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Production of Packaging Molded from Banana Sheath

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ABSTRACT

This research was done to study the effect of methods of making containers by hot air oven (H) and a hot press machine (C) and the ratio of banana stem fiber to binder on the properties of containers made from banana sheath fibers. The ratios between the dried banana sheath powder and the binder (banana starch solution 7.5%) were 60:40, 70:30, 80:20, and 90:10, respectively. It was found that method C had shown low amounts of oil and water absorption and a high resistance to deformation, which was due to compression and penetration. In terms of compression and penetration forces, no significant differences were found for the ratios of 80:20 and 90:10. However, the ratio of 90:10 showed lower fat and water absorption when compared to other ratios. Therefore, the ratio of 90:10 between the banana sheath fiber and the binder and the method C were found to be the best ratio to use when making containers, which are suitable to be applied for further use.

Keywords: Banana fiber, container, hot compression, molding

INTRODUCTION

Kluai Namwa (*Musa sapientum* L.) is a plant that is grown throughout the year in all regions of Thailand. The plantation area of Kluai Namwa covers 80% of the total banana plantation areas (Jirukkakul, 2016). Most of the products (both fresh and processed) are consumed domestically, such as in the form of fried bananas, dried bananas, banana powder, and banana starch (Jirukkakul, 2019). In addition, there are perennial herbs that are widely distributed in tropical and subtropical regions (Bi et al., 2017). When cutting a bunch of bananas from the tree, that tree is not able to grow a new bunch. The bananas trees, which have produced a

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bunch of bananas, have to be cut down, resulting in waste materials (banana trees or banana stalks) from the plantation areas. These waste materials (10-15% of bananas) do not have commercial value, resulting in major wasting of resources (Bi et al., 2017).

In addition, because banana sheaths have a lot of fiber consisting of 50% of cellulose and 17% of lignin (Alarcon & Marzocchi., 2015), they can also be used as a raw material for paper production, just like mulberry, pineapple fiber, or elephant dung (Oliveira et al., 2009). The stalks can be utilized in the process of molding containers, which can replace plastic materials (Liu et al., 2009). The quality of the packaging can be checked by examining the following properties: tensile strength, compression and penetration resistance, and water and oil absorption. In addition, this packaging is also environmentally friendly. At present, environmentally friendly containers are being invented and being called "bio-based food packaging", which is made from natural materials that are biodegradable from renewable resources. One of the natural materials being commonly used to produce bio-based food packaging is starch, which is abundant in cassava, potatoes, corn, and bananas. In general, the production of bio-degradable food packaging has often been processed through thermal extrusion (Tiefanbacher, 1993). Research on the production of foam containers made from starch and water through hot molding revealed that the containers became fragile and were not flexible or water resistant. Therefore, they could not be used for food packaging. Shorgen et al. (2002) studied disposable food packaging made from potato starch and corn starch and found that adding the fibers of softwoods had helped to increase the strength of the starch-made foam container. Moreover, the addition of Monostearyl citrate improved the water resistance and flexibility of the containers. Soykeabkaew et al. (2004) studied the characteristics of cassava starch foam reinforced with jute and hemp fibers by extruding the foam into the hot mold at 220^{o}C for 150 s. It was found that 5 - 10% of fiber increased the bending resistance and bending modulus of the starch foam. Jute fibers have more bending resistance than hemp fibers. In addition, Cinelli (2006) studied the natural biodegradable foam containing potato starch, corn fibers, and polyvinyl alcohol as the main components. It was molded through the hot mold at a temperature of 200^{o}C for 120 - 180 s. The study revealed that the corn fiber added to the mixture had increased the density of the foam, and the addition of polyvinyl alcohol had made the foam stronger. Furthermore, the foam could better withstand the compression, and these added materials were also able to increase the water absorption resistance. Therefore, for food storage, the development of containers made from banana sheaths has become an interesting alternative. The containers were also beautiful and increased a variety of product distribution. The objective of this study is to investigate the effect of the ratio of banana fiber to binder on the properties of the food containers made by hot air oven and hot press molding techniques.

MATERIALS AND METHODS

This study used the factorial for the completely randomized design (CRD) experiment. The studied factors were the dried banana sheath containers molded by using the hot air oven and the hot press at different ratios (90:10, 80:20, 70:30 and 60:40) of the dried banana sheath powder and the binder (7.5% banana flour solution). The package properties were analyzed in relation to thickness, weight, moisture, tensile strength, compression resistance, penetration resistance, and water and oil absorption.

Banana Fiber Preparation

The banana sheaths were peeled off into sheets, which had been cut from the cultivated banana trees. The sheaths were dried in the sun for 8 h or baked in an oven at 55^{o}C for 5 h. This condition affected the moisture content of sheets was less than 14%. The sheaths were then ground using hammer mill into a powder, screened through 80 wire mesh and then sifting was kept in a ziplock bag until needed for the further processes of mixing and extrusion.

Binder Preparation

The binder in this study was cultivated banana flour solution. The solution was created by mixing 7.5% of banana flour with water (7.5 g banana flour with 92.5 ml of water) and heating at 90^{o}C for 10 min until it became a gel.

Testing through Extrusion

By Hot Air Oven (H). The prepared banana fiber powder was measured with the binder at ratios of 90:10, 80:20, 70:30, and 60:40, and then the materials were mixed together using a food blender for 15 min. The 100 grams of the mixed material was placed into the mold and baked for 18 h at 60^{o}C (Sibaly & Jeetah, 2017). Then it was left in the mold to cool at room temperature. The work piece was then removed from the mold and kept in a ziplock bag until its properties were ready to be tested.

By Hot Compression (C). The banana fiber powder and the binder were measured at the ratios of 90:10, 80:20, 70:30 and 60:40. Then the materials were mixed using the food blender for 15 min. Aluminum foil was cut to the size of the mold (12 cm diameter with 1 cm edge high) and was then placed in the mold to prevent mold stickiness. The temperature of the hot compressor was set at 150^{o}C, the empty mold was heated for 10 min. Then the mixed materials were put into the mold, and the compression pressure was increased to 700 kPa (Muratore et al., 2019). Compression on the work piece continued for 30 min, and then the mold was left to cool to room temperature. Finally, the work piece was removed from the mold and kept in a ziplock bag until its properties were ready to be tested.

Packaging Testing

Thickness. Thickness was tested using Dial Thickness gauge (model 7301, Mitutoyo, Japan) with resolution of 0.01 mm. The results of the thicknesses were used in the analysis of the tensile strength.

Weight. Weight was tested in accordance with ASTM D646 (1996) standard. The 3 samples of 20 × 25 cm were cut and stored in a temperature and relative humidity controller at 27 ± 1°C and at 65 ± 2% for at least 24 h. Then 1 cut sheet at a time was weighed. Finally, the average standard weight in grams per square meter was reported.

Moisture content. Moisture content was tested in accordance with AOAC (2000) standard. Aluminum cups with lids were heated in a hot air oven at a temperature of 105 ± 2°C for 1 h. Then the cups were left to cool in a desiccator for 30 min before being weighed with the lids. After that, sampling was carried out to store a sample cup in a temperature and relative humidity controller at 27 ± 1°C and 65 ± 2% RH for at least 24 h. The sample was then cut into the size of approximately 2 × 2 cm^2 and put in a 3 g aluminum cup to be recorded as the pre oven sample weight (W1). After that, the sample in the cup with the lid open was put into the oven at 105 ± 2°C for 24 h. The weight was recorded as the post oven sample weight (W2). This moisture content test was repeated at least 5 times per 1 sample, and the average moisture content was reported in percentage units.

Calculation:Moisture content (%) = (W1– W2) /W1 × 100

Tensile Strength and Elongation. Tensile strength and elongation were tested in accordance with the ASTM D882 (1997) standard. The container sample was cut to 1 cm in width and 12 cm in length. The sample was fixed by 1 cm clamps on both sides of the Texture Analyzer (model TA.XT plus, by Micro Systems Ltd., UK). The tensile strength was directly calculated when the force at break was divided by the area used to pull (MPa). Elongation is measured as the distance that the sample can stretch (%).

Compression Resistance. Compression resistance was tested in accordance with the ASTM D642 (2010) standard. The container sample was cut to 5 × 5 cm^2 in size and then placed on the base of the Texture Analyzer (model TA.XT plus, by Micro Systems Ltd., UK). The cylindrical P/50 probe was installed into the Texture Analyzer. The compression resistance is the maximum force (MPa) that causes a sample to transform by 10%.

Penetration Resistance. Penetration resistance or puncture test was tested in accordance with ASTM F904 (2016) standard. The sample was cut to 5 × 5 cm^2 in size and placed on the cylindrical base of the Texture Analyzer (model TA.XT plus, by Micro Systems Ltd., UK), which had been installed with the cylindrical probe P / 6. Puncture force was the maximum force (MPa) used to penetrate the sample.

Water Absorption Property. The Water absorption property was tested in accordance with modified ASTM D 3285 (2005) standard. The sample was cut to 2.5 × 2.5 cm^2 and then stored in the temperature and relative humidity controller at a temperature of 27 ± 1°C and 65 ± 2%RH for at least 24 h. The sample was then removed from the controller and was weighed prior to the testing (W1). After that, the sample was put in a beaker containing 100 mL of distilled water, and immediately started the timer. At the 60th second, the sample was removed and placed on tissue paper. Then another tissue paper was immediately placed on top. The metal roller was used to roll over the tissue paper back and forth. Finally, the sample was weighed again (W2).

Calculation: Water absorption value (%) = (W2 –W1) / W1 × 100

Oil Absorption. Oil absorption was tested in accordance with modified ASTM D 3285 (2005) standard. The sample was cut to the size of 2.5 × 2.5 cm^2 and stored in the temperature and relative humidity controller at a temperature of 27 ± 1°C and at 65 ± 2%RH for at least 24 h. Then, it was removed from the controller and was weighted prior to the testing (W1). The sample was then put into a beaker containing 100 mL of oil, and then immediately started the timer. At the 60th second, the sample was removed and placed on tissue paper. Then immediately another piece of tissue paper was placed on the top. The metal roller was used to roll back and forth over the tissue paper. Finally, the sample was weighted again (W2).

Calculation:Oil absorption value (%) = (W2 –W1) / W1 × 100

Analysis of Results. Three (3) replications were done, and the average value was calculated. The package properties were analyzed by using SPSS: one - way Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) at a confidence level of 95%.

RESULTS AND DISCUSSIONS

Physical Properties

The physical properties of the paper were determined from thickness, standard weight, and moisture content. According to the current study, the container molded by Method C had lower thickness and moisture content, but had higher standard weight per area than

Table 1
Thickness, standard weight and moisture content of packaging molded from banana sheath

Fiber:Binder	Thickness (mm)	Weight (g/m^2)	Moisture content (%)
Hot air			
60:40	5.63±0.09	2266.67±47.29	10.60±4.31
70:30	5.47±0.32	2426.67±28.77	12.15±0.24
80:20	5.71±0.30	2834.67±56.21	12.44±0.32
90:10	6.57±0.45	2901.33±84.66	10.80±0.29
Compression			
60:40	4.18±0.18	2762.67±46.19	8.80±0.12
70:30	4.10±0.28	3200.00±144.00	8.23±0.30
80:20	4.04±0.27	3354.67±88.12	8.88±0.64
90:10	3.91±0.11	3584.00±204.27	9.48±0.54

the container molded by Method H as shown in Table 1. An identical surface area of the package, Method C had higher mass content than Method H because of their short edge.

Since the container molded by Method C received compression resulting in high density of the structure, it had more weight per area, but less thickness than the container molded by Method H. Neither container had a statistically significant difference ($p>0.05$) in the amount of banana sheath fibers at 60-90%, but the standard weight was in the range of 2762-3584 g / m^2. The weight increase was consistent with the amount of banana sheath fibers. The standard weight of the container made from banana sheath in both methods was found to be higher after the banana sheath fibers had been added. Meanwhile, the thickness and moisture content were similar. The container molded by Method H had the thickness and moisture of 5.63-6.57 mm and 10.60-12.44%, respectively, while the container molded by Method C, had the thickness and moisture content of 3.91-4.18 mm and 8.23-9.48%, respectively. The moisture content of the banana sheath container was lower than the biodegradable starch container (25.3-28.6%) (Medina-Jaramillo et al., 2017).

For containers, the absorption properties are important when storing liquid products or storing products in humid conditions. Therefore, the packaging should have a low liquid absorption value to ensure the durability of the packaging for various uses.

Based on the water absorption test, it was found that the container molded by Method H had absorbed more water than the container from Method C ($p<0.05$) as shown in Figure 1. Due to the porous structure, water was found to infiltrate the material. Conversely, when the banana sheath fibers were added, water absorption decreased because the binder was the flour solution, which has good compatibility with water. When banana sheath fibers were added, the amount of the binder was reduced, resulting in a decrease in water absorption. However, the ratios of banana sheath fiber per binder at 70:30, 80:20 and 90:10 were not found to be significantly different ($p> 0.05$).

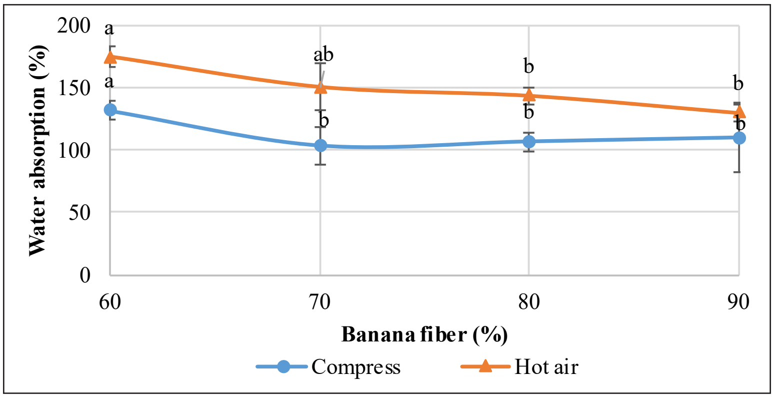

Figure 1. Water absorption of packaging molded from banana sheath

Like water absorption, Method H (p <0.05) showed higher oil absorption than Method C (Figure 2) due to the loose structure which allowed oil particles to penetrate the structure more easily than in Method C. However, when the fiber content increased, the oil absorption reduced due to the close arrangement of fiber particles of the banana sheath, which had been packed up and had prevented the oil from penetrating. The container made from the ratio of 90:10 showed only 20% oil absorption. The absorption of water and fat can be improved by coating the container in order to reduce the permeability of water, oil, and other solutions.

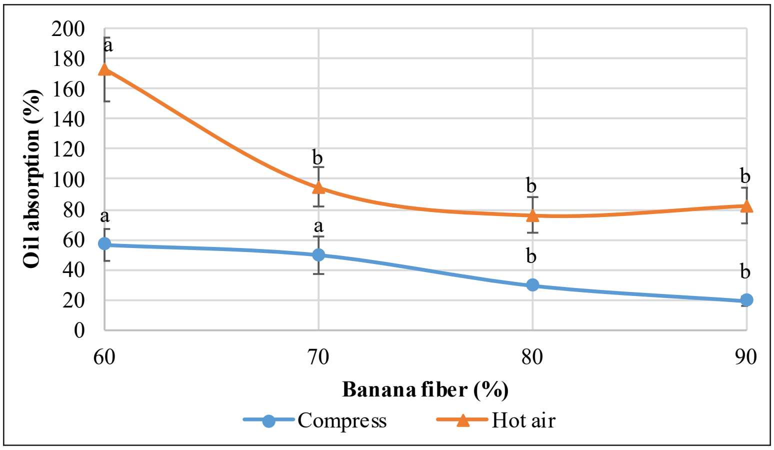

Figure 2. Oil absorption of packaging molded from banana sheath

Mechanical Properties

Mechanical properties are important properties for containers, especially during transportation when damage may be caused to agricultural products and food. Therefore, strength is essential when testing containers. When molding the container in the oven, a mold was used and was heated along with the material. The force, resulting in deformation from compression, was in the range of 180-550 N, as shown in the Figure 3. The sample with the highest compression force had been made of 60% dried banana sheath fiber. When increasing the amount of dried banana sheath fiber, the compression resistance was found to decrease. This was due to a distribution of fibers in the materials in the molding force, causing the fiber particles to become untightened. In addition, the small particles are easily deformed (Sibaly & Jeetah, 2017).

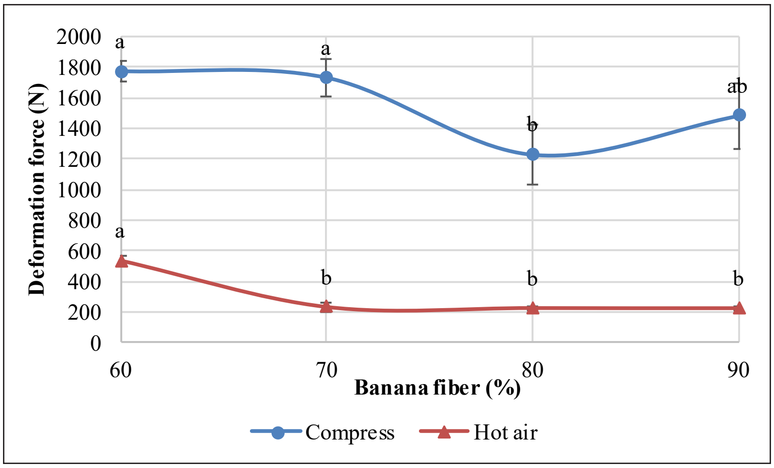

Figure 3. Compression resistance of packaging molded from banana sheath

Based on the container molded by Method C, the compression resistance required a lot of force to make the container deform because when the container was being molded, the material was pressed into the mold and heated, which resulted in a high density of the material particles. Therefore, the force that caused deformation from compression was very high. The compressive force was in the range 1200-1800 N, which decreased in contrast with increased amounts of banana sheath fiber. However, the compressive force increased when the amount of banana sheath increased to 90%. Yet, there was no difference found from the banana sheath container having 80% of banana sheath ($p > 0.05$). Higher compressive force indicated the strength of the containers to withstand deformation. In short, molding the containers by hot compressor had made the containers stronger than those containers molded by Method H.

Puncture force of the banana sheath fiber container molded by Method C increased when the fiber content was increased by 80% and decreased by 90%, which was similar to paper made from banana sheath fibers (Romdhonee & Jeetah, 2017). However, no difference was found in the penetrating force at the fiber content of 80-90% ($p > 0.05$) (Figure 4). The penetrating force of the container made from banana sheath increased when the amount of banana sheath fiber was increased. The increased penetrating force indicated a composition

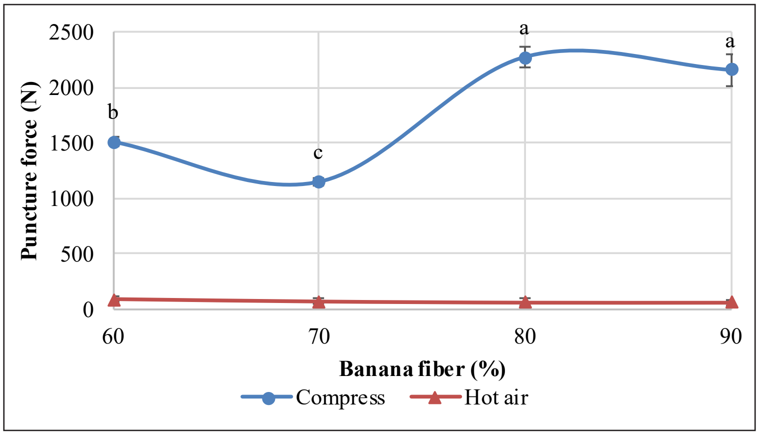

Figure 4. Penetration resistance of packaging molded from banana sheath

of alpha cellulose in larger quantities and a decrease in microfibilar angle. Moreover, the increased density contributed to resistance to the penetrating force. Likewise, the paper made from pineapple fibers (Sibaly & Jeetah, 2017) had higher penetrating force when the amount of fibers was increased. Meanwhile, the containers molded by Method H had low penetrating force and no difference was indicated when the fiber content was increased ($p > 0.05$) because the structure of the banana sheath fiber is uneven. Furthermore, the packaging had uneven thickness, which was caused by the uneven distribution of fibers. Therefore, in the areas where the fiber particles were not dense, it was easily penetrated. Also, the fact that the containers were thin had made them fragile. Moreover, the puncture force related to the deformation force which against the percentage by mass of fiber. The Method C had higher density and the stiffness. Thus, the resistance of puncture and deformation force were higher than Method H ($p<0.05$) (Sibaly & Jeetah, 2017).

The dried and crushed banana sheath fibers, which had been used as a material in the banana sheath containers, increased the adhesion efficiency between the fiber particles and the binder. When increasing the amount of fiber, the tensile strength resistance was also increased, making the containers to become stronger (Zhao et al., 2019) (Figure 5) due to the cross-linking of the cellulose molecular chain (Muratore et al., 2019) which can be attributed to higher cellulose crosslinking as their cellulose chains reacts each other. There was also the bonding strength between the sheath fiber and banana starch solution during the molding process. The tensile strength of Method H was greater than Method C because of the molding method was used in the experiment. Method H affected the tough but not tight while Method C affected high density and resistant puncture. This is similar to pineapple fiber paper and banana fiber paper, which had shown greater tensile strength resistance when the amount of fibers was increased (Sibaly & Jeetah, 2017; Ramdhonee & Jeetah, 2017). However, it was still less than the biological material PHBV (28.1 MPa) (Zhao et al., 2019) and the paper (321.20 MPa) (Muratore et al., 2019).

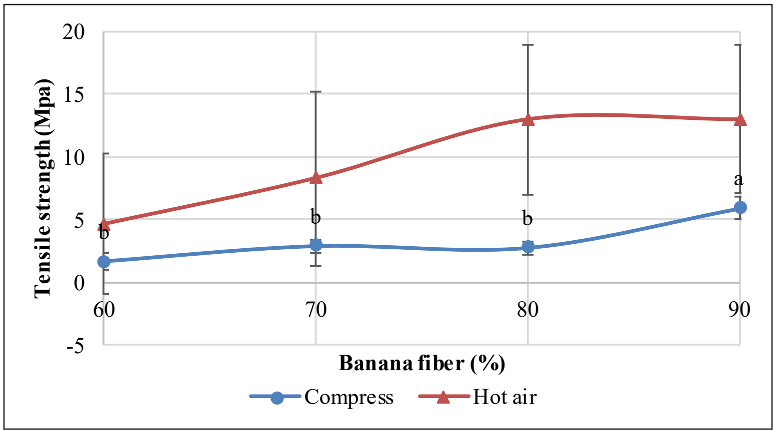

Figure 5. Tensile strength resistance of packaging molded from banana sheath

The elongation of the banana sheath containers was found to increase along with an increase in the amounts of banana sheath fibers. However, the variation of elongation at break with fiber content is so small, less than 1%. The containers molded by Method H were different at 70-90% of banana sheath. In contrast, for the containers molded by Method C, there was no difference found between 60-80% of the banana sheath fiber. However, elongation increased when the banana sheath fiber was increased to 90%. Because the molded containers were hard, they were found to be strong, but less flexible. This contributed to the low elongation of the containers, making the containers strong with an elongation value of not more than 1.4% (Figure 6).

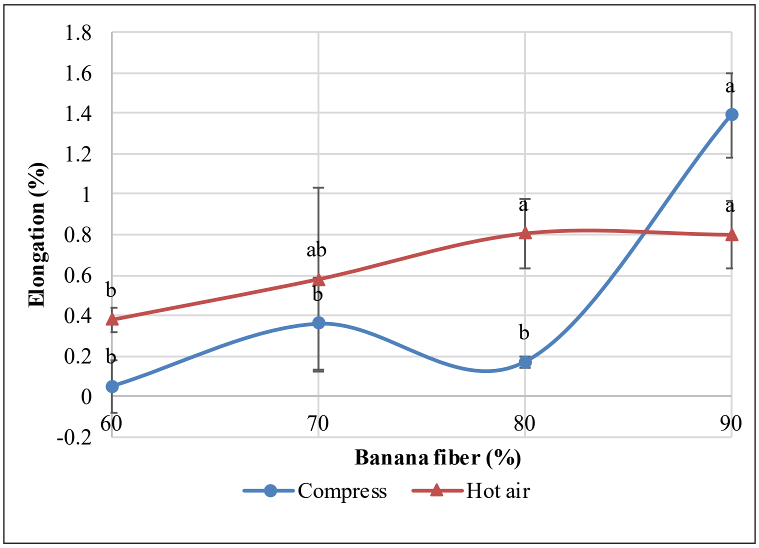

Figure 6. Elongation of packaging molded from banana sheath

CONCLUSIONS

The ground dried banana sheath powder, which was used as a material for making the containers had contributed to an even distribution in the structure, as well as the adhesion of the particles. The containers, molded by the hot compression, indicated that the mechanical properties had consisted of resistance values in compression, penetration, and tensile strength. It was found that the samples containing 90% of banana sheath fibers and the hot press method were resistant to deformation, penetration and tensile strength, and had shown lower water and oil absorption. However, further experiment will be to improve the water and oil absorption by coating with edible film.

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REFERENCES

Alarcon, L. C., & Marzocchi, V. A. (2015). Evaluation for paper ability to pseudo stem of banana tree. *Procedia Materials Science, 8*, 814-823.

AOAC. (2000). *Official methods of analysis of AOAC international*. Gaithersburg, USA: Association of Official Agricultural Chemists.

ASTM D3285. (2005). *Standard test method for water absorptiveness of nonbibulous paper and paperboard (Cobb Test)*. American Standard Testing Method. West Conshohocken, PA: ASTM International.

ASTM D642. (2010). *Standard test method for determining compressive resistance of shipping containers, components and unit loads*. American Standard Testing Method. West Conshohocken, PA: ASTM International.

ASTM D646. (1996). *Standard test method for grammage of paper and paperboard (Mass Per Unit Area)*. American Standard Testing Method. West Conshohocken, PA: ASTM International.

ASTM D882. (1997). *Standard test method for tensile properties of thin plastic sheeting*. American Standard Testing Method. West Conshohocken, PA: ASTM International.

ASTM F904. (2016). *Standard test method for comparison of bond strength or ply adhesion of similar laminated mode from flexible materials*. American Standard Testing Method. West Conshohocken, PA: ASTM International.

Bi, Y., Zhang, Y., Jiang, H., Hong, Y., Gu, Z., Cheng, L., … & Li, C. (2017). Molecular structure and digestibility of banana flour and starch. *Food Hydrocolloids.*, *72*, 219-227.

Cinelli, P., Chiellini, E., Lawtom, J. W., & Imam, S. H. (2006). Foamed articles based on potato starch, corn fibers and poly (vinyl alcohol). *Polymer Degradation and Stability, 91*(5), 1147-1155.

Jirukkakul, N. (2016). The study of edible film production from unriped banana flour and riped banana puree. *International Food Research Journal, 23*(1), 95-101.

Jirukkakul, N. (2019). Physical properties of banana stem and leaf papers laminated with banana film. *Walailak Journal of Science and Technology (WJST), 16*(10), 753-763.

Liu, H., Wu, Q., & Zhang, Q. (2009). Preparation and properties of banana fiber-reinforced composites based on high density polyethylene (HDPE)/Nylon-6 blends. *Bioresource Technology, 100*(23), 6088-6097.

Medina-Jaramillo, C., Ochoa-Yepes, O., Bernal, C., & Fama, L. (2017). Active and smart biodegradable packaging based on starch and natural extracts. *Carbohydrate Polymers, 176*, 187-194.

Muratore, F., Barbosa, S. E., & Martini, R. E. (2019). Development of bioactive paper packaging for grain-based food products. *Food Packaging and Shelf Life, 20*, 1-7.

Oliveira, L., Evtuguin, D., Cordeiro, N., & Silvestre, A. J. D. (2009). Structural characterization of stalk lignin from banana plant. *Industrial Crops and Products, 29*(1), 86-95.

Ramdhonee, A., & Jeetah, P. (2017). Production of wrapping paper from banana fibres. *Journal of Environmental Chemical Engineering, 5*(5), 4298-4306.

Shogren, R. L., Lawton, J. W., & Tiefenbacher, K. F. (2002). Baked starch foams: Starch modifications and additives improve process parameters, structure and properties. *Industrial Crop and Products, 16*(1), 69-79.

Sibaly, S., & Jeetah, P. (2017). Production of paper from pineapple leaves. *Journal of Environmental Chemical Engineering, 5*(6), 5978-5986.

Soykeabkaew, N., Supaphol, P., & Rujiravanit, R. (2004). Preparation and characterization of jute and flax-reinforced starch-based composite foams. *Carbohydrate Polymers, 58*(1), 53-63.

Tiefenbacher, K. F. (1993). Starch-based foamed materials-use and degradation properties. *Journal of Macromolecular Science, Part A: Pure and Applied Chemistry, 30*(9-10), 727-731.

Zhao, X., Ji, K., Kurt, K., Cornish, K., & Vodovotz, Y. (2019). Optimal mechanical properties of biodegradable natural rubber-toughened PHBV bioplastics indended for food packaging applications. *Food Packaging and Shelf Life, 21*, 1-11.