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Optimizing the Production of Biodegradable Containers from Corn Husks Using Hot Mold Forming: Study on Temperature, Forming Time and Husk Arrangement

Uaangkoon Ueasomrittipon, Tanee Sreewongchai[1], Sudsaisin Kaewrueng and Supakit Sayasoonthorn

Department of Farm Mechanics, [1]Department of Agronomy,
Faculty of Agriculture, Kasetsart University, Thailand
**Email- agrspks@ku.ac.th*

***Abstract*:** Corn husks are an abundant agricultural byproduct left over from the processing of animal feed. This byproduct holds the potential to create value-added products for farmers. The objective of this research is to utilize discarded corn husks by converting them into containers through hot mold forming. The variables studied include temperature, time, husk arrangement, and binder ratio. The testing process involved the following steps: setting the temperature at three levels-130°C, 140°C, and 150°C; forming time at three levels-1 minute 30 seconds, 2 minutes, and 2 minutes 30 seconds; and arranging the corn husks in two ways: 1) using 3 mature husks with 6 young husks, and 2) using 6 mature husks. The binder ratio (water: starch) was set at 1:1 and 1:2. The mold used for forming had dimensions of 12x12x2.5 cm (W x L x H). After forming, the containers were tested for storage over a period of 1 month and were evaluated according to the community product standards 1557/2563. The optimal conditions for producing containers from corn husks through hot mold forming were a temperature of 140°C, a forming time of 2 minutes, and the first husk arrangement method. The containers produced under these conditions were strong, durable, free from mold, well-formed, and stable. After a 1-month storage period, no mold was observed, and the containers remained strong and intact. However, after 3 months, mold was found on all containers made from corn husks under all conditions.

***Keywords*:** Corn husk, Agricultural by product, Biodegradable containers

Thailand is currently grappling with a significant waste management issue, particularly with the disposal of single-use containers, a problem largely driven by the growing preference for convenience among consumers. Foam food containers, which are widely popular due to their low cost, lightweight, and ease of availability, are particularly problematic. These containers, however, take an alarming 450 years to decompose, posing serious environmental challenges. The widespread use of foam containers, especially by vendors of ready-to-eat meals, exacerbates this issue as they are discarded immediately after use, contributing significantly to the country's waste problem. Moreover, the disposal of foam is expensive, requiring considerable resources for proper waste management.

In response to this pressing issue, researchers have proposed a solution that not only mitigates environmental concerns but also provides economic benefits to farmers. By utilizing the abundant agricultural byproducts from animal feed processing, specifically corn husks, this research aims to add value to these materials while reducing environmental waste. Corn husks are one of the most prevalent agricultural waste products. In 2023,Thailand's corn production is estimated to reach 5.4 million metric tons, which marks an increase from previous years. This growth is attributed to an expansion in planting areas and favorable farm-gate prices. The higher production also aligns with the country's efforts to manage agricultural byproducts, such as corn husks, more sustainably. Farmers often dispose of these waste materials through burning, which is a major contributor to air pollution and smog.

Given Thailand's extensive corn cultivation, the country faces a significant challenge each year in managing the agricultural waste generated post-harvest and processing. To address this, researchers propose converting corn husks into biodegradable containers that can naturally decompose within a short period, offering a sustainable alternative to traditional, non-biodegradable packaging materials. Corn is a key agricultural product in Thailand, ranking among the country's primary crops. It is predominantly cultivated in the northern and central regions, where favorable climatic conditions support its growth. The production of corn has been steadily increasing due to its economic importance, particularly in the animal feed industry, where it serves as a crucial ingredient. However, the processing of corn for feed generates substantial agricultural byproducts, with corn husks being one of the most abundant. While traditionally considered waste, corn husks have the potential to be transformed into valuable products, enhancing both the sustainability and profitability of corn cultivation.

Recent studies have highlighted the utility of agricultural

byproducts like corn husks in creating biodegradable materials (Castrillón et al 2021), aligning with global efforts to reduce plastic waste and promote environmentally friendly alternatives. The conversion of these byproducts into biodegradable containers addresses waste management issues and provides an additional revenue stream for farmers.(Maraveas 2020, Enawgaw et al 2023)

This study aims to optimize the production of biodegradable containers from corn husks using hot mold forming, focusing on the effects of temperature, forming time, and husk arrangement on the quality and durability of the final product. By exploring these variables, the research seeks to contribute to the sustainable use of agricultural byproducts in Thailand, offering a viable solution for reducing environmental impact and enhancing the economic value of corn cultivation (Enawgaw et al 2023).

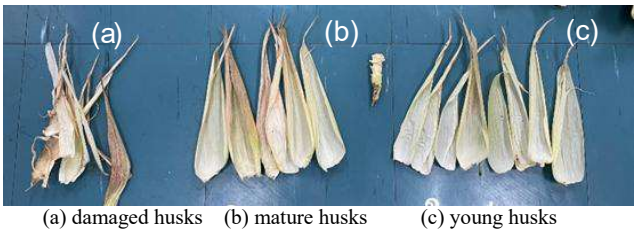
MATERIAL AND METHODS

The equipment used for the molding process includes a BAMBOO II thermal press machine with a mold size of 12 x 12 x 2.5 cm. Sweet corn husks are used as the primary material, with tapioca flour acting as the binder to facilitate adhesion. Wax paper is placed between the corn husks and the mold to prevent sticking. The testing process begins with the selection of corn husks, avoiding any husks with mold. The selection must also ensure that the husks are appropriate for the specific arrangement required and that overly small husks are not used, as they can complicate the arrangement process. The fresh corn husks are then cleaned and air-dried for 1-2 days to reduce moisture and prevent mold growth. After drying, the husks are sorted, removing any moldy or excessively small pieces. On average, each ear of corn has about 14-15 husks, comprising 8 young husks and 6 mature husks, accounting for 58% and 42% of the total, respectively (Fig. 1). Before performing the thermal molding, spray plain water evenly on the corn husks to help them unfold, making it easier to arrange them on the molding machine. Then, cut parchment paper to fit the molding blocks for both the upper and lower molds. This will prevent the corn husks from sticking to the molds and make cleaning easier.

The testing begins with arranging the corn husks in two methods. In Method 1, use 9 corn husks-3 mature husks and 6 young husks-arranged in 3 layers. In Method 2, use 6 mature corn husks arranged in 2 layers. In both methods, the husks are arranged in alternating layers, perpendicular to each other. It is crucial to arrange the corn husks meticulously during molding, as improper arrangement may cause gaps or misshapen containers. Molding is then performed at set temperatures of 130, 140, and 150 degrees Celsius, with molding times of 1:30, 2:00, and 2:30 minutes. Tapioca flour is used as a binder at ratios of water to flour of 1:1 and 1:2. Each condition is tested in three repetitions. After molding, the excess edges are trimmed off (Fig. 2).

After one month of storage at room temperature, the container samples are evaluated according to the Thai Community Product Standards 1557/2563. The evaluations include measuring moisture content using a hot air oven at 105 degrees Celsius for 3 hours until the weight remains constant. Microbial testing is also conducted with the following criteria: (a) Mold must be less than 100 colonies per sample, (b) No presence of Salmonella spp., (c) No presence of Staphylococcus aureus, and (d) Total plate count must be less than $1x10^3$ colonies per sample.

The containers are then assessed using a Rubric score of 1 to 5 (Fig. 3).



(a) damaged husks (b) mature husks (c) young husks

Fig. 1. Corn husk

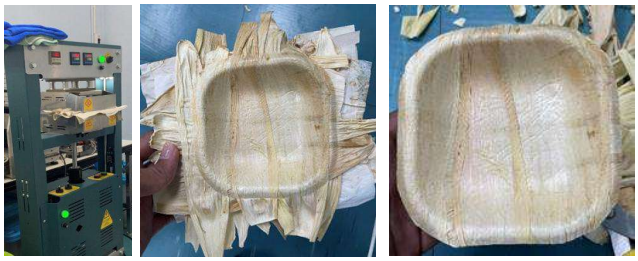


Fig. 2. Thermal molding of containers from corn husks

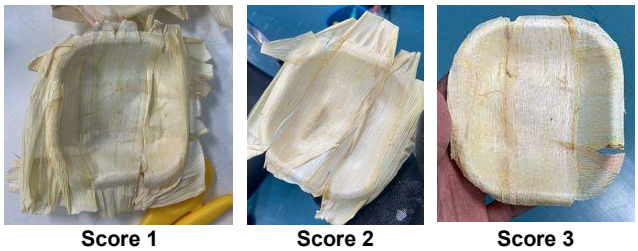


Fig. 3. Rubric score assessment (1-5 point)

Score 1: The container lacks form, is too thin to maintain shape, or has mold.
Score 2: The container forms but is not very strong; no mold is present. There may be visible starch residue, and some parts are incomplete, such as loose or perforated corn husks.
Score 3: The container forms with moderate strength but has thin spots. Some areas may be swollen or not tightly bonded.
Score 4: The container is strong and has sufficient thickness, with corn husks firmly attached and no mold present.
Score 5: The container is very strong, with substantial thickness and all corn husks firmly attached. There are no gaps, holes, or burn marks, and the container has an appealing color with no mold or dirt.

RESULTS AND DISCUSSION

Thermal molding of containers from corn husks: The molding temperature, molding time, the arrangement of corn husks, and the binder ratio are significant factors influencing the quality of the molded containers (Tables 1, 2). The binder ratio 1:1 for Arrangement Method 1, at a molding time of 1.30 minutes and temperatures of 130, 140, and 150 degrees Celsius, the score was consistently 2 under all conditions. At molding times of 2 and 2.30 minutes, the scores were maximum at140 and 150 degrees Celsius was 5. For arrangement method 2, at a molding time of 1.30 minutes, the maximum score was 3 at temperatures of 150 degrees Celsius. At molding times of 2 and 2.30 minutes, the maximum scores were 3.5 and 4 at 140 and 150^{O}C, respectively.

The optimal condition for molding containers from corn husks, achieving the highest Rubric score of 5, was at a temperature of 140 degrees Celsius and a molding time of 2 minutes using Arrangement Method 1. This method involved using 3 mature corn husks and 6 young corn husks with a binder ratio of 1:1, resulting in the best outcomes in terms of strength, durability, and overall quality of the container. However, at 150 degrees Celsius and a molding time of 2.30 minutes with arrangement method 1 and a binder ratio of 1:1, a score of 5 was also achieved. Despite this, the higher temperature and longer time led to increased energy consumption, making it less favorable. Additionally, containers produced under the optimal conditions maintained their integrity without mold growth for up to 1 month. However, when stored for up to 3 months, mold was observed in containers under all conditions, highlighting the limitations of the material for long-term storage.

Binder ratio 1:2 for Arrangement Method 1, at molding times of 1.30, 2.00, and 2.30 minutes the maximum scores at 150, 140, and 150 degrees Celsius were 3, 4, and 3, respectively. For Arrangement Method 2, at a molding time of 1.30 minutes and temperatures of 150 degrees Celsius, the maximum scores were2. At molding times of 2.00 and 2.30 minutes, the maximum scores were consistently 2 across all temperature ranges.Using a binder ratio of 1:2, the optimal condition remains Arrangement Method 1 at 140 degrees Celsius. However, scores decreased when molding time exceeded 2 minutes or when Arrangement Method 2 was used. The results show that adjustments in temperature and molding time directly impact the strength and integrity of the containers. Temperatures that are too high or too low, as well as inappropriate molding times, can lead to containers with incomplete or insufficient structural strength. This experiment highlights the importance of controlling these variables when producing biodegradable containers from corn husks. A critical aspect of molding containers from corn husks is the

Table 1. Thermal molding of containers with a binder ratio of 1:1

Temperature	Molding time (minutes)					
	Arrangement method 1			Arrangement method 2		
	1.30	2.00	2.30	1.30	2.00	2.30
130	2	2.5	3	1	2.5	3
140	2	5	3.5	2	3.5	3
150	2	3	5	3	2	4

Table 2. Thermal molding of containers with a binder ratio of 1:2

Temperature	Molding time (minutes)					
	Arrangement method 1			Arrangement method 2		
	1.30	2.00	2.30	1.30	2.00	2.30
130	2	3.5	1	1	2	2
140	2	4	2.5	1	2	2
150	3	3	3	2	2	1

Table 3. Inspection of containers according to Thai community product standards 1557/2563

Item	Test results	Unit	Reference testing methods
Moisture	8.2	%	-
Mold	<10est.	cfu/piece	In-house method TE-Mi-017 based on AOAC (2019) 997.02
Salmonella spp.	Not Detected	per piece	ISO 6579-1:2017/Amd.1:2020.
Staphylococcus Aureus	Not Detected	per piece	ISO 6888-3:2003/Cor 1:2004.
Total plate count	1.5 x 10^2est.	cfu/piece	Compendium of Methods for the Microbiological Examination of Foods (APHA), 5th Edition, 2015, Chapter 3

arrangement of the husks during the molding process. Since the molding machine moves during operation, the corn husks can shift, leading to misalignment, gaps, or arrangements that differ from the intended setup. This issue can be mitigated by carefully adjusting and observing the husks until the press reaches the molding point and positioning them correctly. This requires meticulous handling, which extends the molding time. Molding containers from corn husks differs from using other natural materials like banana leaves, teak leaves, or lotus leaves, which are larger and typically used as a single piece. Corn husks are smaller, requiring multiple husks to form one container, making the arrangement process more challenging. Thus, selecting a mold size appropriate for corn husks is crucial. Corn husk containers are not suitable for holding liquids or wet foods as they tend to swell and disintegrate. However, they are well-suited for dry items, such as snacks or dry foods.

Inspection of containers according to Thai community product standards 1557/2563: The results of the container Inspection according to the Thai Community Product Standards 1557/2563 (Table 3). The results show that the moisture content is 8.2%, and mold count is less than 10 est. No *Salmonella* spp. or *Staphylococcus aureus* were detected. The total plate count is 1.5 x 10^2 est. cfu/piece, complies with the Thai Community Product Standards 1557/2563 for containers. This shows that containers made from heat-molded corn husks can be used safely.

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CONCLUSION

The container production from corn husks using hot molding demonstrates the efficiency of transforming agricultural waste into value-added products. The optimal conditions for molding were temperature of 140°C, using a Type 1 arrangement with 6 mature corn husks layered in two levels, a 1:1 binding starch ratio, and molding time of 2 minutes. Utilizing corn husks for container production presents a promising option for reducing agricultural waste and creating biodegradable containers. However, further process development is needed to enhance the durability and longevity of the products.

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