2018 Simulation of tensile behavior of plant fibers using the Discrete Element Method (DEM),” Compos. Part A Appl. Sci. Manuf. 114 196–203
[12] Nagaraja R, Gurumurthy B R and Shivanna M B 2014 Bio Softening of Arecanut Waste Areca Husk, Leaf and Leaf Sheath For Value Added Compost IMPACT Int. J. Res. Appl. Nat. Soc. Sci. 2 105–12
[13] Chen H 2014 Chemical Composition and Structure of Natural Lignocellulose Biotechnology of Lignocellulose (Dordrecht: Springer) pp 25–71